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Epidemiology and control of echinococcosis in central Asia, with particular reference to the People's Republic of China

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ABSTRACT

At least 270 million people (58% of the total population) are at risk of cystic echinococcosis (CE) in Central Asia including areas of Mongolia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Afghanistan, Iran, Pakistan and western China. The annual surgical incidence rate in Uzbekistan and Tadjikistan has been estimated to be as high as 25–27 cases/100,000 with the highest prevalence reaching 10% (range from 0.8 to 11.9%) in some Tibetan communities in western China. *Echinococcus* transmission in the region is largely associated with social factors including limited community knowledge of echinococcosis, small-scale household animal production, home killing of livestock, and the feeding of dogs with uncooked offal. Alveolar echinococcosis (AE) is also endemic in Central Asia and is recognized as a major problem in some Tibetan communities with up to 6% of villagers infected in some villages. In western China, 5–30% of the population are seropositive against *E. granulosus* antigens, indicating that a large number of individuals have been exposed to the parasite. Although echinococcosis control programs have been initiated in some countries in Central Asia, control efforts are generally fragmented and uncoordinated. Monthly deworming of dogs with praziquantel (PZQ), as a key measure to control the *Echinococcus* parasites, has been used in western China. However, the approach has proven difficult in local semi-nomadic communities. Additional control measures including health education, domestic livestock animal treatment/vaccination and dog vaccination are needed in CE-endemic areas to accelerate progress.

1. Introduction

Echinococcosis, caused by *Echinococcus granulosus* sensu latu (cystic echinococcosis; CE) or *E. multilocularis* (alveolar echinococcosis; AE), is increasingly recognized as a major population health problem and economic importance globally (Budke et al., 2006; Craig et al., 2007; McManus et al., 2003; Torgerson et al., 2010; Torgerson, 2013). Recent epidemiological studies show that echinococosis causes serious problems in Central Asia. With about 466 million people living in this region, which includes Mongolia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Afghanistan, parts of Iran, Pakistan and areas of western China, more than half of the inhabitants are exposed; in particular, herdsman and farmers are at high risk of infection with *E. granulosus* and *E. multilocularis* (Table 1) (Bai et al., 2001; Craig, 2006; Wang et al., 2006; Yang et al., 2006; Yu et al., 2008).

Climate and geography determine the biomes of Central Asia which comprise temperate montane grasslands and shrublands, deserts and xeric shrublands and temperate coniferous forests. The life style of the communities and animal production in this region depend on these individual biomes; indeed, these communities have historically been tied closely to the semi-nomadic life-style. Sheep and cattle are the main livestock and these are normally accompanied by the presence of domestic dogs. These animals play a key role in the transmission of echinococcosis. It is noteworthy that although the disease is notifiable in a number of countries in Central Asia, and most if not all former soviet states in the region, its control is generally neglected, with only a few countries such

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Table 1
Populations at risk of echinococcosis in countries of Central Asia.

Country or territory	Population (millions)*	Cases per 100,000 (year)	Estimated cases annually	Rural population (% of total population)*	Populati-on at risk (millions)	References
Afghanistan	30.5	No data available	–	77	23.5	Carter et al. (2009); Eckert et al. (2001); Kronmann et al. (2008); Le Riche et al. (1988); Pilsczek (2011)
Iran	77.36	No data available	–	31	24	Borji et al. (2012b); Geramizadeh et al. (2012); Rajabloo et al. (2012)
Kazakhstan	16.6	6·5/100000 (2003)	1079	46	7.6	Shaikenov et al. (2004)
Kyrgyzstan	5.5	20/100000 (2002)	1100	65	3.6	Torgerson et al. (2003b); Kuttubaev et al. (2004)
Mongolia	2.6	0.9/100000 (2008)	23.4	32	0.8	Gurbadam et al. (2010); Ebright et al. (2003); Ito et al. (2010)
Pakistan	176.7	No data available	–	64	113	
China (western)**	70	6/100000 (2008)	4200	60	42	Wang et al. (2010)
Siberia, Russia	40	No data available	–	26	10.4	Stauga and Schmiedel (2012)
Tajikistan	7.6	28/100000 (2002)	2128	74	5.6	Muminov et al. (2004)
Turkmenistan	5.1	17/100000 (2002)	867	52	2.7	Torgerson et al. (2006)
Uzbekistan	29.5	10/100000 (2010)	2966	64	18.1	Hong et al. (2013)
Total	466.28	9/100,000†	12363	58.7	273.7	

* Data from the World Bank (http://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?page=6).
** Western China; 5783 cases were reported in 2008 in 6 provinces with a total population of 96 million people, giving an incidence of 6 cases per 100,000. People living in rural areas are at most risk of infection.
† The overall annual incidence (9/100,000) was estimated based on data from Kazakhstan, Kyrgyzstan, Mongolia, western China, Tajikistan, Turkmenistan and Uzbekistan with the total number of annual cases being12363 among 136.9 million people.

as China having initiated a control program. In western China, the control program, now expanded to 217 counties, includes human echinococcosis case finding and treatment, combined with dog deworming with praziquantel as the key measures.

