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REVIEW

Angiostrongylus cantonensis in the vector snails *Pomacea canaliculata* and *Achatina fulica* in China: a meta-analysis

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Abstract Angiostrongyliasis is a food-borne parasitic disease induced by the nematode *Angiostrongylus cantonensis*, and has been recognized as the main cause leading to human eosinophilic meningitis. Humans usually acquire infection by digestion of infected *Pomacea canaliculata* and *Achatina fulica*, the most predominant intermediate hosts found in China. This meta-analysis was aimed to assess the prevalence of *A. cantonensis* infection among these two snails in China in the past 10 years. Data were systematically collected in electronic databases such as PubMed, Web of Science, ScienceDirect, CNKI, SinoMed, VIP, CSCD, and Wanfang from 2005 to 2015. Thirty-eight studies with a total of 41, 299 *P. canaliculata* and 21,138 *Ac. fulica* were included in the present study. The overall infection rate of *A. cantonensis* in China was estimated to be 7.6 % (95 % confidential interval (CI) = 0.063 to 0.090) in *P. canaliculata* and 21.5 % in *Ac. fulica* (95 % CI = 0.184 to 0.245), respectively. No significant difference was observed in prevalence rates among publication year and sample size for both snails. Also, it was found that the prevalence in *Ac. fulica* is significantly higher than that in *P. canaliculata* (odds ratio (OR) = 3.946, 95 % CI = 3.070 to 5.073). The present study reveals that snail infection with *A. cantonensis* is clearly prevalent in China. Further studies are required to improve strategies for control of infections of snails, particularly those of *Ac. fulica*, and to detect further factors and conditions such as geographic region, temperatures, and diagnosis method.

Langui Song, Xiaowen Wang and Zi Yang contributed equally to this work.

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Introduction

Angiostrongylus cantonensis, a food-borne zoonotic parasite, has been recognized as the primary pathogen associated with human eosinophilic meningitis or eosinophilic meningoencephalitis (Eamsobhana 2014). This neurotropic nematode has molluscan intermediate hosts such as raw apple snails (*Pomacea canaliculata*) and raw giant African land snails (*Achatina fulica*) (Chiu et al. 2014; Estebenet and Martín 2002) and uses as final hosts several species of rodents. The adult worms live in the pulmonary arteries of rats. Humans are non-permissive, accidental hosts, thus presenting severe central nervous system symptoms due to larvae migrans. Humans acquire the infection by ingesting positive raw or undercooked snails (even by contact to their slime), poorly cleaned contaminated vegetables, or other infected paratenic hosts such as freshwater prawns, crabs, or frogs (Lv et al. 2009a). Thousands of diagnosed cases of eosinophilic meningitis caused by *A. cantonensis* have been reported worldwide (Wang et al. 2012).

Angiostrongyliasis is of increasing public health importance as globalization contributes to the geographical spread and thus represents a threat for most countries as an imported disease (Kim et al. 2014). The parasite has spread from its traditional endemic areas in Asia and in the Pacific Basin to the American continent including the USA, Brazil, and Caribbean islands (Rosen et al. 1967; Park and Fox 2013; Simoes et al. 2011; Slom et al. 2002). Recently, the incidence of human infections has increased rapidly. Most reports of the disease come from Thailand and Taiwan with increasing reports from China (Punyagupta et al. 1975; Tsai et al. 2001; Lv et al. 2008; Zhang et al. 2008a; Tseng et al. 2011). The rapid global spread of this parasite, the existence of the intermediate hosts existing in a large amount of countries, and the emerging occurrence of the infection pose great challenges in clinical and laboratory diagnosis, as well as in epidemiology and basic biology. Effective prevention of the disease and control of the spread of the parasite require a thorough and enhanced understanding of the hosts, including their distribution, the epidemiology of angiostrongyliasis, as well as the human and environmental factors that contribute to transmission. As a consequence, the current knowledge on life cycles and the pathogenicity of the parasite and the disease, as well as the recent epidemiological status together with significant progress in laboratory investigation of *A. cantonensis* infection, are overviewed here to promote understanding and awareness of this emerging neglected disease (Wilkins et al. 2013).

Over the past 10 years, many studies have been done to examine the prevalence of *A. cantonensis* in *P. canaliculata* and *Ac. fulica* since these two snails are the most predominant and edible snails in China. To the best of our knowledge, there is no related review and the aim of this systematic review and meta-analysis study was to evaluate the prevalence of *A. cantonensis* infection among *P. canaliculata* and *Ac. fulica* in China and its association with several risk factors.

Materials and methods

1. Search strategy

We systemically searched the PubMed, Web of Science, ScienceDirect, CNKI, SinoMed, VIP, CSCD, and Wanfang databases (Table S1), and manually retrieved the academic conference proceedings of the relevant researches about the *A. cantonensis* infection among *P. canaliculata* and *Ac. fulica* in mainland China. The retrieval time: From Jan 2005 to Aug 2015. The key words: *Pomacea canaliculata*, *Achatina fulica*, and *Angiostrongylus cantonensis*. Following the initial search, suitable articles were identified according to the titles, abstracts, and keywords, and then duplicates were removed by using a reference management software (Endnote X7). Next, the study quality was independently assessed by two skilled authors. Also, the reference lists of the related articles were checked to avoid missing relevant studies. The authors assessed the full text to include or exclude the study when the information in the title and abstract was inadequate. Finally, we reviewed the identified studies to evaluate the eligibility on the basis of the inclusion and exclusion criteria. All the above procedures were conducted by two independent and trained authors at School of Public Health, and inconsistency between authors were resolved through discussion.

