



Echinococcus infections in the Baltic region



Audronė Marcinkutė^{a,1}, Mindaugas Šarkūnas^{b,*,1}, Epp Moks^c, Urmas Saarma^c,
Pikka Jokelainen^{d,e}, Guna Bagrade^f, Sniedze Laivacuma^g, Kęstutis Strupas^h,
Vitalijus Sokolovas^h, Peter Deplazesⁱ

^a Clinic of Infectious, Chest Diseases, Dermatovenereology and Allergology, Vilnius University and University Hospital Santariškių Clinics, Lithuania

^b Department of Infectious Diseases, Veterinary Academy, Lithuanian University of Health Sciences, Tilžės Street 18, 47181 Kaunas, Lithuania

^c Department of Zoology, Institute of Ecology and Earth Sciences, University of Tartu, Estonia

^d Institute of Veterinary Medicine and Animal Sciences, Estonian University of Life Sciences, Tartu, Estonia

^e Faculty of Veterinary Medicine, University of Helsinki, Finland

^f Latvian State Forest Research Institute "Silava", Salaspils, Latvia

^g Riga Stradins University, Riga, Latvia

^h Santariškių Clinics, Vilnius University, Lithuania

ⁱ Institute of Parasitology, University of Zürich, Switzerland

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ABSTRACT

In the Baltic countries, the two zoonotic diseases, alveolar echinococcosis (AE) caused by *Echinococcus multilocularis*, and cystic echinococcosis (CE) caused by *Echinococcus granulosus*, are of increasing public health concern. Observations from Estonia, Latvia and Lithuania indicate that the distribution of both parasites is wider in the Baltics than previously expected. In this paper, we review and discuss the available data, regarding both parasitoses in animals and humans, from the Baltic countries and selected adjacent regions. The data are not easily comparable but reveal a worrisome situation as the number of human AE and CE cases is increasing. Despite improvements in diagnostics and treatment, AE has a high morbidity and mortality in the Baltic region. For the control of both zoonoses, monitoring transmission patterns and timely diagnosis in humans as well as the development of local control programs present major challenges.

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1. Introduction

Species of the genus *Echinococcus* Rudolphi, 1801 are small intestinal cestodes of carnivore definitive hosts. Parasite eggs, which can survive in the environment, are infective to a variety of herbivorous and omnivorous intermediate or accidental hosts. The larval stages (metacestodes) in the intermediate hosts have a high potential for asexual reproduction and production of numerous protoscoleces (Thompson, 1995).

Metacestodes of *Echinococcus granulosus*, a complex of species, strains and genotypes with a taxonomy under revision (reviewed Romig et al., 2015), are causing cystic echinococcosis (CE; hydatid disease) in intermediate and in human accidental hosts, with a high global burden of disease (Budke et al., 2006). Metacestodes (cysts from a few cm to up to 10–30 cm) can be seen during meat inspection, autopsy or necropsy. Therefore, in contrast to many

other infectious diseases, historic observations are of value for the understanding of the epidemiology of these zoonotic parasites.

The “northern biotype of *E. granulosus*” (Raush, 1995), currently named *E. canadensis*, which includes the cervid strain or genotypes G8 and G10 (Romig et al., 2015; Oksanen and Lavikainen, 2015), is transmitted almost exclusively in a wild animal cycle with the wolf as definitive hosts and ungulates of the family Cervidae as intermediate hosts. In addition, domesticated reindeer and dogs (as definitive hosts) can be involved in certain epidemiological situations. Only few zoonotic infections with the cervid strain have been observed in humans, associated with relatively moderate pathology, mainly in the lungs (Romig et al., 2015; Oksanen and Lavikainen, 2015). In contrast, in endemic regions of southern and central Europe, *E. granulosus* (sheep strain, genotypes G1, G2, G3), and *E. granulosus* pig strain (genotype G7; also grouped under *E. canadensis*, and proposed as *E. intermedium*) occur mostly in synanthropic cycles with the domestic dog as definitive and sheep (G1) or pigs (G7) as major intermediate hosts, respectively.

Echinococcus multilocularis is transmitted in Europe mainly by wild animals, with the red fox (*Vulpes vulpes*), the wolf (*Canis lupus*) and the raccoon dog (*Nyctereutes procyonoides*) as definitive hosts

* Corresponding author.

E-mail address: minsar@iva.lt (M. Šarkūnas).

¹ These authors contributed equally to this study.

Table 1
Echinococcus species recorded until 2014 in the Baltic countries Estonia, Latvia and Lithuania.

Country	Species, strain (genotype)	Definitive hosts	Intermediate and aberrant ^a hosts, (human)	References
Estonia	<i>E. granulosus</i>	Dog	Pig, cattle, sheep, moose	Saar (1931); Lešins (1955); University of Tartu (zoological collection)
	<i>E. granulosus</i> (G1)	Dog		Laurimaa et al. (2015b)
	<i>E. canadensis</i> , cervid strains (G8, G10) <i>E. multilocularis</i>	Wolf Fox, raccoon dog	Moose, roe deer	Moks et al. (2006, 2008); I. Jõgisalu (pers. comm.) Moks et al. (2005), Laurimaa et al. (2015c)
Latvia	<i>E. granulosus</i>		Pig, sheep	Vaivarina (1950)
	<i>E. canadensis</i> , cervid strain (G10)	Wolf		Bagrade and Saarma (unpublished)
	<i>E. multilocularis</i>	Fox, wolf, raccoon dog		Bagrade et al. (2008, 2009); Bagrade, (2008); Pojakova, (2009)
Lithuania	<i>E. granulosus</i>	Dog, wolf	Pig, cattle, sheep (human)	Historic citations see Sections 5.1.1 and 5.2.1
	<i>E. granulosus</i> ; pig strain (G7)	Dog	Pig, cattle, ^a human	Bružinskaitė et al. (2009); Marcinkutė et al. (2006)
	<i>E. multilocularis</i>	Fox, raccoon dog, dog	<i>Ondatra zibethicus</i> , (<i>Microtus</i> sp.; pig, ^a human)	Mažeika et al. (2003); Bružinskaitė et al. (2007, 2009); Bružinskaitė-Schmidhalter et al. (2012); (Loibiene R. and Šarkūnas M., personal communication)

^a Non-fertile metacestodes, therefore no significance for transmission.

and rodents mainly of the genera *Arvicola*, *Microtus* and *Myodes* as intermediate hosts (Eckert et al., 2011). Domestic dogs and, to a lesser extent, cats can be involved in the transmission cycle (Deplazes et al., 2011). The parasite is endemic in the northern hemisphere: the highest prevalence of infection is reported in Central Europe, North America (mostly in Alaska and the northern part of Canada) and in the arctic, subarctic and temperate climate zones of Asia (Eckert et al., 2011).