In this paper, we discuss the epidemiological situation and risks of acquiring *Echinococcus* infection using population-based reports from Central Asia. Control studies and practice are also summarized using data collected mainly from China. Only limited information is presented here on the molecular characterisation of *Echinococcus* genotypes in Central Asia as two excellent reviews on the genetic diversity of isolates from different livestock species (Cardona and Carmena, 2013a) and canines (Cardona and Carmena, 2013b) are available.

2. China

2.1. Endemicity of cystic and alveolar echinococcosis

The endemicity of CE in China has been reviewed in a number of articles (Chai, 1995; Chi et al., 1989; Eckert et al., 2001; Wen and Yang, 1997) which showed that the disease occurred in many parts of China in the 1990s, being present in at least 21 provinces, comprising 87% of its total territory with highly endemic areas in western China including Xinjiang, Gansu, Ningxia, Inner Mongolia, Qinghai, Tibet, and Sichuan provinces/autonomous regions. Tibet had the highest annual incidence of human CE with 32 cases/100,000 inhabitants, followed by Qinghai (10.1/100,000), Ningxia (4.5/100,000), Xinjiang (3.0/100,000) and Gansu (0.9/100,000) (Chi et al., 1989; Wen and Yang, 1997); in some areas the morbidity rate of the disease reached an average of 4.5% (Chai, 1995). A national epidemiological survey for major parasitic diseases in 2004 showed that the prevalence of CE in China was 1.08%, with an estimated 380,000 residents having detectable hydatid cysts by ultrasonography (US). Very few AE cases were reported before the 1990s.

Recent reports have shown that CE is still highly endemic in western China (Budke et al., 2004; Cai et al., 2012b; Li et al., 2010a,b; Schantz et al., 2003; Wang et al., 2006). The China CDC reporting system revealed a total of 10,790 CE cases from 2004 to 2008 with 98.2% of the patients from Xinjiang, Gansu, Ningxia, Inner Mongolia, Qinghai and Sichuan (Wang et al., 2010). These cases were mainly from two highly endemic zones, one in northern Xinjiang and the other on the Qinghai-Tibet Plateau and its adjacent areas including Southern Ningxia Hui Autonomous Region, southern Gansu province and western Sichuan province (Fig. 1).

In northern Xinjiang, 0.3–3% of the population were reported having detectable CE cysts by ultrasound imaging (Chai et al., 2004; Nuerguli et al., 2010) with the highest prevalence (8.7%) in Mongolian and Kazak herdsman communities (Wang et al., 2009). The prevalence of CE in school children was high in northern Xinjiang, ranging from 0.2 to 2.5% (Nulsadeke et al., 2004).

AE is endemic in northern Xinjiang with Tacheng and Yili prefectures being relatively highly endemic with prevalences of 0.3–0.6% (Wang et al., 2009; Zhou et al., 2000).

On the Qinghai-Tibet Plateau and its adjacent areas (Fig. 1), the prevalence of human AE/CE has been shown to range from 0.4% to 9.5%, being especially high in Tibetan communities, especially in herdsmen/pastoralists (He, 2000; Wang et al., 2006, 2014; Yu et al., 2008). A survey of 10,186 local residents examined by ultrasound in 31 Tibetan townships in Ganze and Aba Tibetan Autonomous Prefectures of northwest Sichuan province identified 645 (6.3%) echinococcosis cases with 3.2% due to CE, 3.1% due to AE and 0.04% of subjects having both CE and AE (Li et al., 2010b). In Shiqu County, also in western Sichuan Province, both CE and AE were co-endemic with prevalences of 6.8% of CE and 6.2% of AE in local villagers (Li et al., 2005). In Darlag County, Guoluo Tibetan Autonomous