2. Inclusive criteria

(a) Studies that were published from Jan 2015 to Aug 2015
(b) Studies that were published in Chinese or English
(c) Studies that contained original data, such as sample size and infection rate
(d) Studies that were conducted in mainland China, including villages, ditches, ponds, snail farms, restaurants, market, etc

3. Exclusion criteria

(a) Studies containing overlapping data
b) Studies with poor quality, such as without information on the detection of *A. cantonensis* in snails and sampling methods of snails
(c) Experimental studies, in which the snails were experimentally infected with the first stage of *A. cantonensis* instead of natural infection

4. Data extraction

The following information was extracted from all the included studies: first author, year of publication, geographical region of study, sample size (number of examined *P. canaliculata* and *Ac. fulica*), prevalence rate, detection method, weight range, annual average temperature, and mean annual precipitation.

5. Statistical analysis

Point estimates and their 95 % confidence intervals (CI) were calculated for all included studies. For each snail, proportions of individual studies and overall prevalence were presented by forest plots. Cochrane Q statistics from a chi-square test ($p < 0.1$ was significant) and inconsistency index ($I^2 > 50$ was significant) were used to determine and quantify the effect of heterogeneity (Higgins and Thompson 2002). The fixed-effects model was employed when heterogeneity was acceptable, otherwise the random-effects model was used. For each study, continuous variables were converted to ordinal variables or binary variables, such as publication year, sample size, and then meta-regression analysis was performed; for categorical variables like geographical region and detection method, the subgroup analysis was used. Odds ratio (OR) was used to compare the pooled prevalence between the two invasive snails. Begg's and Egger's tests and funnel plots were used for the appraisal of publication bias. All the statistical analyses were performed using Stata (Version 12.0, Stata Corp, College Station, Texas)).

Results

Study characteristics

According to the search strategy, inclusion and exclusion criteria, a total of 38 studies (33 in Chinese and 5 in English) among 226 articles were eligible in this meta-analysis. During the study selection process, 151 duplicates, 6 experimental studies, 27 irrelevant surveys (prevention and control research, case report, distribution, seroprevalence, etc.), and 4 overlapping data were excluded successively (Fig. 1). The outcomes of eligible literatures are shown in Table 1. Our analysis included a total of 41,299 *P. canaliculata* and 21,138 *Ac. fulica*.

Meta-analysis

For *P. canaliculata*, a wide variation was found in the prevalence estimate among different studies ($Q = 1790.78$ ($df = 33$), $p < 0.0001$; $I^2 = 98.2$ %), and thus, random-effects model was used. The pooled prevalence of *A. cantonensis* infection was 7.6 % (95 % CI = 0.063 to 0.090) (range = 0.00 to 0.32). The forest plot diagram of this review is shown in Fig. 2. Also, the same analysis was conducted for *Ac. fulica*. Like *P. canaliculata*, the prevalence of *A. cantonensis* infection is strongly heterogeneous among different studies ($Q = 1134.65$ ($df = 35$), $p < 0.0001$; $I^2 = 96.9$ %), and the pooled prevalence of *A. cantonensis* infection among *Ac. fulica* using the random-effects model was 21.5 % (95 % CI = 0.184 to 0.245) (range = 0.00 to 0.45). The forest plot diagram of this review is displayed in Fig. 3.

For each snail, the meta-regression tested the following risk factors as potential sources of heterogeneity: (1) year of publication (≤2008 vs ≤2011 vs >2011) and (2) sample size (≤500 vs ≤1000 vs >1000). The results of the meta-regression are exhibited in Table 2. For *P. canaliculata*, the *A. cantonensis* infection rate decreased by sample size and the publication year of papers but it was not statistically significant ($p > 0.05$) (Table 2). For *Ac. fulica*, similarly, the *A. cantonensis* infection rate decreased by the publication year of articles but increased by the sample size, and it was still not significant ($p > 0.05$) (Table 2).

There is a varying prevalence of *A. cantonensis* infection in different geographic regions. For *P. canaliculata*, the minimum prevalence was 0 % in Shanghai (2014), Guangzhou, Guangdong (2012), Yunnan (2010), and Qionghai, Hainan (2008) and the maximum prevalence was about 32 % in Foshan, Guangdong (2008); for *Ac. fulica*, the minimum prevalence was 0 % in Shanghai (2014) and Yunnan (2010), respectively, and the maximum prevalence was about 45 % in Dongguan,