Humans may get infected by uptake of eggs, and the tumour-like growth of the metacestode stage of *E. multilocularis*, mainly in the liver, may lead to a serious disease—alveolar echinococcosis (AE).

The numbers of recently reported human AE cases have increased in some endemic areas in Central Europe as well as in the Baltics (Bružinskaitė et al., 2007) and Poland (Nahorski et al., 2013). Although generally a rare disease, AE is of considerable public health importance because of the severe pathology of the tumour-like infection, the high lethality rate of untreated cases and high cost of treatment (WHO, 2001; Vuitton et al., 2015).

Since the 1990s, extensive epidemiological studies have revealed that the known central–European endemic area of *E. multilocularis* is much larger than previously known, including regions in the north and east (WHO, 2001; Romig et al., 2006; Sikó et al., 2011; Vuitton et al., 2015). The parasite has been reported in the Baltics in Lithuania (Mažeika et al., 2003), Estonia (Moks et al., 2005) and Latvia (Bagrade et al., 2008), and in neighbouring Poland (Malczewski et al., 1995) and Belarus (Shimalov and Shimalov, 2001).

In this paper, we review historic and recent epidemiological data from the Baltic region, including locally published reports that are not easily available to a broader readership.

2. *Echinococcus* spp. in the Baltic countries

Since the 1990s, due to the changes in the epidemiological situation or improved diagnostic techniques and medical care, the number of registered human CE and later on AE cases started to increase in Lithuania and Latvia, while remaining at relatively low levels in Estonia.

Most information on *Echinococcus* infections is available for animals. Recent and historic data are reviewed for the different Baltic countries in the following chapters. As shown in Table 1, four confirmed genotypes of the *E. granulosus* complex, namely the sheep strain (G1), pig strain (G7), and cervid strains (G8 and G10), have

been identified in different hosts. The first report on an *E. multilocularis* infection in the region was published in 2003 in Lithuania (Mažeika et al., 2003), followed shortly by reports from the two other Baltic countries. To date, most data are available from definitive hosts, whereas the intermediate rodent hosts have not been systematically investigated for the presence of *E. multilocularis* in the Baltic region.

3. Occurrence and transmission of *Echinococcus* spp. in Estonia

3.1. Animal infections in Estonia

3.1.1. *Echinococcus granulosus* complex

Historically, the first Estonian record of *E. granulosus* dates back to 1904 when the parasite was included in the zoological collection of the University of Tartu. The material was collected near the town Tartu. Unfortunately, the host was not documented and the sample is not preserved. However, *E. granulosus* cysts were reported in the 1930s from pigs (Saar, 1931), and later in pigs, sheep and wild cervids (Lešins, 1955). Notably, 147 (15.7%) out of 938 pigs were infected (Lešins, 1955). Prevalences ranged between 5 and 31.4% in different areas and were highest in counties near the Latvian border and Lake Peipus. The parasite was also detected in other intermediate host species: in 10 out of 244 sheep (4.1%) and in 7 out of 1117 (0.6%) large cervids (unspecified, presumably moose, *Alces alces*). After that, there were no more reports of *Echinococcus* infections for almost half a century, neither from the meat inspections nor from parasitological investigations of wild cervids in the 1970s (Järvis, 1993).

In more recent studies, *E. granulosus* has been found in Estonian wildlife. Wild intermediate host species include moose and roe deer (*Capreolus capreolus*), whereas the grey wolf has been identified as the definitive host. In domesticated intermediate hosts, the parasite has been detected in pigs, sheep and cattle (Tables 1 and 2; Estonian Veterinary and Food Laboratory, 2014).

In 2003, adult stages of the *E. granulosus* complex were detected in 1 out of 26 investigated grey wolves (3.8%; Moks et al., 2006). The parasite was identified as *E. canadensis* (G10).

Infection in wolves and wild cervids (Moks et al., 2006, 2008; I. Jõgisalu, Estonian Environmental Agency, personal communication) suggest a wild animal cycle for this tapeworm in Estonia. In 2004–2005, *E. canadensis* cysts were detected in 16 (0.8%) out of

2038 hunted moose (Moks et al., 2008). Most of the cysts were in the lungs, and the number of cysts ranged from one to six per animal. The phylogenetic position of the Estonian genotypes has been examined in detail (Moks et al., 2008; Saarma et al., 2009). Of the parasite samples from moose, 11 belonged to genotype G8 and 5 to genotype G10, and this was the first record of G8 in Eurasia (Moks et al., 2008).

The Estonian Veterinary and Food Laboratory has reported a few cases of *Echinococcus* sp. infections in farm animals and in wildlife in 2004–2006, likely to belong to the *E. granulosus* complex (Estonian Veterinary and Food Laboratory, 2014). In 2004, 4 out of 444 084 pigs (0.0009%) and 8 out of 6202 moose (0.1%) were found to be infected. Cysts were also detected in 2 out of 1787 imported reindeers (0.1%) in 2005, and in 1 out of 53 903 cattle (0.002%) in 2007. Although there are no reported cases of *E. granulosus* infection in companion animals, a recent investigation revealed this species in dogs (Laurimaa et al., 2015b).

3.1.2 *Echinococcus multilocularis*

E. multilocularis has been found in Estonia in both rural and urban areas, but so far only in the definitive host species (Table 1). The parasite was identified in Estonia for the first time in 2003 (Moks et al., 2005) in 5 out of 17 (29.4%) red foxes. In these foxes, the number of adult *E. multilocularis* ranged from 3 to 927, and the parasite species was confirmed with molecular methods including sequencing. A more recent study, involving a considerably larger number of red foxes from across the country, showed that the prevalence of *E. multilocularis* in red foxes has remained virtually unchanged (Laurimaa L., unpublished data). *E. multilocularis* was recently identified also in raccoon dogs (Laurimaa et al., 2015c).