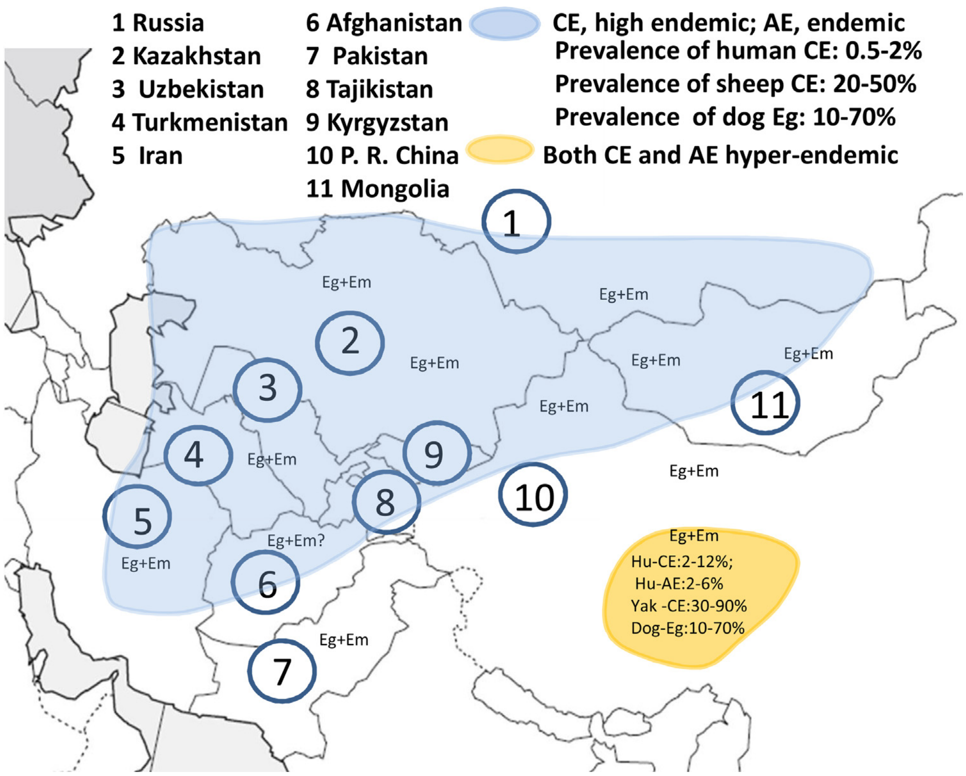

Fig. 1. Distribution and endemicity of cystic echinococcosis (CE) caused by *Echinococcus granulosus* (Eg) and alveolar echinococcosis (AE) due to *E. multilocularis* (Em) in Central Asian countries.

Prefecture, Qinghai Province, 236 out of 1723 (13.7%) people were clinically diagnosed as having echinococcosis with 5.5% of cases being due to CE and 8.2% due to AE. The prevalence in herdsmen and monks/nuns was shown as high as 23.0% and 13.2%, respectively (Han et al., 2009). These and other recent reports indicate that, currently, both CE and AE are still highly endemic in these areas (Cai et al., 2012a; Fang et al., 2012; Niu and An, 2012; Nulsadeke et al., 2004). It is noteworthy that school aged children in Qinghai province had CE and AE prevalences of 1.0% (206/20730) and 0.6% (114/20730), respectively, with the AE cases being located in the south (Cai et al., 2012a).

It is of note that 5–30% of the population in western China have been shown to be seropositive against *E. granulosus* antigens, indicating a large population have been exposed to *Echinococcus* infection (Cao et al., 2004; Chai et al., 2003, 2007; Huang et al., 2012; Li et al., 2006; Liu et al., 2009; Liu and Yin, 2009; Ma et al., 2006a,b; Niu et al., 2011; Qiu et al., 2003; Wang et al., 2002; Yi et al., 2008; Yu et al., 2008; Zhang et al., 2007).

2.2. *Echinococcus in definitive hosts*

Dogs play an important role in transmission of CE in China (Budke et al., 2005; Cai et al., 2012b; Chai, 2009; Chi et al., 1989; Hartnack et al., 2013; Zhao et al., 2009). In northern Xinjiang, investigations using copro-antigen ELISAs showed that 11–51% of dogs were infected with *E. granulosus* (Hou and Sun, 2005; Ma et al., 2011; Malike et al., 2011), similar to levels reported in the 1980s (Chai et al., 2003). Necropsy showed that 5–36% of dogs were infected with *E. granulosus* in southern Gansu province (Li et al., 2006; Qi et al., 2003; Zhao et al., 2009). On the Qinghai-Tibet Plateau, the prevalence of *E. granulosus* in dogs ranged from 10 to 67% by necropsy (Cai et al., 2012b; Han et al., 2009; He and Wang, 2001; Yang et al., 2009; Yu et al., 2008). Copro-antigen ELISA showed that in Ruorgai, Litang and Sheda counties in Sichuan Province, 21%(67/315), 29%(62/210), and 14.6%(44/302) of dogs were, respectively, infected with *E. granulosus* (Gu et al., 2012). Copro-antigen ELISA also revealed 6.2% (12/193) of dogs were infected with *E. granulosus* in Zhiduo County, Qinghai province (Wu et al., 2007).