Fig. 1 Flow diagram of study selection for the meta-analysis

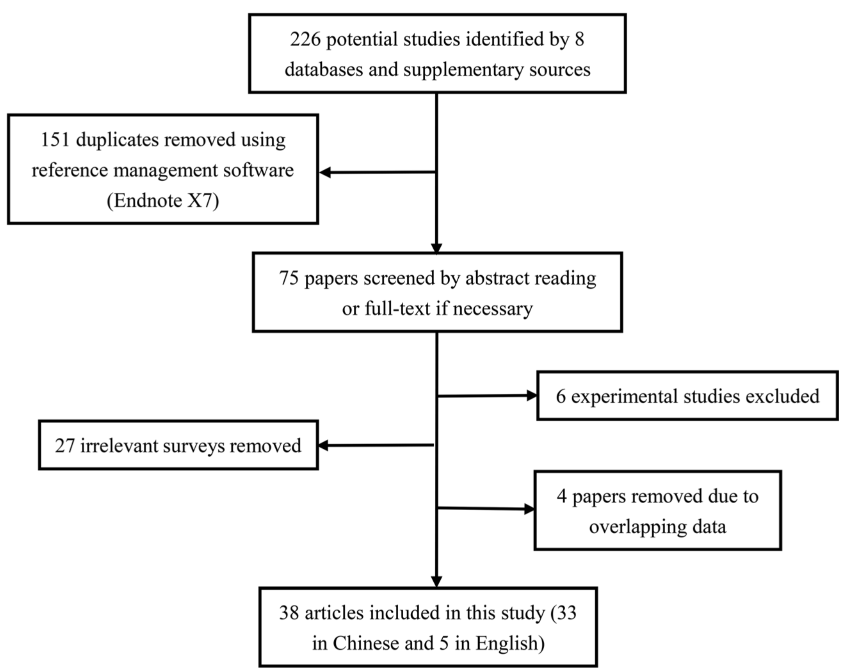

Table 1 Baseline characteristics of the included studies

No.	Province	City	*Pomacea canaliculata*		*Achatina fulica*		Detection method	Reference
			Sample size	Infection no (%)	Sample size	Infection no (%)		
1	Guizhou	–	1287	5 (0.4 %)	240	27 (11.3 %)	TH	(Li et al. 2015)
2	Shanghai	–	133	0 (0.0 %)	25	0 (0.0 %)	LM	(Guo et al. 2014)
3	Guangxi	Beihai	144	2 (1.4 %)	98	21 (21.4 %)	ED	(Xie and Wu 2013)
4	Guangdong	Shenzhen	100	30 (30.0 %)	135	21 (15.6 %)	TH	(Huo et al. 2012)
5	Guangdong	Dongguan	128	34 (26.6 %)	97	44 (45.4 %)	TH	(Chen et al. 2012a)
6	Guangdong	Panyu	357	11 (3.1 %)	367	83 (22.6 %)	ED	(Chen et al. 2012b)
7	Guangdong	Guangzhou	161	0 (0.0 %)	226	30 (13.3 %)	ED	(Huang et al. 2012)
8	Guangdong	Zhanjiang	20	2 (10.0 %)	23	3 (13.0 %)	–	(Shen et al. 2012)
9	Guangdong	Guangzhou	734	11 (1.5 %)	795	111 (14.0 %)	ED	(Yang et al. 2012)
10	Guangdong	–	2929	172 (5.9 %)	1354	223 (16.5 %)	TH	(Deng et al. 2012)
11	Hainan	–	518	64 (12.4 %)	534	121 (22.7 %)	ED	(Hu et al. 2011)
12	Guangdong	–	2670	188 (7.0 %)	1927	445 (23.1 %)	ED	(Chen et al. 2011)
13	Hainan	–	538	70 (13.0 %)	554	122 (22.0 %)	LM	(Tong et al. 2011)
14	Guangdong	–	2929	172 (5.9 %)	1354	223 (16.5 %)	TH	(Deng et al. 2010)
15	Guangdong	Pearl River Delta	1684	115 (6.8 %)	913	155 (17.0 %)	TH	(Huang et al. 2010)
16	Guangdong	Qingyuan	223	6 (2.7 %)	102	3 (2.9 %)	ED	(Lin et al. 2010)
17	Yunnan	–	914	4 (0.4 %)	76	0 (0.0 %)	LM	(Wang et al. 2010)
18	Yunnan	–	50	0 (0.0 %)	172	64 (37.2 %)	ED	(Li et al. 2010)
19	China	–	11709	796 (6.8 %)	3549	476 (13.4 %)	ED	(Lv et al. 2009b)
20	Hainan	–	418	58 (13.9 %)	410	155 (37.8 %)	LM	(Tong et al. 2009)
21	Guangdong	–	3723	242 (6.5 %)	2217	618 (27.9 %)	ED	(Zhang 2009)
22	Guangdong	Yangchun	465	4 (0.9 %)	350	27 (7.7 %)	ED	(Zhang et al. 2009a)
23	Guangdong	Fuoshan	742	234 (31.5 %)	589	240 (40.7 %)	TH	(Zhang et al. 2008b)
24	Fujian	Fuzhou	919	173 (18.8 %)	65	10 (15.4 %)	ED	(Ye et al. 2008)
25	Guangdong	Luoding	676	14 (2.1 %)	253	47 (18.6 %)	ED	(Ou et al. 2008)
26	Guangdong	Jiangmen	720	13 (1.8 %)	695	313 (45.0 %)	ED	(Zhang et al. 2008a)
27	Guangdong	Luoding	100	2 (2.0 %)	106	14 (13.2 %)	TH	(Lin et al. 2008)
28	Guangdong	Zhaoqing	315	34 (10.8 %)	255	32 (12.5 %)	ED	(Sun et al. 2008)
29	Guizhou	Guiyang	722	9 (1.2 %)	470	55 (11.7 %)	LM	(Tang et al. 2008)
30	Hainan	Qionghai	100	0 (0.0 %)	100	20 (20.0 %)	TH	(Tong et al. 2008)
31	Guangdong	Maoming	432	87 (20.1 %)	276	106 (38.4 %)	ED	(Zhang et al. 2008c)
32	Fujian	Nanan	297	20 (6.7 %)	299	108 (36.1 %)	TH	(Chen et al. 2008)
33	Guangdong	–	2296	98 (4.3 %)	1033	123 (11.9 %)	LM	(Deng et al. 2008)
34	Guangdong	Lianjiang	296	24 (8.1 %)	388	93 (24.0 %)	ED	(Li et al. 2007)
35	Guangdong	Jiangmen	720	13 (1.8 %)	465	195 (41.9 %)	ED	(Huang et al. 2007)
36	Guangxi	–	638	69 (10.8 %)	226	20 (8.8 %)	ED	(Zhang et al. 2007a)
37	Hainan	Dingan	140	10 (7.1 %)	100	19 (19.0 %)	TH	(Liu et al. 2007a)
38	Hainan	Qionghai	352	38 (10.8 %)	300	60 (20.0 %)	TH	(Hu et al. 2007)