The red fox and raccoon dog were the main hosts of rabies in Estonia for decades (Süld et al., 2014). In 2013, Estonia officially declared its rabies-free status. Shortly after the start of the anti-rabies vaccination campaign in autumn 2005, the number of foxes and raccoon dogs increased considerably. Moreover, foxes started to colonize Estonian urban areas, where they have been reported in 33 out of the 47 cities nationwide (Plumer et al., 2014). In the city of Tartu, 2 (7.1%) out of 28 fox faeces but none of the analysed 91 dog faeces were positive for *E. multilocularis* (Laurimaa et al., 2015a). In this study a non-invasive genetic method was applied that allows the identification of both *E. multilocularis* and the host species from carnivore faecal samples.

3.2. Human infections in Estonia

To date, 13 cases of echinococcosis in humans have officially been registered in Estonia (Estonian Health Board, 2014). However, AE and CE have yet to be confirmed in this country as the causative species of *Echinococcus* was not identified. These human

echinococcosis cases have been reported as follows: single cases in 1986, 2000, 2003, 2008, and 2014 (until September 2014); two cases in 2007; and three cases in both 2012 and 2013. The patient in the year 1986 was a foreigner, and three other cases are classified as imported.

Only two cases of human echinococcosis have been described in more detail. In one of them, a single large cyst (15 × 12 × 10 cm) was successfully surgically removed from the right lung of a 62-year-old male patient (Lapidus et al., 2004). The diagnosis was confirmed by histopathology based on wall structure and presence of protoscoleces. In another case a suspected liver cyst was removed laparoscopically from a younger female patient complaining of severe abdominal pain in 2005. During surgery, the cyst ruptured, and in the following years new cysts were found in several organs, and further surgical interventions and albendazole treatment were attempted with limited success (Kivi, 2011).

4. Occurrence and transmission of *Echinococcus* spp. in Latvia

4.1. Animal infections in Latvia

4.1.1. *Echinococcus granulosus* complex

Historical data on *Echinococcus* infections in Latvia is limited. Based on slaughterhouse records, 0.8% of sheep and 2.8% of pigs were infected with *E. granulosus* (Vaivarina, 1950; reviewed by Danilevičus, 1964). The pig–dog life cycle was considered most typical for the region. Collected data from the archive of the Parasitological Laboratory (Latvia University of Agriculture, Faculty of Veterinary Medicine) on dynamics of helminthoses in Latvia in 1976–1996 shows that the incidence of echinococcosis in cattle was 0.001–0.11%, 0.005–0.2% in sheep and 0.002–0.2% in pigs (Anna Krūklīte, Faculty of Veterinary Medicine, Latvia, personal communication). Furthermore, the Latvian Food and Veterinary Service has reported cases of echinococcosis in farm animals in 2004–2007 and 2010 of <0.2% (LFVS, 2004–2010). These reported cases were not specified, but most likely belong to the *E. granulosus* complex. There are no confirmed reported cases on *E. granulosus* infection in dogs in Latvia for at least two decades.

Genetically confirmed data on *E. granulosus* infection in Latvian wildlife is available for wolves (Bagrađe and Saarma, unpublished data), (Tables 1 and 3). *Echinococcus* parasites identified by morphological features have been detected in 1 (2.9%) of 34 investigated wolves (Bagrađe et al., 2009), however this finding was later confirmed to be *E. canadensis* (G10) (Bagrađe and Saarma, unpublished data). There is no recent information about *Echinococcus* infection in wild intermediate host species, and historical research done on the helminth fauna of cervids has not revealed CE infections (Prieditis and Daija, 1972; Michelson, 1976). The populations of

Table 2
Prevalence studies on *E. granulosus* and *E. multilocularis* in wild and domestic animals in Estonia.

Host species	<i>Echinococcus</i> sp.	No positive/investigated	Prevalence % (95% CI)	Location (if specified)	References
Pig	<i>E. granulosus</i>	147/938	15.7 (13.5–18.1)	Eastern and Southeastern Estonia	Lešins (1955)
Sheep	<i>E. granulosus</i>	10/244	4.1 (2.1–7.2)	Slaughterhouses in Tartu, Otepää	
Moose	<i>E. granulosus</i>	7/1117	0.6 (0.3–1.2)	Slaughterhouses in Mustvee, Võru	
Pig	<i>Echinococcus</i> sp.	4/444 084	0.0009 (0.0004–0.002)	Most parts of Estonia	EVFL ^a
Moose	<i>Echinococcus</i> sp.	8/6202	0.1 (0.06–0.2)	Most parts of Estonia	
Reindeer	<i>Echinococcus</i> sp.	2/1787	0.1 (0.02–0.4)	Imported	EVFL ^a
Cattle	<i>Echinococcus</i> sp.	1/53903	0.002 (0.0005–0.009)	Most parts of Estonia	EVFL ^a
Fox	<i>E. multilocularis</i>	5/17	29.4 (11.7–53.7)	Tartumaa, Põlvamaa, Hiiumaa	Moks et al. (2005)
Wolf	<i>E. granulosus</i> (G10)	1/26	4 (0–14)	Järvamaa	Moks et al. (2006)
Moose	<i>E. granulosus</i> (G8, G10)	16/2038	0.8 (0.5–1.2)	Harjumaa, Raplamaa, Läänemaa, Pärnumaa	Moks et al. (2008)
Fox	<i>E. multilocularis</i>	2/28	7.1 (1.2–21.7)	Tartu, urban foxes	Laurimaa et al. (2015a)
Dog	<i>E. granulosus</i> (G1)	4/181	2.2 (0.6–5.6)	Tartu (urban area)	Laurimaa et al. (2015b)
Raccoon dog	<i>E. multilocularis</i>	4/249	1.6 (2.4–5.6)	Järvamaa, Saaremaa	Laurimaa et al. (2015c)

^a EVFL—Estonian Veterinary and Food Laboratory, 2014.

Table 3
Prevalence studies on *E. granulosus* and *E. multilocularis* in wild and domestic animals in Latvia.