Dogs also likely play an important role in the transmission of AE in China, with 3–23% of dogs infected with *E. multilocularis* on the Qinghai-Tibet Plateau (Budke et al., 2005; Cai et al., 2012b; Hartnack et al., 2013; He and Wang, 2001; Moss et al., 2013; Vaniscotte et al., 2011; Yu et al., 2008; Zhao et al., 2009). Copro-PCR analysis showed in one study that 15% of Tibetan foxes harboured *E. multilocularis* infection (Vaniscotte et al., 2011) whereas in another, 62% of Tibetan foxes were shown infected with *Echinococcus* spp., with 19% having *E. multilocularis* infection (Jiang et al., 2012). Notably, another survey showed 27% of foxes were infected with *E. shiquicus*, (Jiang et al., 2012), while 11.3% (27/239) of pikas (*Ochotona curzoniae*) were shown infected with this recently described new species of *Echinococcus* (Han et al., 2009). It is not known whether *E. shiquicus* is infective to humans.

2.3. *Echinococcus in intermediate hosts*

A recent survey of 14 prefectures in Xinjiang showed that the mean prevalence of CE in sheep and cattle was 50% (44–78%) and 15% (4–60%), respectively (Malike et al., 2011). Another investigation of five counties in northern Xinjiang showed that the prevalence of CE in one-year-old sheep was 44–47% (Chai et al., 2004), indicating the high-endemic situation has been maintained although it is lower than before the 1990s (Chi et al., 1989).

In Tibetan communities in Qinghai, Gansu and Sichuan provinces, the CE prevalence in sheep and yaks was reported as 26–82% and 38–78%%, respectively (Cai et al., 2012b; He and Wang, 2001; Yang et al., 2009; Yu et al., 2008; Zhao et al., 2009).

2.4. Echinococcus in wild animals

A striking feature of the ecology of *E. multilocularis* in China is the diversity of hosts that contribute to the parasite's transmission shown to depend on a wildlife, predator/prey, cycle involving foxes, as well as dogs, and small mammals, especially microtine rodents and Ochotonid lagomorphs (Giraudoux et al., 2006). The prevalence of *E. multilocularis* in pikas (*O. curzoniae*) and woolly hares (*Lepus oiostolus*) was 3.45% and 12.5%, respectively in ZeKu County, Qinghai province (He and Wang, 2001). In Zhiduo County, Qinghai Province, 15% (14/93) of pikas were shown infected with *E. shiquicus* (Wu et al., 2007). In Gannan Tibetan Autonomous Prefecture, Gansu Province, a survey showed that 1.2% (1/87) of *O. daurica* and 2.3% (3/132) of *Myospalax fontanieri* were infected with *E. multilocularis* but no AE was found in *Marmota himalayana*, *O. tibetana* or *Mus musculus* (Zhao et al., 2009).

Copro-antigen ELISA also revealed 36% (5/14) of wolves were infected with *E. granulosus* in Zhiduo County, Qinghai province (Wu et al., 2007).

The sheep strain (G1 genotype) of *E. granulosus* is the major strain present in western China (Heath et al., 2005; Li et al., 2008; Ma et al., 2008; Xiao et al., 2006) with the G6 genotype also occurring in some areas of Xinjiang and Qinghai (Hu et al., 2013; Zhang et al., 1998).

2.5. Risk factors for echinococcosis

Several risk factor analysis studies have shown that pastoral herdsmen are at a higher risk of *E. granulosus* infection, and that Tibetan, Kazakh and Mongol ethnic groups had a higher prevalence than farmers or urban inhabitants (Bai et al., 2001; Nulsadeke et al., 2004; Tiaoying et al., 2005; Wang et al., 2006, 2014; Yu et al., 2008). Dog ownership is also a key risk factor for both human CE and AE (Yang et al., 2006), with higher prevalence in female subjects than in males (Han et al., 2009; Yu et al., 2008).

Pre-school children may be the high-risk age for acquiring *Echinococcus* infection as this group have high contact with dogs (Chai, 1995).

2.6. Transmission dynamics of echinococcosis

Domestic dogs play an important role in the transmission dynamics of both CE and AE (Craig, 2006). The common practices of home slaughter and of feeding dogs on offal harbouring hydatid cysts facilitate completion of the life cycle of *E. granulosus* (Chai, 1995). A history of dog ownership and the number of dogs owned over a period of time were shown to be highly significantly correlated with relative risk of acquiring human AE in Han/Hui farmers and Tibetan pastoralists, despite the fact that these communities are ethnically and culturally very different (Craig, 2006).