The references are in chronological order

TH tissue homogenate, *ED* enzyme digestion, *LM* lung microscopy

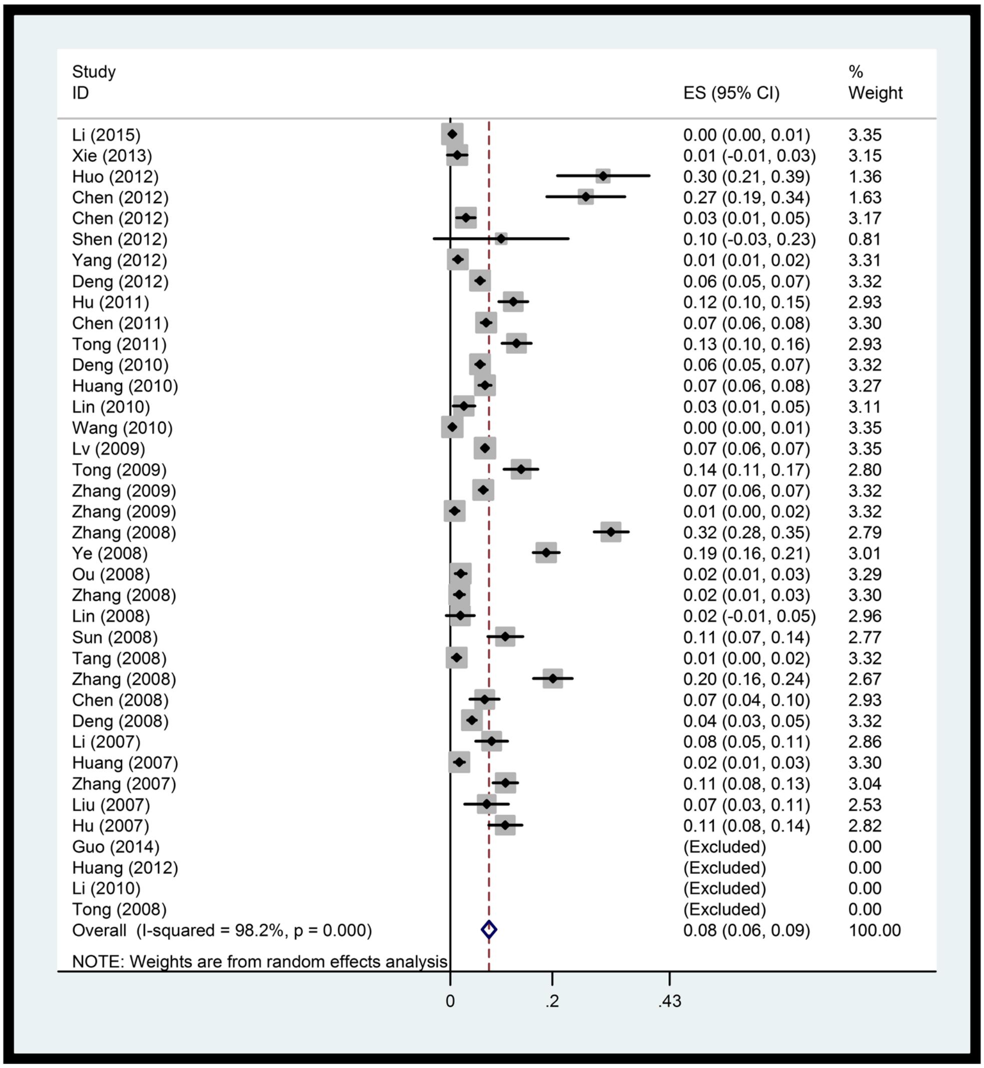

Fig. 2 Proportion meta-analysis plot of *A. cantonensis* infection among *Pomacea canaliculata* in China

Guangdong (2008) and Jiangmen, Guangdong (2012), respectively, suggesting the presence of heterogeneity among geographic regions, and therefore, subgroup analysis was used. For *P. canaliculata*, except for Guizhou Province ($I^2 = 72.8$ %, $p = 0.055$) and Hainan Province ($I^2 = 45.0$ %, $p = 0.122$), the outcomes revealed strong heterogeneity in other geographical regions ($p < 0.001$), respectively, and the prevalence was different in geographical regions (Tables 1 and 3). For *Ac. fulica*, except for Guizhou Province ($I^2 = 0$ %, $p = 0.858$), the results showed strong heterogeneity in other geographical regions ($p < 0.01$), respectively, and likewise, the prevalence was different in geographical regions (Tables 1 and 3).

It is reported that the detection effectiveness varies among different methods (Liu et al. 2007a), which might be another source of heterogeneity, and so subgroup analysis was performed. The results are shown in Table 4. The results showed a wide variation in each detection method for both *P. canaliculata* and *Ac. fulica*.