Host species	<i>Echinococcus</i> sp.	No positive/investigated	Prevalence% (95% CI)	Location (if specified)	References
Sheep	<i>E. granulosus</i>		0.8	Not specified	Vaivarina (1950)
Pig	<i>E. granulosus</i>		2.8		
Fox	<i>E. multilocularis</i>	16/45 8/42	35.6 (23.2–50.2) 19.1 (10.0–33.3)	Most parts of Latvia Rīga, Valka and Jelgava districts	Bagrade et al. (2008) Poļakova (2009)
Wolf	<i>E. multilocularis</i> <i>E. granulosus</i>	2/34 1/34	5.9 (0.65–20.07) 2.9 (0.00–16.22)	Dobele, Ugāle Saulkrasti	Bagrade et al. (2009)
Raccoon dog	<i>E. multilocularis</i>	1/19 6/42	5.3 (0.1–26.0) 14.3 (5.4–28.5)	Ugāle Rīga, Valmiera and Jelgava districts	Bagrade (2008) Poļakova (2009)
Pig	<i>Echinococcus</i> sp.	2/504680	0.0004	Most parts of Latvia	LFVS ^a
Cattle	<i>Echinococcus</i> sp.	1/90760	0.001	Most parts of Latvia	LFVS ^a
Sheep and goats	<i>Echinococcus</i> sp.	1/8978	0.01	Most parts of Latvia	LFVS ^a

^a LFVS - Latvian Food and Veterinary Service, 2004–2010.

wildlife animals involved in the known *E. canadensis* (G10) life cycle are stable with a tendency to increase in Latvia (data of the State Forest Service).

Echinococcus identified based on morphological features on genus level, has been reported in foxes hunted in Latvia (Keidāns et al., 2005) and *Echinococcus* metacestodes have been diagnosed in beavers (*Castor fiber*) (Kaspržaka et al., 2004). However, in both these findings, the *Echinococcus* sp. was not confirmed by molecular tools.

4.1.2 *Echinococcus multilocularis*

So far, *E. multilocularis* parasites in Latvian wildlife have been found in canids (Tables 1 and 3). Investigations of red foxes ($n = 45$) during 2003–2008 from various regions of the country revealed a prevalence of 35.6% with an intensity of infection ranging from 1 to 1438 worms (Bagrade et al., 2008). In the same study, 19 raccoon dogs were examined, and a lower prevalence of 5.3% was determined (Bagrade, 2008). Other investigations conducted by the former National Diagnostic Centre of Latvia (now Institute of Food Safety, Animal Health and Environment “BIOR”) in 2007–2008 (material collected from 3 head forestries) revealed prevalences of 14.3% in raccoon dogs ($n = 42$) and 19.1% in foxes ($n = 42$) (Poļakova, 2009). A recently performed survey (2010–2014) conducted by “BIOR” in collaboration with LSFRI “Silava” on the helminth fauna of foxes ($n = 430$) and raccoon dogs ($n = 305$) in Latvia revealed almost a halved prevalence of *E. multilocularis* in foxes whereas the prevalence in raccoon dogs was similar to the data of the survey conducted in 2003–2008 (Bagrade and Dekšne, unpublished data). The population of raccoon dogs in Latvia is stable but there has been a decreasing tendency of fox numbers in recent years (data of the State Forest Service). From 34 wolves examined, 2 (5.9%) were infected with *E. multilocularis* with worm burdens of 62 and 380 (Bagrade et al., 2009).

4.2. Human infections in Latvia

4.2.1 Cystic echinococcosis

Only fragmented information is available concerning the epidemiological situation of human CE and AE in Latvia. In the period 1999–2005, 29 CE cases were registered at the Infectology Centre of Latvia (Keiss et al., 2007). During the last decade, awareness of echinococcosis has increased and since 2001, an increase in human CE cases has been recorded. In the Infectology Centre of Latvia, 11 new cases were registered (0.43/100.000 inhabitants per year) in 2005. Later on, the number of diagnosed human CE cases has risen to 17 in 2008 (0.77 cases/100.000 inhabitants per year) but decreased and remained stable in the years 2009–2012 (0.27–0.34 cases /100.000 inhabitants per year). Since echinococcosis is not

a notifiable infectious disease in Latvia, the number of presently reported cases is probably underestimated.

Data of 93 Latvian patients with CE, diagnosed in the period between 2002 and 2012, was recently reported by Laivacuma and Viksna (2014a). Diagnosis was based on ultrasonography and computer tomography (CT), serology and in some cases morphological investigations of biopsy or surgically obtained material from space occupying lesions. The majority (72.7%) of CE patients were females aged between 56 and 65 years. The majority of patients lived in a rural household (71.9%) and owned dogs (56.1%) or livestock (35.1%). The most frequent complaints at the moment of admission were abdominal discomfort or tightness (38.5%), abdominal pain (24.0%), malaise (15.4%), jaundice (11.5%) and skin itching (10.6%). Ultrasound analyses showed that echinococcosis manifested more often as a solitary lesion (64.9%) in the right hepatic lobe (62.2%) in an otherwise unchanged liver (65.8%). The size of lesion was <5 cm in 40.5% of cases. Analysis of the cysts at the moment of diagnosis most often revealed 3rd (CE3) and 4th (CE4) stage (according to the WHO classification criteria). Chemotherapy was applied in 82 out of 93 patients (88.5%), but most patients received only one course of albendazole per year. Radical metacestode resection was performed in 18 (19.3%) patients, while PAIR was performed on 19 (20.4%) patients (Laivacuma and Viksna, 2014a).

4.2.2 Alveolar echinococcosis

As with CE, no systematic data collection on the occurrence of AE in Latvia has been done. In the report by Tulin et al. (2012), 29 AE cases registered at the Pauls Stradins University Hospital during the period 1996–2010 are summarised. Radical operations were performed in 12 (41.3%) of these AE patients, 11 of them had asymptomatic or none complicated disease. Recurrence appeared in 1 patient (8.3%). Non-radical or palliative operations due to AE complications were performed in 15 patients (51.7%). Post-operative complications occurred in 17% of AE patients, and 1 patient died.

In the period 1999–2010, 14 human AE cases were registered at the Infectology Centre of Latvia. As diagnosis was mainly based on serological findings, seronegative cases of AE must be considered. Eleven of these AE patients were women. At the time of diagnosis, the youngest patient was 13 and the oldest 63 years old (majority of patients were of 51–56 years old). Ultrasonographic evaluation of *Echinococcus* lesions showed that all patients had abnormalities in the liver, but in 2 patients other organs (kidney and lung) were affected. In 6 patients, structures adjacent to the liver (bile ducts and blood vessels) were affected by the metacestode, which is characteristic for *E. multilocularis* infections (Laivacuma and Viksna, 2014b).