The overall dynamic force of transmission of echinococcosis is the fact that a large number of intermediate host animals including livestock animals are infected. In addition, the ownership of a large number of dogs is a major factor for transmission of *E. granulosus*. In China, almost all Tibetan families own dogs (Sben et al., 2004) and 43–82% families in Xinjiang have at least one dog, indicating the importance of dog ownership in the family setting (Yimit et al., 1994).

Home killing of animals for family meat consumption is another key element for CE transmission and surveys have shown that over 80% of Xinjiang families slaughtered sheep and cattle at home. It is difficult to limit this home killing activity due mainly to traditional activities and local customs, the lack of supply of basic living materials and the economic cost of abattoir slaughter (Chi et al., 1989, 1990; Zhang et al., 1991b, 1994). Prevention or restriction of home killing of livestock has provided a major control option for CE in those areas and countries where effective control has been achieved (Craig and Larrieu, 2006). For AE transmission, small mammals such as rodents and pikas play a key role as intermediate hosts, and dogs, including stray dogs, are important definitive host animals for transmission of AE to humans in Tibetan areas (Giraudoux et al., 2013a). Different ecosystems of *E. multilocularis* in China and Central Asia have their own characteristics and these can serve as a reference for estimating transmission and control of AE (Giraudoux et al., 2013a,b).

2.7. Control

A program based on monthly praziquantel (PZQ) treatment of all registered dogs and culling unwanted and stray dogs has been designed to control CE in high endemic areas in China. The strategy is aimed at preventing eggs being released from dogs into the environment by treating animals before adult tapeworms are patent so as to decrease *E. granulosus* transmission.

The frequency of dosing dogs was determined based on the developmental time of *E. granulosus* in the local Xinjiang dog breed, which showed animals experimentally infected with protoscoleces first released eggs after 43–45 days (Zhang et al., 1989, 1991a).

A pilot field control project has been undertaken in two counties (Hutubi and Wensu) in Xinjiang, China; the counties had a population of 255,504 in 52,300 households and 30,380 dogs (Zhang et al., 2009). Control measures included selection of a village hydatid disease control officer (VHDCO) for each village to register and monthly dose all dogs present with baited PZQ, to explain the features of the control program to residents, and to distribute education materials to every family. The control measures also included elimination of stray and unwanted dogs.

After 4 years of PZQ treatment, the prevalence of *E. granulosus* in dogs was reduced in the two counties from 14.7% to 18.6%, respectively, to zero, and this caused a 90%–100% decrease of CE in sheep born after commencement of the control program. The control measures were thus shown to be efficient, highly cost-effective and practicable for implementation in rural communities. The two counties, with different ethnicities, were selected originally to determine whether the same control measures could be used and accepted in different communities and this proved to be the case (Zhang et al., 2009).

Since 2005, the Chinese Government has launched a major echinococcosis control program comprising 217 counties in western China. The control program is organised under the National Health and Family Planning Commission (NHFPC) (formerly the Ministry of Health) of the People's Republic of China and includes two stages—the initiation stage (2005–2009) and the extension/control stage (2010–2020) with five control measures operating: (1) health education; (2) mass-community screening with ultrasound; (3) patient treatment; (4) monthly dog treatment with praziquantel; and (5) animal offal inspection and control in slaughterhouses. Program progress is monitored using hospital patient records,child serologyand dog copro-antigen ELISA as control indicators.

The control outcomes from some counties (e.g. Haiyan County, Qinghai Province and Tianzu County, Gansu Province) indicated that after 5–6 years, the prevalence of CE in sheep dropped from more than 50% to less than 3% (Zhang, 2006). In Ningxia Hui Autonomous Region, the CE incidence dropped from 7.1/100,000 in 2006 (Feng et al., 2009) to 2.4/100,000 in 2011 (Feng et al., 2012). Other survey data indicated that CE has decreased overall in Gansu although, in some areas, the prevalence has still remained high (Bartholomot et al., 2002; Giraudoux et al., 2006; Li et al., 2002; Wang and Zhang, 2000).

3. Afghanistan

There have been no detailed epidemiological studies on echinococcosis in Afghanistan although there are clinical reports of CE in Afghan immigrants (Carter et al., 2009; Pilsczek, 2011) and sporadic case reports of soldiers in the US military returning after a tour of duty (e.g. Kronmann et al., 2008). Further, a case of confirmed AE in the UK may have been contracted in Afghanistan (Graham et al., 2002). A survey in 1988 showed that 73% (77/105) of stray dogs from Kabul were infected with *E. granulosus*, with some being heavily infected (152,700 worms were present in one animal) (Le Riche et al., 1988). Given that more than 80% of the population of Afghanistan is involved in farming, agriculture and livestock husbandry, 10 times the number of stray dogs were shown present compared with the number of house-dogs in the Kabul area (Nadim and Rostami, 1974), the continuation of conflict, the unstable political situation and the fact there may be very limited control, it is likely that echinococcosis is highly endemic there.