Additionally, we performed a binary meta-analysis to find out the more susceptible intermediate host of *A. cantonensis*. The OR is highly heterogenous among different studies ($Q = 537.20$ (df = 36), $p < 0.0001$; $I^2 = 93.3$ %), and hence, random-effects model was employed and the outcomes revealed that the differences of prevalence was statistically significant between *P. canaliculata* and *Ac. fulica*, demonstrating a higher infection rate in *Ac. fulica* than that in *P. canaliculata* (OR = 3.946, 95 % CI = 3.070 to 5.073), $p < 0.0001$) (Fig. 4).

Publication bias analysis

For *A. cantonensis* infection among *P. canaliculata*, publication bias was examined with Begg's and Egger's tests, and the results revealed that publication bias was statistically significant ($p < 0.001$) (Fig. 5a); for *A. cantonensis* infection among *Ac. fulica*, the publication bias was not so evident, with $p > 0.05$ ($Z = 1.73$) for Begg's test and $p = 0.049$ for Egger's

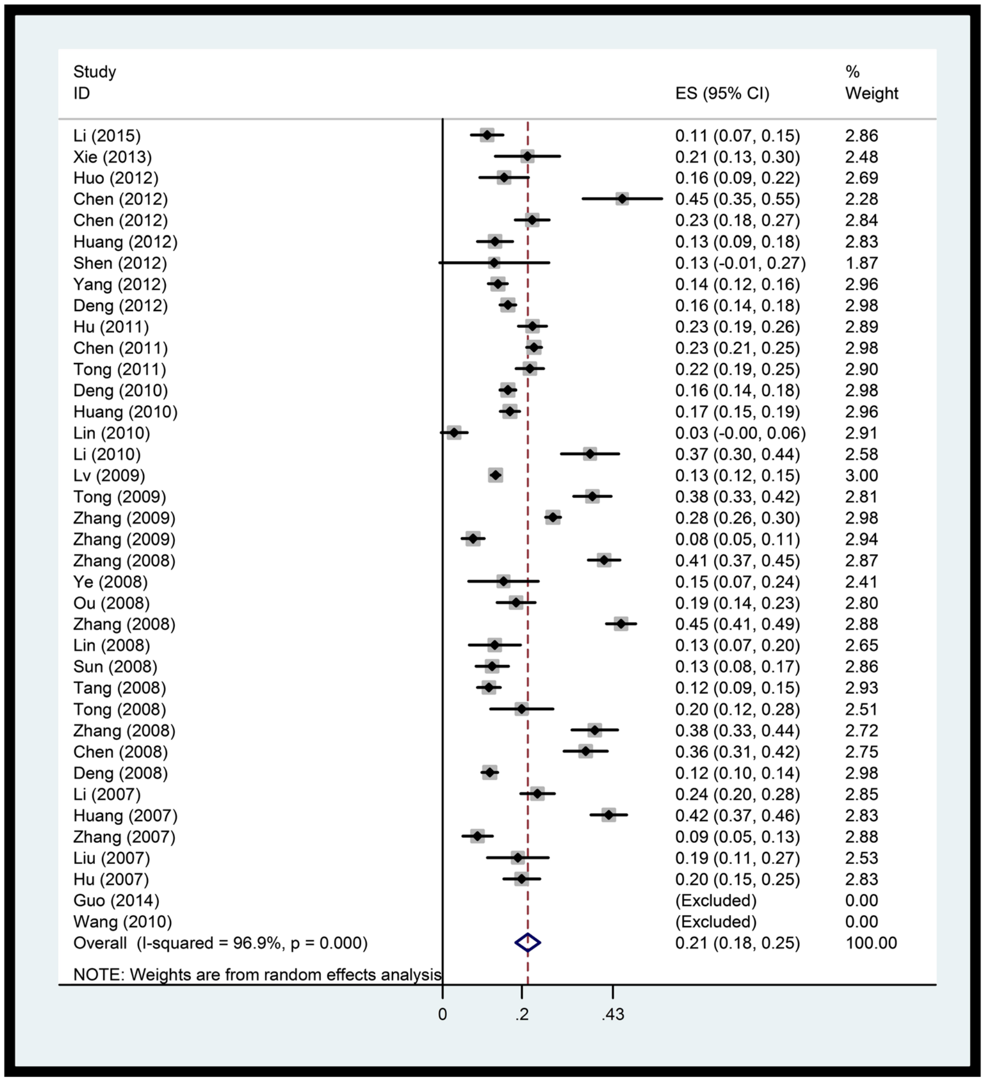

Fig. 3 Proportion meta-analysis plot of *A. cantonensis* infection among *Achatina fulica* in China

test (Fig. 5b); for the odds ratios, the results showed that there was no evident publication bias, with both $p > 0.05$ (Fig. 5c).