5. Occurrence and transmission of *Echinococcus* spp. in Lithuania

5.1. Animal infections in Lithuania

5.1.1. *Echinococcus granulosus* complex

First historical cases of *E. granulosus* cysts in cattle (Gelažius, 1924) and pigs (Sniečkienė, 1937) in Lithuania were mentioned by veterinary practitioners. In the 1960s, single cases were registered in livestock animals (Nainys and Kazlauskas, 1954; Šivickis, 1955). More detailed observations were reported by Čygas (1956, 1957) in four districts of central Lithuania: 22.3% of pigs (215/965; CI 19.7–25.0), 6.7% of sheep (39/580; CI 4.8–9.1) and 1.1% of cattle (8/729; CI 0.5–2.2) were infected with *E. granulosus* metacestodes.

Epidemiological investigations for *Echinococcus* spp. in animals are summarised in Table 4. In a study on seasonal dynamics of *E. granulosus* in pigs (Danilevičius, 1962), the prevalences were comparable during all seasons in pigs over 9 months of age. However, in 7–9 and 3–7 month old pigs, prevalences increased from 5.2% and 1.8% in April to 12.3% and 5.4% in November, respectively. Danilevičius (1964) reported prevalences of *E. granulosus* in pigs ranging between 5.0 and 12.9% in most parts of Lithuania (1961–1962; $n = 30\ 641$). The prevalence was higher in pigs from small farms (10.5%) when compared to those in large industrial farms (8.3%). Home slaughtering of pigs and sheep is traditional in Lithuania, and *E. granulosus* was documented in a dog-pig life cycle in the sixties (Danilevičius, 1964).

The helminth fauna of carnivores from Lithuania has been investigated in few earlier studies. During necropsy of various carnivores, *E. granulosus* was found in 4 out of 19 dogs (21.0%) and 1 out of 41 wolves (2.4%) (Kazlauskas and Prūsaitė, 1976). According to Musteikaitė et al. (1961), amongst other Taeniid cestodes, *E. granulosus* was prevalent in 5 out of 83 (6.02%) necropsied dogs from south-eastern Lithuania while no *E. granulosus* infection was found in cats. The mean prevalence of *E. granulosus* in dogs was 7.8% (1958–1962; $n = 102$) in the south and north of Lithuania, with more frequent infections in rural dogs (6 out of 44 dogs; 13.6%) as compared to urban dogs (2 out of 58 dogs from Vilnius Šiauliai; 3.4%) (Danilevičius, 1964).

From the sixties until the end of the century, only data from the Lithuanian State Veterinary Service (LSVS) on prevalences of *Echinococcus* infections in slaughtered animals was available. According to this data, the annual incidences of *E. granulosus* were 0.02–0.1% in cattle and 0.04–1.09% in pigs (LSVS, 1996).

In a study performed in the southwestern part of Lithuania during 2005–2006, CE was detected in 13.2% (81/612) of pigs reared in small family farms and in 4.1% of those reared in industrial farms. Molecular analysis of isolated taeniid eggs revealed *Taenia* spp. in 10.8%, *E. granulosus* (G 6/7) in 3.8% and *E. multilocularis* in 0.8% of the dogs investigated. In addition, 3 samples from livers of humans, 1 sample from a cow, 7 samples from pigs, and eggs from 8 dog faeces samples confirmed the presence of the ‘pig strain’ (G 6/7) (Bružinskaitė et al., 2009). The high prevalence of CE (13.2%), *T. hydatigena* larval stages (2.5%) and *E. multilocularis* lesions (0.5%) in pigs indicates that there is a high exposure of pigs to cestode eggs primarily in small farms where dogs are often kept to guard the premises. Usually, the majority of these dogs are chained, which may limit their access to offal of home-slaughtered pigs. However, 3.5% of chained dogs were infected with *E. granulosus*, possibly due to the fact that many dogs were fed with offal, without regular anthelmintic treatment.

Presently, a significant proportion of pigs (36%) are reared in small family farms in Lithuania (Department of Statistics, Lithuania) and considerable numbers of these pigs, which are intended for home consumption, are slaughtered under home conditions. A

questionnaire study suggested that there may be some propensities for seasonal transmission of *E. granulosus* in Lithuania as 60.4% of farmers slaughter pigs during the cold period of the year. This tradition causing a seasonal transmission of *E. granulosus* infections has already been discussed by Danilevičius (1964). If confirmed, seasonal control programs could be effective against *E. granulosus* sensu lato (s.l.) in Lithuania. In a pilot study over 4 consecutive years in Lithuania (Radziulis et al., 2011), the effect of regular praziquantel dosing of dogs four times per year during the period of the most intensive pig slaughtering (October–April) in endemic villages was examined. It was shown that regular deworming of dogs was sufficient to reduce the prevalence of *E. granulosus* in dogs from 5.9% (CI95% 3.6–9.1%) to 0% (CI95% 0.0–0.9%), in contrast to the control villages without intervention in which no significant reduction was observed. The prevalence of CE in the villages with treated dogs was 38.2% and 44.2% in fattener pigs and sows, respectively, at the beginning of the study, and they decreased to 0% (CI95% 0.0–0.9%) in the third year of the study.

5.1.2. *Echinococcus multilocularis*

The presence of the most important definitive and intermediate hosts for *E. multilocularis* suggested that conditions to maintain its life cycle are favourable in Lithuania. Important intermediate rodent hosts (e.g. *Arvicola terrestris*, *Microtus arvalis*) were recorded in Lithuania by Prūsaitė et al. (1988). In later studies performed in different landscapes of Lithuania, the presence of other possible intermediate hosts was recorded by Balčiauskas and Juškaitis (1997), Juškaitis and Baranauskas (2001), and Mažeikytė (2002). In these studies, it was shown that populations of rodents were mainly composed of *Myodes glareolus*, *M. arvalis*, *Apodemus flavicollis*, *Microtus agrestis*, and *Apodemus agrarius*.

While the rodent intermediate hosts have not been investigated systematically in the past, *E. multilocularis* was identified morphologically for the first time in one of 5 muskrats (*Ondatra zibethicus*) captured in the Šilutė district (Mažeika et al., 2003). Only recently, in the framework of an EMIRO project, a first *E. multilocularis* infection in a *Microtus* sp. (out of 300) was observed (Loibienė R. and Šarkūnas M., personal communication). Furthermore, infertile and calcified metacestodes of *E. multilocularis* were identified by PCR in 0.5% (3/685) of pig livers, and 2 out of 240 dogs (0.8%) from the same area excreted *E. multilocularis* eggs (Bružinskaitė et al., 2009) as confirmed by multiplex PCR (Trachsel et al., 2007).