4. Mongolia

There have been no systematic epidemiological studies undertaken on echinococcosis in Mongolia. However, since the collapse of the Soviet Union in 1990, the health system has been in transition with the result that control programs for deworming dogs have been curtailed resulting in increased numbers of human cases (Ebright et al., 2003; Ito et al., 2010). The number of patients with echinococcosis increased to 18% of the total number of surgical cases at the First Hospital of Ulaanbaatar in 1993 compared with 7.8% of all surgical patients with CE and 1.9% with AE in 1950 (Ebright et al., 2003; Ito et al., 2010). Only a few human AE cases have been reported recently (Ito et al., 2010). Human CE cases have been shown to be distributed in 12 provinces with 10 bordering China and Russia (Jabbar et al., 2011). Notably, the camel strain (G6 genotype) of *E. granulosus* plays an important role in CE transmission and appears responsible for most cases of human infection in western Mongolia (Jabbar et al., 2011) although the G6/7 and G10 genotypes were recently reported in wolves from this area (Ito et al., 2013). Serological surveys showed that 8.5% and 9.1% of inhabitants were serologically positive against *E. granulosus* antigens in Ulaanbaatar, Dornod and Selenge (Huh et al., 2006; Lee et al., 1999). In Bulgan, 0.2% (4/1609) of villagers were identified as having CE cysts by US and dog surveys showed that 35.7% were necropsy-positive for *Echinococcus* worms (Wang et al., 2005). In north-western areas of Mongolia, 5.2% of subjects were found to be strongly seropositive for antibodies to *E. granulosus* antigen B by ELISA (Watson-Jones et al., 1997). No control program for echinococcosis has been instigated to date in Mongolia.

5. Kazakhstan

Control programs for parasitic diseases in the former Soviet Union maintained human echinococcosis surgical cases at a low level of about 1–5 per 100,000 per year in the five republics of the former Soviet Union before the Union collapsed in 1991. After the collapse, echinococcosis re-emerged in these independent countries with a serious epidemic of CE cases. In many areas, surgical incidence is now more than 10 cases per 100,000 (Torgerson et al., 2006). Both CE and AE are endemic in Kazakhstan (Torgerson, 2013). Factors impacting on the transmission of echinococcosis in Kazakhstan include the degradation of the traditional nomadic system of livestock breeding, closure of large collective farms, the development of small private farms, the abandonment of routine anthelmintic prophylaxis of dogs and inadequate disposal of animal carcasses (Shaikenov et al., 2003).

In Kazakhstan, the annual incidence of surgical cases of CE increased from 0.9 to 1.4 cases per 100,000 for the period 1974–1990 to 2.5 and 5.9 cases per 100,000 in 1997 and 1999, respectively, representing an increase in annual case numbers from 221 in 1990 to 807 in 2000 (Shaikenov et al., 1999; Torgerson et al., 2002). This increase in incidence was most marked in the south of the country in Zhambyl Oblast, rising from 3.8 in 1990 to 12.3 per 100,000 in 2000, and South Kazakhstan Oblast rising from 2.7 in 1990 to 9.8 per 100,000 in 2000 (Shaikenov et al., 1999; Torgerson et al., 2002).

There are some recent reports on the prevalence of CE in domestic animals in Kazakhstan (Torgerson, 2013). In the south, the prevalence of *E. granulosus* in adult sheep increased from 38% in 1986 to 62% in 1999 (Shaikenov et al., 1999). An examination of 1464 dogs showed that 5.8% of village dogs were infected with *E. granulosus*, whereas the prevalence in working shepherding dogs was 23% (Shaikenov et al., 2003; Torgerson et al., 2003a). A purgation study in south east Kazakhstan indicated that 13% of dogs in one rural community were infected with *E. granulosus* and 5% with *E. multilocularis* (Torgerson et al., 2009a). The prevalence of *E. multilocularis* in dogs in parts of Kazakhstan is as high as in Tibet (Ziadinov et al., 2008) A survey in southern Kazakhstan, which used a PCR-based assay to amplify an *E. granulosus*-specific DNA fragment, showed that 5 of 120 garden soil samples samples contained *E. granulosus* eggs (Shaikenov et al., 2004).