Discussion

A. cantonensis is a parasitic nematode that leads to human angiostrongyliasis, the most common cause of human eosinophilic meningitis in Southeast Asia and the Pacific Basin (Eamsobhana 2014). In recent years, the infection rate of humans infected with *A. cantonensis* increased dramatically worldwide, mostly in Thailand, Taiwan, and in the mainland of China (Punyagupta et al. 1975; Tsai et al. 2001; Lv et al. 2008; Zhang et al. 2008a; Tseng et al. 2011). Therefore, it is necessary to increase the understanding of *A. cantonensis*-related epidemiological knowledge, and to improve the public

Table 2 Meta-regression analysis to determine sources of heterogeneity in *Pomacea canaliculata* and *Achatina fulica*

Sources	*Pomacea canaliculata*				*Achatina fulica*			
	Coefficient	*p*	95 % CI		Coefficient	*p*	95 % CI	
			Lower	Upper			Lower	Upper
Publication year	−0.0018404	0.265	−0.037361	0.0336801	-.0264249	0.269	−0.0742723	0.0214225
Sample size	−0.0200758	0.917	−0.0561747	0.0160231	0.0010441	0.967	−0.050082	0.0521703
Cons	0.1225932	0.008	0.0339933	0.2111931	.2620728	<0.001	0.149673	0.3744726

Table 3 Subgroup analysis for comparison of prevalence in different geographical regions

Geographical regions[a]	No. of papers	*Pomacea canaliculata*				*Achatina fulica*			
		Test(s) of heterogeneity		Significance tests(s) of *ES*		Test(s) of heterogeneity		Significance tests(s) of *ES*	
		I^2	*p*	*Z*	*p*	I^2	*p*	*Z*	*p*
Guizhou	2	72.8 %	0.055	1.75	0.081	0.0 %	0.858	9.63	<0.001
Shanghai	1	–	–	–	–	–	–	–	–
Guangxi	2	97.2 %	<0.001	1.29	0.198	86.9 %	0.006	2.33	0.020
Guangdong	22	97.1 %	<0.001	8.72	<0.001	97.5 %	<0.001	10.15	<0.001
Hainan	6	45.0 %	0.122	11.79	<0.001	87.7 %	<0.001	8.38	<0.001
Yunnan	2	–	–	2.00	<0.001	–	–	10.10	<0.001
Fujian	2	97.4 %	<0.001	2.12	0.034	93.5 %	<0.001	2.51	0.012
Overall	37	98.2 %	<0.001	10.99	<0.001	96.9 %	<0.001	13.83	<0.001

[a] The national survey not included

awareness of the need not to eat undercooked or raw snails (Eamsobhana 2014). This study was aimed to assess the prevalence of *A. cantonensis* infection among *P. canaliculata* and *Ac. fulica*, the most predominant intermediate hosts of *A. cantonensis* in China. Because a single study can only use a relatively small sample size, and due to such potential risk factors as publication year of the articles, geographical regions, and detection methods, the results of each study on the prevalence of *A. cantonensis* infection vary from one another. The present study applies statistical methods to sort, analyze, and summarize a large amount of collected research data in order to provide a quantitative solution with respect to the inconsistency of the results of such studies. To the best of our knowledge, this study is the first meta-analysis of *A. cantonensis* infection among *P. canaliculata* and *Ac. fulica* in mainland China.

To date, out of 32 provinces (autonomous regions or municipalities) in China, seven provinces (Fujian, Jiangxi, Zhejiang, Hunan, Guangdong, Guangxi, and Hainan) were recognized to be *A. cantonensis* endemic (Zhang et al. 2009b; Lv et al. 2009b). Although other places may be not suitable for these two snails to breed, especially *Ac. fulica*, which occurs only south of 25° N latitude, we should not ignore the fact that *P. canaliculata* and *Ac. fulica* are popular edible snails, and can be transported to the non-endemic areas in China (Lv et al. 2008, 2009b); considering China's rapid economic development and urbanization over the past decades, China has witnessed the largest human movement and studies show that population movement plays a significant role in the epidemiology of many infectious diseases (Alirol et al. 2011; Cao and Guo 2011). Therefore, most people in China are at risk of angiostrongyliasis regardless of the snail distribution, and thus, several outbreaks of angiostrongyliasis occurred in China (Lv et al. 2009a; Deng et al. 2011). The overall prevalence rate of *A. cantonensis* infection among *P. canaliculata* is 7.6 % while the overall infection rate among *Ac. fulica* is 21.5 %. Compared with the results of the first national survey on *A. cantonensis* in China (6.8 % in *P. canaliculata*; 13.4 % in *Ac. fulica*) (Lv et al. 2009b), the prevalence rate obviously increased for both snails. In recent surveys conducted in Guangdong Province, the infection rate in *Ac. fulica* was in up to 45 % in Dongguan (Chen et al. 2012b); the prevalence rate was about 30 % in *P. canaliculata* in Shenzhen (Huo et al. 2012), which implies

Table 4 Subgroup analysis for comparison of prevalence in different detection methods

Detection methods	No. of papers[a]	*Pomacea canaliculata*				*Achatina fulica*			
		Test(s) of heterogeneity		Significance tests(s) of *ES*		Test(s) of heterogeneity		Significance tests(s) of *ES*	
		I^2	*p*	*Z*	*p*	I^2	*p*	*Z*	*p*
Tissue homogenate	12	98.6 %	<0.001	6.32	<0.001	94.9 %	<0.001	8.97	<0.001
Lung microscopy	6	97.8 %	<0.001	4.06	<0.001	97.5 %	<0.001	4.23	<0.001
Enzyme digestion	9	97.4 %	<0.001	7.28	<0.001	97.7 %	<0.001	9.14	<0.001
Overall	37	98.2 %	<0.001	10.99	<0.001	96.9 %	<0.001	13.83	<0.001

