Mathematical Biosciences 299 (2018) 85–96

Contents lists available at ScienceDirect

Mathematical Biosciences

journal homepage: www.elsevier.com/locate/mbs

Impact of disposing stray dogs on risk assessment and control of Echinococcosis in Inner Mongolia

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ARTICLE INFO

Keywords:
Echinococcosis
Disposing stray dogs
Dynamic model
Basic reproduction number
Risk index

ABSTRACT

Echinococcosis has been recognized as one of the most important helminth zoonosis in China. Available models always consider dogs as the mainly definitive hosts. However, such models ignore the distinctions between domestic dogs and stray dogs. In this study, we propose a 10-dimensional dynamic model distinguishing stray dogs from domestic dogs to explore the special role of stray dogs and potential effects of disposing stray dogs on the transmission of Echinococcosis. The basic reproduction number R_0, which measures the impact of both domestic dogs and stray dogs on the transmission, is determined to characterize the transmission dynamics. Global dynamic analysis of the model reveals that, without disposing the stray dogs, the Echinococcosis becomes endemic even the domestic dogs are controlled. Moreover, due to the difficulties in estimating the parameters involved in R_0 with real data and the limitation of R_0 in real-world applications, a new risk assessment tool called relative risk index $\mathscr{I}_{risk}$ is defined for the control of zoonotic diseases, and the studies of the risk assessment for Echinococcosis infection show that it is essential to distinguish stray dogs from domestic dogs in applications.

1. Introduction

Echinococcosis, as one of the most serious zoonotic parasitic diseases with great economic and public health significance, has been prevalent to large areas of the world [1]. There are two main forms of Echinococcosis in humans. Cystic Echinococcosis (CE) is distributed in the Eastern and Middle Asian countries as well as some of the Northern African countries. The endemic area of Alveolar Echinococcosis (AE) stretches from Eastern France through the ex-Soviet States, China, Northern Japan to regions of North America and Canada [2–4]. The prevalent scope of Echinococcosis in China is mainly located in the northwestern alpine meadows and the pastoral/agro-pastoral regions [5]. However, Xinjiang, Ningxia, Sichuan, Tibet, Gansu, Qinghai and Inner Mongolia are the main endemic areas with high risk of infection of Echinococcosis to both animals and humans [6–8]. The number of infectious domestic animals of Echinococcosis is more than 10^8, in which the number of infectious dogs is at least 5×10^6 [9].

The life cycle of Echinococcus granulosus includes three stages of egg, larva and adult. Adult worms attach to the intestinal walls of the definitive hosts (typically, dogs, wolves and foxes in China). Then, adult worms produce eggs which shed in faeces of the definitive hosts and contaminate the environment (e.g., earth, grass, vegetables, water and so on) in various ways. The eggs hatch in the small bowels after ingestion by intermediate hosts (sheep, goats, cattle, camels) and then release an oncosphere. Furthermore, the oncospheres penetrate the intestinal wall into various organs (livers and lungs). Then the oncospheres develop into metacestode cysts in the host's organs, producing protoscolices which will develop into adult worms when they are eaten by a definitive host [10]. Humans are incidental hosts for Echinococcus granulosus, they are only infected by eggs but do not induce further transmission. The life cycle of Echinococcus granulosus is given in Fig. 1.

To better understand the transmission characters of Echinococcosis in some endemic areas of China, China Animal Health and Epidemiology Center (CAHEC) carried out a survey on the annual total numbers of sheep, domestic dogs, stray dogs and the infection rates of Echinococcosis in sheep, cattle, dogs in Inner Mongolia (Fig. 2). The survey report suggests that Echinococcosis has a much higher infection rate than that has been expected in the target region [11]. As shown in Fig. 2(d), the summary from the survey indicates that the infection rate of dogs is the highest among the various hosts of Echinococcus granulosus. There are multiple risk factors for Echinococcosis transmission caused by domestic dog, stray dog, wild animal, custom of herdsmen, and treatment of herdsmen. The survey results show that, among the

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https://doi.org/10.1016/j.mbs.2018.03.008
Received 12 August 2017; Received in revised form 5 March 2018; Accepted 7 March 2018
Available online 08 March 2018

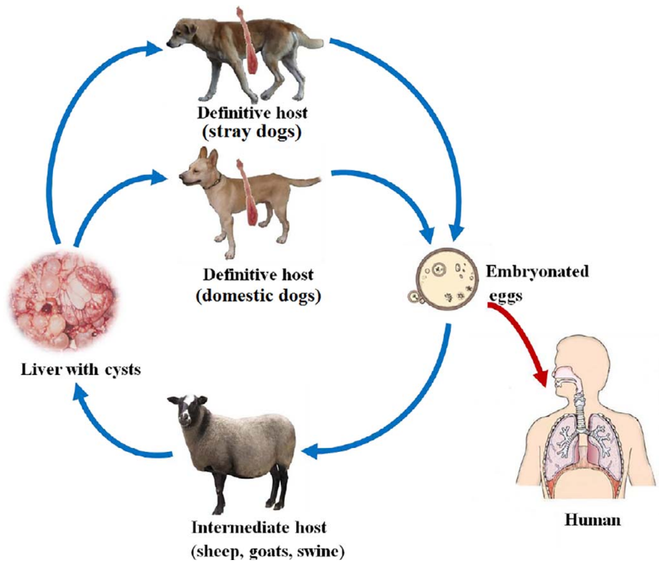

Fig. 1. Life cycle of Echinococcus granulosus.