A recent survey showed that 19.5% (8/41) of wolves were infected with *E. granulosus* (Abdybekova and Torgerson, 2012). Given that southern Kazakhstan is a major area for animal production, it would seem that wolves could play a role in transmission of CE in this area although it is unknown whether they participate in a domestic cycle (by predating or scavenging sheep) or whether they are involved in an entirely independent wildlife cycle. There have been no reports of recent control efforts or instigation of a renewed formal control program for echinococcosis in the last 20 years in Kazakhstan.

6. Kyrgyzstan, Tadjikistan and Uzbekistan

The annual incidence of CE in Kyrgyzstan, based on hospital records, increased from 5.4 cases/100,000 in 1991 to 14 cases/100,000 in 1998 (Torgerson et al., 2000), and then to 20 cases/100,000 in 2001 (Torgerson et al., 2006). Between 1995 and 2011, human AE increased from <3 cases per year to an alarming >60 cases per year (Usubalieva et al., 2013). The prevalence of CE also increased in major livestock species such as sheep with a doubling of reported prevalence in some areas (Torgerson et al., 2006). In 2006, approximately 64% of sheep were infected in central Kyrgyzstan (Torgerson et al., 2009b), whereas the prevalence of *E. granulosus* in the rural dog population approached 25% in 2001 (Torgerson et al., 2006). A survey in south-eastern Kyrgyzstan by Ziadinov et al. (2008) showed that 18% and 11% of dogs were infected, respectively, with *E. granulosus* and *E. multilocularis* A recent report from southern Kyrgystan has reaffirmed the important role that domestic dogs play in the transmission of these parasites (Van Kesteren et al., 2013). High prevalence of *E. multilocularis* in foxes was revealed also in central Kyrgyzstan; of 151 foxes, 96 (64%) were infected with a mean abundance of 8669 parasites per fox (Ziadinov et al., 2010). The World Bank has recently proposed an *Echinococcus* control programme for Kyrgyzstan, which includes providing anthelminthics for dogs (World Bank, 2011), and this programme was apparently already underway in October 2012.

Similarly, areas in Tadjikistan are highly endemic for echinococcosis with an incidence of up to 27 cases/100,000 (Torgerson et al., 2006). By 2000 there were 167,300 (0.7%)

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Echinococcus-seropositive persons with 12,520 patients in Uzbekistan (Abdiev et al., 2000). In addition, 47.2% (5,174/10,953) of sheep, 20.8% (852/4,089) of cattle and 13% (109/838) of dogs were infected with *E. granulosus* (Musinov, 1998). Another investigation showed that 18% of dogs were infected with *E. granulosus* (Ziadinov et al., 2008). A detailed analysis of hospital records of 4089 surgical cases indicated an annual incidence of nearly 25 cases/100,000 per year (Torgerson et al., 2006). During the period 2002–2010, 8014 patients received surgical removal or drainage of CE in 14 emergency state hospitals in Uzbekistan and 2966 patients were found in 2010 (Hong et al., 2013). In the same study, the 22,959 sheep were examined and 479 (2.1%) and 340 (1.5%) of these were found positive for CE cysts in the liver and lungs, respectively, emphasising the public health importance of CE as a zoonosis in Uzbekistan (Hong et al., 2013).

AE is endemic in Tadjikistan and Uzbekistan (Torgerson et al., 2010). The echinococcosis control situation in Kyrgyzstan, Tadjikistan and Uzbekistan is similar to that of Kazakhstan.

7. Pakistan

There have been no clinical reports, to date, of AE cases in Pakistan. Although there have been very few epidemiological-based publications, the incidence of CE in Pakistan appears generally low based on the relatively small number of hospital cases reported but the prevalence in rural communities is unknown so the general endemic situation may be underestimated. The case records of all patients who presented with hepatic CE at the Aga Khan University Hospital, Karachi, from 1995 to 2006, showed that a total of 106 cases were admitted with a mean age of 34 years; 60 (56.6%) were men, 72 (67.9%) were resident in rural areas of Pakistan and 21 (19.8%) were Afghan refugees (Mumtaz et al., 2009). Indeed, increased incidence of CE due to the migration of infected people into Pakistan, particularly at the Pakistan–Afghan border, may be a major problem for the future and the focus of the prevention of CE in Pakistan should be aimed at this migrant group.

Slaughterhouses inspections in the Punjab revealed that of 39,738 animals examined, 6.7% were found infected with *E. granulosus*; the prevalence and fertility of CE cysts was highest in camels (prevalence 17.3%; proportion fertile 95%), followed by sheep (prevalence 7.5%; proportion fertile 86.4%), buffaloes (prevalence 7.2%; proportion fertile 84.3%), goats (prevalence 5.5%; proportion fertile 79.09%) and cattle (prevalence 5.2%; proportion fertile 75.3%) (Latif et al., 2010). Both the common sheep strain (G1) and buffalo strain (G3) were shown to be cycling among these livestock (Latif et al., 2010). Some areas in Pakistan may be highly endemic for CE given that *E. granulosus* was found in 38.9% of cattle, 33.1% of buffaloes and 58.9% of camels slaughtered at Sihala abattoir, Islamabad (Khan et al., 1990). No control program for CE is currently under way in Pakistan.