Older studies in potential definitive hosts of *E. multilocularis* do not document the occurrence of this parasite in Lithuania. Out of 164 hunted red foxes (collected from 24 districts in the whole of Lithuania) and 10 raccoon dogs (from the northern part of Lithuania) examined morphologically, none were infected with *Echinococcus* spp. (Danilevičius, 1964). Furthermore, during necropsy of various carnivores, *E. granulosus* was identified in dogs and wolves but no record was made of *Echinococcus* spp. in 122 red foxes and 58 raccoon dogs examined (Kazlauskas and Prūsaitė, 1976).

E. multilocularis intestinal stages were detected for the first time in a study performed during 2001–2006. *E. multilocularis* was isolated in 158 (58.7%) of 269 red foxes examined and positive foxes were found in most of the investigated areas in Lithuania (Bružinskaitė-Schmidhalter et al., 2012). Furthermore, in this study a high prevalence of *E. multilocularis* (53%; CI 37.9–68.3%) was registered in the suburban area of Kaunas city. Worm burdens varied between 1 and 20 924 (mean 1309), and 17% of the infected adult red foxes were harbouring heavy infections (>1000 worms per animal) while none of the juvenile foxes were heavily infected. This result differs from other studies that have suggested urban juvenile foxes play a major role in the transmission of *E. multilocularis* (Deplazes et al., 2004).

Table 4
Prevalence studies for *E. granulosus* and *E. multilocularis* in wild and domestic animals in Lithuania.

Host species	<i>Echinococcus</i> sp.	No positive/investigated	Prevalence % (95% CI)	Location, if specified	Reference
Pig	<i>E. granulosus</i>	2 640/30 641	8.6 (8.3–8.9)	Most parts of Lithuania	Danilevičius (1964)
Dog	<i>E. granulosus</i>	8/102	7.8 (3.8–14.9)		
Fox	<i>Echinococcus</i> sp.	0/164	0.0 (0.00–2.75)		
Raccoon dog	<i>Echinococcus</i> sp.	0/10	0.0 (0.00–32.09)		
Wolf	<i>E. granulosus</i>	1/41	2.4 (0.01–3.74)	Not specified	Kazlauskas and Prūsaitė (1976)
Dog	<i>E. granulosus</i>	4/19	21.0 (7.95–3.89)		
Fox	<i>E. multilocularis</i>	0/122	0.0 (0.00–3.67)		
Raccoon dog	<i>E. multilocularis</i>	0/58	0.0 (0.00–7.43)		
Dog	<i>E. granulosus</i>	5/83	6.0 (2.27–13.67)	South eastern Lithuania	Musteikaitė et al. (1961)
Dog	<i>E. granulosus</i>	9/240	3.8 (1.7–7.0)	Southwestern Lithuania	Bružinskaitė et al. (2009)
	<i>E. multilocularis</i>	2/240	0.8 (0.1–0.3)		
Dog	<i>E. granulosus</i>	19/360	5.28 (3.2–8.1)	Southwestern Lithuania	Radziulis et al. (2011)
	<i>E. multilocularis</i>	4/360	1.11 (0.0–2.8)		
Fox	<i>E. multilocularis</i>	158/269	58.7 (52.6–64.7)	22 Districts of Lithuania	Bružinskaitė-Schmidhalter et al. (2012)
Raccoon dog	<i>E. multilocularis</i>	7/85	8.2 (3.4–16.2)		

The high prevalences and abundance of *E. multilocularis* in the different districts in rural and peri-urban red foxes (36–83%, up to 20,924 worms per animal) and raccoon dogs (0–17%, up to 2379 worms per animal) (Bružinskaitė, 2007) allow the conclusion that the whole of Lithuania has to be regarded as a highly endemic area with high environmental contamination with parasite eggs.

5.2. Human infections in Lithuania

5.2.1. Cystic echinococcosis

In the 19th century, only single human CE cases were diagnosed in Lithuania, and during 1920–1940, three case reports with surgery or autopsy findings of CE were published (Dakinevičius, 1931; Buinevičius, 1935; Zubinas, 1936). In another report summarising surgical liver interventions in 400 patients between the 1940s and 1970s, liver CE was diagnosed in three patients (Šiurkus, 1969). Based on analysis of data collected from 54 hospitals in 1958–1961, seven cases of human CE were registered in Lithuania (Danilevičius, 1964). The age-range of the patients was 35–69 years. Two of the patients died. The morbidity during this period increased from 0.03/100,000 in 1958 to 0.1/100,000 in 1960.

In the last decade, the diagnostic techniques have improved and the incidence of human CE cases has increased up to 13 new registered cases per year in 2005 (0.39/100,000 inhabitants per year) (Marcinkutė et al., 2006). Later on, the number of diagnosed human CE cases rose to 35 in 2009 (1.11 cases/100 000 inhabitants per year) remaining at a comparable level until 2013 (1.15 cases/100 000 inhabitants per year) (Table 5). The reported CE cases were recorded only at the University Hospital of Infectious Diseases and Tuberculosis and at the Santariškių Clinics, Vilnius University. As no obligatory notification of CE exists in Lithuania, it can be assumed that the number of reported cases is underestimated in some districts. Most CE cases were registered from southeastern and northwestern areas of Lithuania with a particularly high number of CE cases registered from the Vilnius district (Fig. 1). Based on these findings, the Vilnius district has to be considered a hyper-endemic zone. Based on the geographical distribution of findings in animal hosts and the origin of the reported human cases, it can be concluded that the transmission of *E. granulosus* may occur throughout the whole country.

5.2.2 Alveolar echinococcosis

From 1997, when the first confirmed AE cases were diagnosed in Lithuania, until 2006, 80 AE cases have been diagnosed at the

State Hospital for Tuberculosis and Infectious Diseases in cooperation with the Santariškių Clinic (Vilnius University) (Bružinskaitė et al., 2007). Diagnoses were based on serologic testing using ELISA (Bordier Affinity, Crissier, Switzerland), Western blot (LDBIO, Lyon, France) and imaging methods (ultrasound scan, computed tomography), and were confirmed by histopathologic examination or typical liver lesion morphologic features. Of these AE patients, 81% were farmers or people involved in agricultural activities. Since 2007, 10–23 new cases were recorded annually (Table 5). The AE cases were recorded from many parts of the country (Fig. 2) suggesting that the whole territory of Lithuania should be considered as an endemic area for AE.