[a] One paper not mentioned the specific detection method

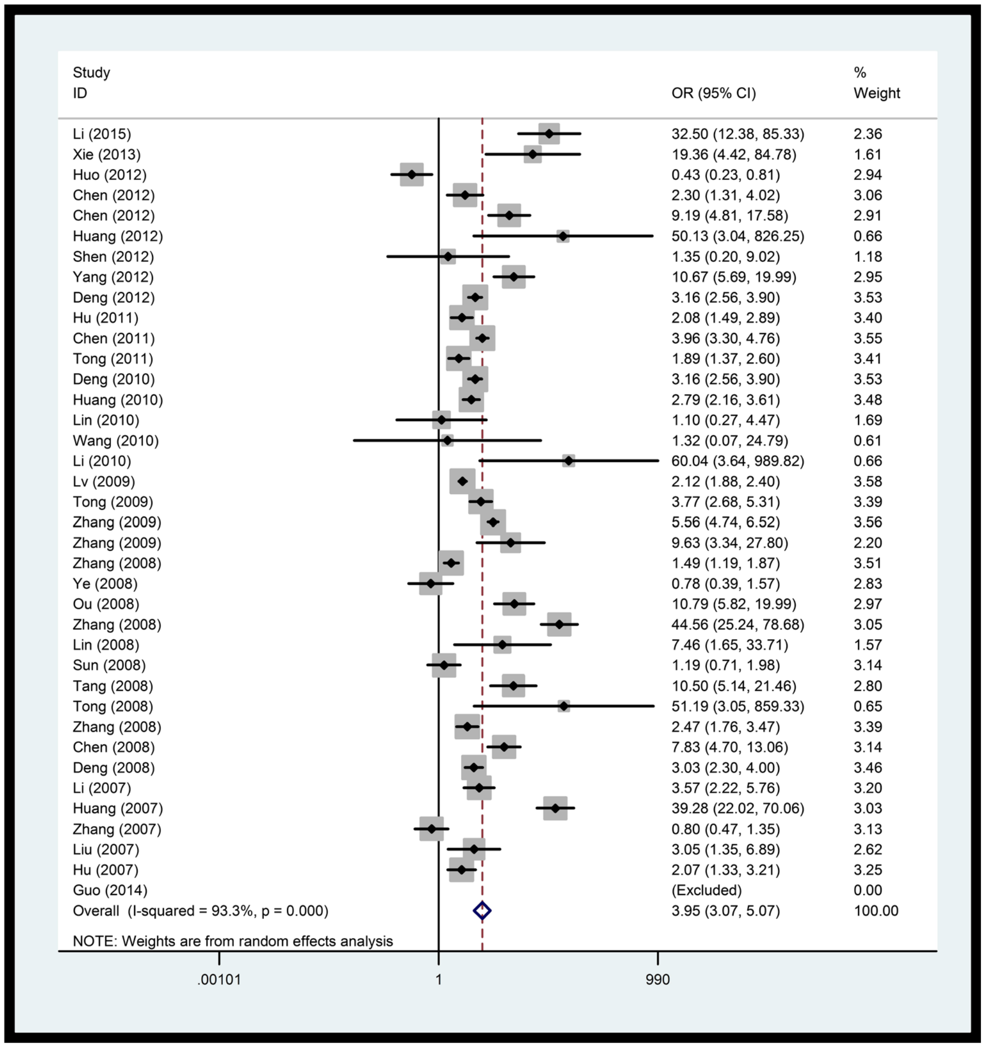

Fig. 4 Binary meta-analysis plot of *A. cantonensis* infection between *Achatina fulica* and *Pomacea canaliculata* in China

high risk of angiostrongyliasis outbreaks in Guangdong Province because a substantial fraction of people there enjoys to eat raw or undercooked snails.

According to our meta-regression results, the publication year of articles and sample size have little association with the prevalence value ($p > 0.05$). However, some researchers found an annual variation in *A. cantonensis* infection among snails, which might be due to dramatic temperature or rainfall change (Lv et al. 2006; Huang et al. 2009). With the impact of global warming, the distribution of snails will expand to the north, and it is much likely that the *A. cantonensis* infection rate will increase, leading to an increase of human angiostrongyliasis.

In addition, there was a wide range of the prevalence rates among different provinces, which suggested the presence of heterogeneity in geographic regions. For *P. canaliculata*, except for Guizhou Province ($I^2 = 72.8$ %, $p = 0.055$) and Hainan Province ($I^2 = 45.0$ %, $p = 0.122$), the subgroup analysis outcomes revealed strong heterogeneity in other geographical regions ($p < 0.001$) (Tables 1 and 3); for *Ac. fulica*, except for Guizhou Province ($I^2 = 0$ %, $p = 0.858$), likewise, the results showed strong heterogeneity in other geographical regions ($p < 0.01$) (Tables 1 and 3), indicating other sources of heterogeneity. It is reported that the detection effectiveness is different among different methods (Liu et al. 2007b), which might be another source of heterogeneity, and thus a subgroup analysis was performed, but unfortunately, it cannot explain the source of heterogeneity, with all the $I^2 > 00$ % and $p < 0.001$ (Table 4). In future researches, we should subgroup the studies into smaller units of geographical region to reduce the heterogeneity, and add other variables in subgroup analysis, such as temperature, rainfall, etc.