8. Iran

CE is endemic in Iran, particularly in the northern and western rural regions. The annual surgical incidence of CE in south-western Iran was shown by Ahmadi and Hamidi (2008) to be 1.33/100,000, with housewives and farmers at high risk of infection *with E. granulosus*. Another report showed that 318 CE patients were recorded in Tabriz within a 10-year period, with the majority being females, aged 20–40 years (Vahedi and Vahedi, 2012). A US survey showed 0.2% of the population had CE in rural communities in Kerman, south eastern Iran (Harandi et al., 2011).

Livestock slaughterhouse inspection indicated that in western and northern Iran 2–15% of sheep, goat, cattle or buffalos were infected with *E. granulosus*, indicating an endemic or low endemic situation in these areas (Pour et al., 2011; Borji et al., 2012a; Mansoorlakooraj et al., 2011). *E. granulosus* DNA was also found in the fecal samples of 16.9% of dogs, 66.7% of jackals, and other wild carnivores in Razavi Khorasan province, northern Iran (Beiromvand et al., 2011). *E. multilocularis* infection was detected in the faeces of all wild carnivores sampled in this area as well as in five dogs (6.5% prevalence) (Beiromvand et al., 2011). Human cases of AE have been reported in northern and southern Iran (Beiromvand et al., 2011; Geramizadeh et al., 2012).

High prevalence (up to 64%) of *E. granulosus* has been reported in Iranian stray dogs (Eslami et al., 2010; Harandi et al., 2011). A control program was conducted in rural and urban areas of the city of Kerman from 1991 to 1994; it was based on killing stray dogs (a total of 6500) and treating pet and sheep dogs ($n = 278$) with PZQ once every six months for one year. The average infection rate in dogs remained at 5% in 1993 but then dropped to 1.5% in 1994. The prevalence of infection in sheep dropped from 5.4% in 1994 to 0.5% in 1995, indicating that stray dogs likely play an important role in transmission of the disease in Iran (Sharifi et al., 1996).

In order to assess the monetary burden of CE in Iran, Fasihi Harandi et al. (2012) obtained epidemiological data, including prevalence and incidence of CE in humans and animals. The number of surgical CE cases annually for the period 2000–2009 was estimated to be 1295, with the number of asymptomatic individuals in Iran estimated as 635,232. The main livestock involved in CE transmission in Iran are sheep, goats, cattle, buffalo, and camels.

9. Summary

In Central Asia, 270 million people (58% of the total population) living in rural areas are at risk of infection with echinococcosis due to its high endemicity, the traditional farming practices operating, with sheep as major intermediate host animals, the poor local economies and the low levels of education and hygiene. The overall annual echinococcosis incidence for Kazakhstan, Kyrgyzstan, Mongolia, western China, Tajikistan, Turkmenistan and Uzbekistan was estimated at 9/100,000 with the total number of annual cases being 12,363 among 136.9 million people (Table 1). The co-endemicity of AE and CE and the increasing numbers of reported human cases make echinococcosis more important on the Qinghai-Tibetan Plateau than anywhere else in the world. The majority of human cases are associated with sheep-farming and other agricultural activities with particular ethnic groups (Tibetan, Kazakh and Mongolian communities) being at high risk for both CE and AE infection. Dogs are major definitive hosts for *Echinococcus* and they play an important role in echinococcosis transmission.

Although there has been considerable success in the control of *E. granulosus*, through dosing dogs with PZQ, questions remain as to the best combination of available measures that would result in a significant reduction in prevalence/incidence in dogs and the elimination of CE over a shorter intervention period. Recently, the hydatid control community has been provided with more choice given that the EG95 vaccine is available as an additional tool for use in control programs (Craig et al., 2007) but this and other interventions may not prove as suitable or cost-effective in developing countries as in developed countries such as New Zealand or Australia (Tasmania) where successful control has been achieved. Control is also more difficult in a large continental area such as China compared with these island settings. There is thus a requirement for the development of specific control measures for CE which may vary depending on the location. New control measures including sheep vaccination and treatment, health education and dog vaccination are needed.

Since 2005, the Chinese Government has launched a concerted hydatid disease control program for China, which may help to stimulate renewed interest and boost regional investigations in Central Asia on the epidemiology of echinococcosis.

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