According to the data presented in Table 5, a total of 179 AE cases have been registered over a 16-year period (1997–2013). The mean age at first diagnosis was 60 years (range 21–83) and 65.9% were women. The incidence of AE varied from 0.03 in 2004 to 0.57 in 2009 and 0.74 in 2012 per 100,000 of inhabitants (Table 5). AE primarily affected the liver, mostly the right lobe and both lobes in about one third of the cases. A quarter of the cases had extra-hepatic disseminations.

Despite diagnostic and treatment innovations, AE still causes a high mortality in Lithuania. In the period of 1997–2013, 130 of the 179 registered patients with human AE received anthelmintic treatment and 53 of them died within the 16-year observation period. The longest survival from diagnosis was 16 years (23.8% of them received radical surgery). Mortality was 3.3% in 2003, 15.1% in 2007, 3.6% on average during 2008–2010 and 9.9% in 2011–2013. In 35.4% of cases, survival was less than one year from diagnosis due to late diagnosis at stage IV of the disease.

6. Selected neighbouring areas

6.1. General considerations

Historic data and new information concerning the occurrence of *E. granulosus* and *E. multilocularis* are available from the surrounding areas of Estonia, Latvia and Lithuania. It is obvious that CE has been present for decades in the area. Also *E. multilocularis* has been observed for several decades, at least focally, although it is not possible to estimate the abundance of this species retrospectively.

6.2. Poland

Geographically, Poland is located south of the Baltic States and has been known as an endemic area of *E. multilocularis* since 1995. In this paper, however, we will only focus on the epidemiological

Table 5

Number of human cases and minimal^a incidences of cystic (CE) and alveolar echinococcosis (AE) originating from all regions of Lithuania and diagnosed at the University Hospital of Infectious Diseases and Tuberculosis and at the Santariškių Clinics, Vilnius University during 1995–2013 (A. Marcinkutė, Lithuanian (Vilnius) Echinoregistry, November 2014).

		1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CE	Cases/year	1	5	4	1	7	9	8	11	13	9	8	8	35	32	23	24	34	24
	Incidence; cases/100.000	0.03	0.14	0.11	0.01	0.20	0.26	0.23	0.33	0.39	0.028	0.25	0.25	1.11	1.03	0.76	0.8	1.15	0.82
AE	Cases/year	1	0	0	1	4	16	9	16	17	17	5	13	18	13	10	22	16	10
	Incidence; cases/100.000	0.03	0	0	0.03	0.12	0.46	0.26	0.47	0.51	0.52	0.15	0.41	0.57	0.42	0.33	0.74	0.54	0.34
	No of died AE patients	–	–	–	–	1	1	3	1	7	7	3	5	3	4	6	3	5	–

^a As data from other hospitals is missing, the incidence may be underestimated.

situation on the border area to Lithuania. CE has been documented in Poland in the past for example in pigs (4.5%), beef cattle (0.007%), sheep and goats (18.7%) (Derylo and Szilman, 1998); the occurrence of CE in pigs was confirmed recently (Gawor et al., 2014). As in Lithuania, the pig strain (G7) seems to be of major zoonotic significance in Poland (Dybicz et al., 2013).

In red foxes, *E. multilocularis* was described for the first time in the Gdansk region, around 300 km away from Lithuanian border (Malczewski et al., 1995). The high prevalence of this tapeworm in red foxes in the northeast (34.5%) and southeast (39.3%) of Poland with foci of infection in some counties (up to 70% foxes infected) represents a high potential risk for human infection in these areas (Gawor et al., 2004; Karamon et al., 2014). A recent review about human AE (1990–2011) in Poland is documenting a continuous increase of AE cases during the last two decades (Nahorski et al., 2013). It should be noted that this increase began shortly after the first detection of the parasite in foxes. Considering the long incubation period of human AE of up to 15 years, it can be assumed that human AE already existed in the past. This view is supported by the fact that two AE patients were diagnosed in Poland in the seventies of the last century (Nahorski et al., 2013).

6.3. Belarus

Data published in the late 1950s revealed that *E. granulosus* metacestodes were found in 1.3% of cattle, 2.8% of sheep and 14.4% of pigs in Belarus (Chashuk and Chunosov, 1958). The original paper is not available for detailed analysis but high prevalence of *E. granulosus* in pigs indicates that the dog–pig life cycle was probably present in that time.

E. multilocularis was reported to occur in Belarus in animals, as adult and larval stages, and in humans decades ago. In a recent paper, a retrospective overview of data on the occurrence of *E. multilocularis* in its intermediate and definitive hosts was provided by Shimalov (2011). According to old records the *E. multilocularis* metacestodes were found in the striped field mouse (*A. agrarius*) in the Luninetsk district and in two bank voles (*M. glareolus*) from the Luninetsk and Vitebsk regions (Merkusheva, 1963). Later, metacestodes of *E. multilocularis* were probably found in beavers and bank voles in the Berezina Biosphere Reserve (Kolbin and Karasev, 1965; Arzamasov et al., 1982, 1983) however, these findings were most probably misdiagnosed as metacestodes of *E. granulosus* (Merkusheva and Bobkova, 1981).



Fig. 1. Distribution of human cases of cystic echinococcosis in 1997–2013 in Lithuania. The numbers indicate cases reported in the districts. (A. Marcinkutė, Lithuanian Vilnius-Echinoregistry, 2013).



Fig. 2. Distribution of human cases of alveolar echinococcosis in 1997–2013 in Lithuania. The numbers indicate cases reported in the districts. (A. Marcinkutė, Lithuanian Vilnius-Echinoregistry).

In the Bialowieza Forest, *E. multilocularis* metacestodes were found in the 1970s by Shimalov in the bank vole (*M. glareolus*) and field vole (*M. agrestis*) during field practice by biology students of the Brest State Pedagogical Institute (now Brest State University) (Shimalov, 2010). In the Belarusian Polesie, metacestodes of *E. multilocularis* were isolated from two common shrews (*Sorex araneus*), Eurasian water shrew (*Neomys fodiens*), tundra vole (*Microtus oeconomus*), common vole (*Microtus arvalis*), wood mouse (*Apodemus sylvaticus*), two common hamsters (*Cricetus cricetus*), muskrats (*Ondatra zibethica*), European water voles (*A. terrestris*), five bank voles (*M. glareolus*) and three field mice (*A. agrarius*) during 1980–1999 (Shimalov, 1991, 2002; Shimalov and Shimalov, 2001).