Moreover, the odds ratio of the susceptibility of *Ac. fulica* and *P. canaliculata* to *A. cantonensis* was 3.946 (95 % CI = 3.070 to 5.073, $Z = 10.71$, $p < 0.001$), so the susceptibility of *P. canaliculata* and *Ac. fulica* to *A. cantonensis* existed statistically significant differences, indicating *Ac. fulica* is easier to infect with *A. cantonensis* compared to *P. canaliculata*. The result is consistent with the first national survey on *A. cantonensis* in China (Lv et al. 2009b). Though the

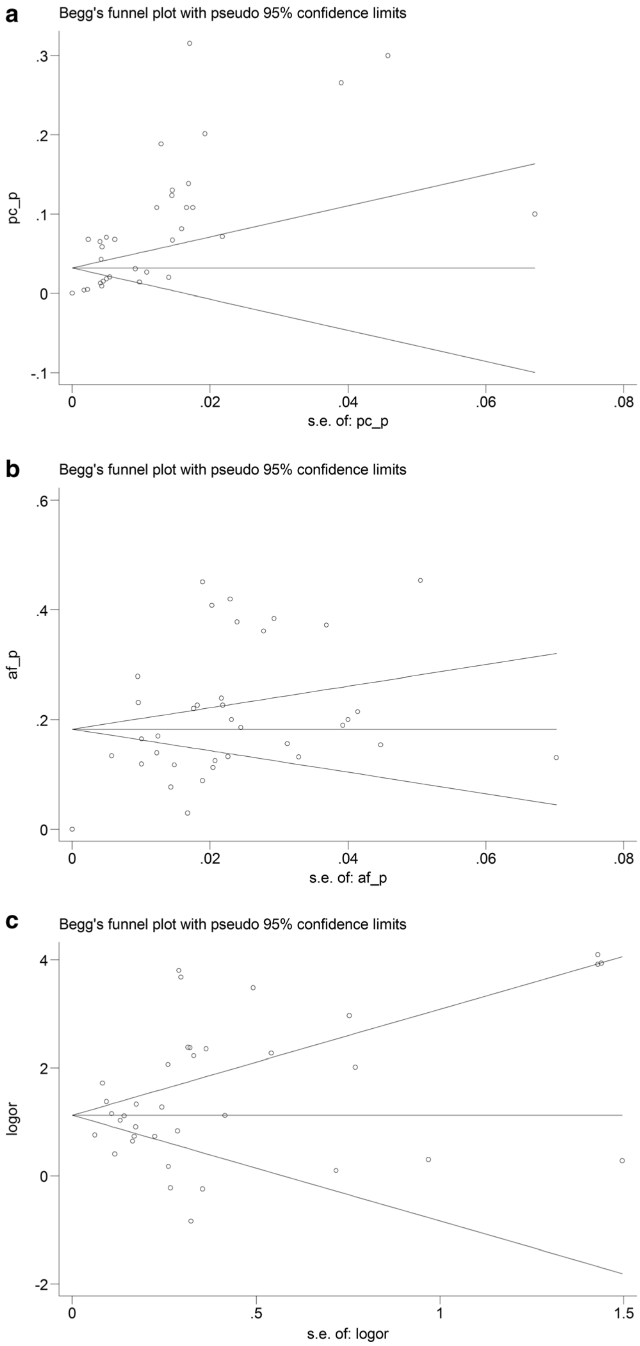

Fig. 5 Funnel plot to detect publication bias. **a** Funnel plot to detect publication bias in 38 studies of *A. cantonensis* infection among *P. canaliculata*; *pc_p* estimate of prevalence in *P. canaliculata*, *s.e.* standard error. **b** Funnel plot to detect publication bias in 38 studies of *A. cantonensis* infection among *Ac. fulica*; *af_p* estimate of prevalence in *Ac. fulica*, *s.e.* standard error. **c** Funnel plot to detect publication bias in 38 studies of *A. cantonensis* infection between *Ac. fulica* and *P. canaliculata*; or odds ratio between the *Ac. fulica* group and the *P. canaliculata* group; *s.e.* standard error

distribution of *Ac. fulica* is much smaller than *P. canaliculata*, it is more susceptible to *A. cantonensis*, and thus it plays an important role in the transmission of the larval worms leading to angiostrongyliasis.

Several limitations of this study may merit attention. First, the heterogeneity in meta-analysis was unavoidable. Meta-regression and subgroup analysis was employed but could not fully explain the source of heterogeneity. Second, some important factors, such as temperature, rainfall, and seasonal and monthly variation which were recognized to be associated with an *A. cantonensis* infection in previous studies (Zeng et al. 2011; Huang et al. 2009), were not included in this meta-analysis because the relevant data were not available or incomplete. Future studies are needed to explore these issues. Third, *A. cantonensis* has a wide range of intermediate hosts (Zhou et al. 2007), but in this study, we only focused on *P. canaliculata* and *Ac. fulica* because they are the two most common and edible snails and thus are the most important intermediate hosts (Lv et al. 2008). However, the other intermediate hosts, like *Cipangopaludina chinensis* or *Camaena sp.* (Zhang et al. 2007b), should not be neglected. To fully elucidate the epidemiology of angiostrongyliasis, further studies should pay attention to the other species intermediate hosts.

Conclusions

The review and meta-analysis help us not only to understand better the prevalence of *A. cantonensis* infection among *P. canaliculata* and *Ac. fulica*, but also provide a scientific basis for prevention and control of the spread of angiostrongyliasis. The *A. cantonensis* infection rate among *P. canaliculata* and *Ac. fulica* is still high in China, especially *Ac. fulica*, and thus comprehensive measures should be taken for snail control to avoid an angiostrongyliasis outbreak. Due to the transportation of snails and movements of the population, people in all regions of China live at risk of an infection. Further studies are required to improve strategies for controlling *A. cantonensis* infection among snails and consequently in human population.

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