above five risk factors, the dog is the most effective one since 91% of the herdsmen fed dogs, 65% of the sheep have close contact with domestic dogs and stray dogs, 47% of the domestic dogs may be in direct contact with stray dogs. Therefore, the dog play a significant role in the transmission cycle of Echinococcus granulosus. In particular, the fact that dogs roaming freely is one of the most key risk factors for Echinococcosis infection [12]. Compared with domestic dogs, the stray dogs with larger roaming range have more chances of contacting the infectious organs and hence present a higher risk of the infection [13–15]. Meanwhile, the administration and the persuasion treatment of stray dogs undertake much heavier pressure than that for domestic dogs due to many working factors including social and religious reasons. Therefore, it is essential and reasonable to distinguish stray dogs from domestic dogs as different definitive hosts, which will allow a better understanding of the transmission dynamics of Echinococcosis.

Mathematical and simulation models have been employed to explain observations of Echinococcosis transmission. Gmmell et al. and Roborts et al. [16,17] established a statistic model which described the dog-sheep life-cycle of Echinococcus granulosus in New Zealand. They used the model to simulate the host-parasite system and discuss previous experimental and survey data. Further study has been developed in an attempt to evaluate a control strategy of Echinococcosis, which provided clear evidence that a high egg production leads to the hyperendemic transmission of Echinococcosis [18]. In [19,20], Gmmell et al. and Roborts et al. used such model to describe the transmission dynamics of the parasite. Cabrera et al. [21] showed a base-line survey on the transmission dynamics of Echinococcus granulosus in sheep in the Department of Florida, Uruguay. They discussed the effects of the different transmission levels of the parasites on potential control strategies. Torgerson et al. [22–24] used maximum likehood techniques to evaluate the abundance and prevalence of infection of Echinococcus granulosus in cattle and sheep in Kazakhstan. Lahmar et al. [25] examined the abundance and prevalence of infection of Echinococcus granulosus in camels in Tunisia. To gain a better understanding of the prevalence and the likelihood of parasite-induced host immunity in response to the infection, Budke et al. [26] established an abundance model about the transmission of Echinococcus granulosus and Echinococcus multiloculars in dogs in Shiqu county, Sichuan province. In [27], a mathematical model for the control of cystic Echinococcosis was presented, the authors indicated that mathematical models would provide a better understanding of the parasite's biology and the dynamics of transmission. Torgerson et al. [28] considered the age variation of larval protoscoleces of Echinococcus granulosus in sheep, their results suggested that removal of old sheep through a culling programme could substantially improve the control of Cystic Echinococcosis.

In order to explore the effective control strategies and prevention measures, Wang et al. [29] proposed a dynamical model which described the dog-livestock-egg-human life-cycle of Echinococcus granulosus in Xinjiang, and they described the dynamics of the model by the basic reproduction number R_0. In [30], the authors used a time-delayed model to explore the effective control and prevention strategies for Echinococcosis transmission. The results also showed a threshold type result that the disease dies out when $R_0 < 1$ and the disease persists when $R_0 > 1$.

As far as we know, almost all the available mathematical modeling studies usually treat both domestic dogs and stray dogs equally in the transmission. However, Inangolet et al. [31] investigated the distribution and infection intensity of Echinococcus granulosus in the dog population and indicated that the stray dogs showed higher infection level and admitted much heavier parasite burden compared with domestic dogs. They only elucidated some static results based on the statistical analysis. The dynamical modeling and mechanism analysis are less explored.

In this study, by taking into account the special role of stray dogs in terms of infection rate and treatment to the outbreak and endemic of Echinococcosis, we propose and study a dynamic model for the transmission of Echinococcosis. Using the modeling and analysis, we investigate the control and prevention strategies related to dogs for the eradication of Echinococcosis infection in Inner Mongolia. The paper is organized as follows. In Section 2, we formulate a dynamic model of Echinococcosis transmission. Section 3 focuses on some basic properties of the system and the detailed analysis of the global stability at disease-free equilibrium and endemic equilibrium. Section 4 shows the model application and investigates the effect of control strategies of stray dogs θ and domestic dogs γ on R_0. It is interesting to find that the infection can not be eliminated without the help of disposing stray dogs. Section 5 is about the risk assessment and some applications of the relative risk. Our studies show that the relative risk will be lower (greater) than the objective reality if all the dogs are considered as domestic dogs (stray dogs). A summary of our findings in this study and future work are presented in the discussion section.

2. Model formulation

We are primarily interested in investigating the role of stray dogs on the transmission of Echinococcosis. Hence, in order to address the role of stray dogs in terms of administration and persuasion treatment, we consider the definitive host dogs separately as domestic dogs and stray dogs. The domestic dog population is decomposed into susceptible individuals $D_{1s}(t)$ and infectious individuals $D_{1i}(t)$. The stray dogs are considered as two groups: susceptible individuals $D_{2s}(t)$ and infectious individuals $D_{2i}(t)$.

As intermediate hosts, the livestock (mainly sheep and cattle) become infected through the effective contact of parasitic eggs. We divide the livestock population into susceptible individuals $L_s(t)$ and infectious individuals $L_i(t)$. Since the latent period of Echinococcosis may last for months or even years [32], we divide the humans into three compartments, namely, susceptible individuals $H_s(t)$, exposed individuals $H_e(t)$, and infectious individuals $H_i(t)$. In reality, humans act as incidental intermediate hosts.

The density of Echinococcus eggs mainly depends on the number of