In 2002, Anisimova (2002) reported *E. multilocularis* metacestodes in 2.6% of examined bank voles and 0.9% of striped field mice, trapped in the forest of Polesie State Radiation and Ecological Reserve while Dubina et al. (2002) in 1 out of 17 investigated nutria (*Myocastor coypus*) in the Vitebsk region.

The definitive host for *E. multilocularis* is the red fox in the central (Anisimova, 2003) and the southern part of Belarus (Shimalov and Shimalov, 2001, 2003). However, information on cases of human AE is limited; two cases were briefly reviewed by Shimalov (2011). In one case, metacestodes were found in the liver of a woman from the Brest area (Korzan et al., 1997), the other patient was a woman from the Mogilev Region (Call for help, 2008).

6.4. North European part of Russia: Kaliningrad, Pskov and Saint Petersburg provinces

Historically, the North European part of Russia was considered to be the area in the former Soviet Union with active transmission of *E. multilocularis* but no AE in humans (Peklo, 2014). While the possibility for *E. multilocularis* transmission in the domestic life cycle was

questioned, *E. granulosus* was considered the only species in domestic animals in this part of Russia (Petrov, 1957). The same areas were considered endemic for *E. granulosus* by Darchenkova et al., (1998), mainly attributed to parasite transmission in traditional husbandry systems involving a dog–reindeer life cycle.

6.4.1. Kaliningrad province

In this province, located between the southern Lithuanian and the northern Polish border, *E. granulosus* was reportedly prevalent in the 1960s. Data presented by Danilin (1961) showed that 0.55–6.8% of cattle and 11.3% of slaughtered pigs were infected with *E. granulosus*. Recently, 20 human *Echinococcus* sp. cases (0.1–0.3/100 000) were registered in adults during the years 2003–2012, and 1 case in a child during 1996–2012. The highest number of human cases was recorded in 2011: 4 cases, (0.42/100 000), (Peklo, 2014).

6.4.2. Pskov and Saint Petersburg provinces

Until 1983, human *Echinococcus* infections were not recorded in this area due to the absence of a reporting system. In Pskov province, bordering Latvia and Estonia, 5 infections with *Echinococcus* sp. were registered in adults and 1 in a child during 1996–2012. This corresponds to 0.1/100 000 cases in adults (2003, 2006–2009) and 0.9/100 000 cases in children (2009) (Peklo, 2014).

In the Saint-Petersburg province bordering Estonia, 18 infections with *Echinococcus* sp. were registered between 1996 and 2012 representing 0.06–0.2 cases per 100 000 of inhabitants. Interestingly, a high number of human *Echinococcus* cases were registered in large cities. For example, in 1996–2012 up to 14 cases/year were registered in adults in Saint-Petersburg (0.1–0.3/100,000) (Peklo, 2014).

7. Discussion and conclusions

E. granulosus (genotypes G1, G7, G8 and G10) and *E. multilocularis* are present in various wild and domestic animals in one or more of the Baltic States: Estonia, Latvia and Lithuania. However, the full host range and the transmission patterns need to be further investigated. A common problem is that available data on animal infections are scarce and thus the contribution of different hosts to the local epidemiology of these parasites is largely unknown. For Estonia and Latvia, the data originate primarily from few research projects, while official monitoring programs require substantial improvements.

The domestic cycle of *E. granulosus* (pig strain) is best known in Lithuania. The small-scale, on-farm transmission pattern (farm dogs and pigs) and the seasonal home slaughtering tradition appear to be the major risks for parasite transmission in the rural environments. So far, this strain is considered responsible for the majority of human CE cases in Lithuania. A promising pilot control experiment confirmed that the treatment of dogs with praziquantel over 4 years during the season of home slaughtering of pigs significantly reduced parasite transmission.

The wild animal cycle of *E. canadensis* (G8 and G10) has been in the focus in Latvia and Estonia. The main wild intermediate host species is moose. Dogs and wolves are the main definitive host species reported so far. The zoonotic significance of this strain has not been documented in the Baltic countries as yet.

Observations from Estonia, Latvia and Lithuania indicate that the distribution of *E. multilocularis* is wider than previously anticipated in Europe. Historic data provide some hints that the parasite may have existed in the area in the past. However, new data with very high prevalences of *E. multilocularis* in foxes and raccoon dogs and a recently increasing incidence of AE in humans in Lithuania support the hypothesis that the epidemiological situation may have changed in the last two decades in some areas, associated with a higher infection risk for humans.

E. multilocularis is detected in definitive host species such as the red fox, raccoon dog, wolf and domestic dog. The intermediate host species have been investigated only in Lithuania. The red fox can be considered as the most important species for the transmission of *E. multilocularis* to humans. The increase in the red fox and raccoon dog populations accompanied by the invasion of foxes into urban areas, as earlier described for central Europe (Deplazes et al., 2004), may substantially increase the risk for transmission of *E. multilocularis* to humans also in urban Baltic environments. The respective epidemiological importance of rural dogs and raccoon dogs is still largely unknown and deserves further study. However, the identification of *E. multilocularis* in dogs in Lithuania suggests that transmission of the parasite can occur in close vicinity to the human population.

In Estonia and Latvia, the published information on *Echinococcus* infections of domestic animals is scarce. Finland, which is located across the Baltic Sea north of Estonia, is considered free of *E. multilocularis*. The risk of exporting the parasite from the Baltics to Finland is targeted by treatment requirements for dogs (Wahlström et al., 2015).

In humans, cases of AE and CE have been increasing since the 1990s in Latvia and Lithuania, while remaining at relatively low levels in Estonia. In Latvia and Lithuania, the differentiation between AE and CE is routinely done, whereas in Estonia the cases are registered simply as echinococcosis. In the future, the causative species of all human infections should be characterised, and the data and samples stored for further morphologic and molecular analyses. Collection of comparable data is crucial for efficient monitoring and decision-making regarding preventive and treatment measures. Severe human cases are frequent, indicating that AE and CE often are diagnosed at a rather late stage. Improved awareness

and diagnostics could result in implementing improved preventive measures and better treatment success. Careful follow-up of the patients, as well as proper staging, are also essential for treatment decisions.

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