CHAPTER FIVE

The Establishment and Function of Schistosomiasis Surveillance System Towards Elimination in The People's Republic of China

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Abstract

Schistosoma japonicum is the main schistosome species in The People's Republic of China, causing intestinal schistosomiasis, a debilitating disease of public health importance. The People's Republic of China used to be heavily endemic with schistosomiasis, but great progress has been made through the vigorous efforts of the national control programmes in the last six decades. Presently, efforts are geared towards eliminating schistosomiasis from The People's Republic of China by the end of 2025 through effective schistosomiasis surveillance, an important component in the drive towards schistosomiasis elimination. Therefore, this article explicitly outlines the development and progress made in schistosomiasis surveillance since 1990 with a special focus on the new surveillance system in use. Although the surveillance system has steadily improved over the years, it is faced with many challenges. Hence, more efforts are needed to establish an effective and sensitive evaluation system for the national schistosomiasis elimination programme in The People's Republic of China.

1. INTRODUCTION

Schistosomiasis, caused by infection with parasitic trematodes, continues to be a public health problem in developing countries, mainly found in Africa, Asia and Latin America. Besides causing serious health problems to humans, schistosomiasis also greatly hinders social and economic development of affected areas (Zheng, 2009). Historically, schistosomiasis was endemic in 12 provinces with 11,600,000 patients and 1,200,000 infected cattle in the 1950s in The People's Republic of China (Chen and Feng, 1999). However, with the strong political commitment and efficient control efforts, great progress has been made in controlling the continued transmission of schistosomiasis in The People's Republic of China (Collins et al., 2012). Disease transmission has been interrupted in five provinces; these include Shanghai (1985), Guangdong (1985), Guangxi (1988), Fujian (1987) and Zhejiang (1995) (Utzinger et al., 2005; Wang et al., 2008). Also, with the implementation of the national medium- and long-term schistosomiasis prevention and control plan (2004–2015) and two rounds of the national programme for schistosomiasis control, the endemic areas have greatly reduced (Wang et al., 2009a,). At the end of 2014, five provinces, including Sichuan, Yunnan, Jiangsu, Hubei and Anhui, attained the status of schistosomiasis transmission control (the infection rates of both residents and domestic animals were less than 1%). Moreover, the lowest levels of infection in both humans and cattle in history have been recorded in the last decade (Xu et al., 2016a). A total of 115, 614 schistosomiasis cases including 30,880 advanced cases were reported at the end of 2014 in The People's Republic of China. In addition, of the 919,579 cattle raised in endemic regions, only 666 were confirmed positive by stool examination (Fig. 1).

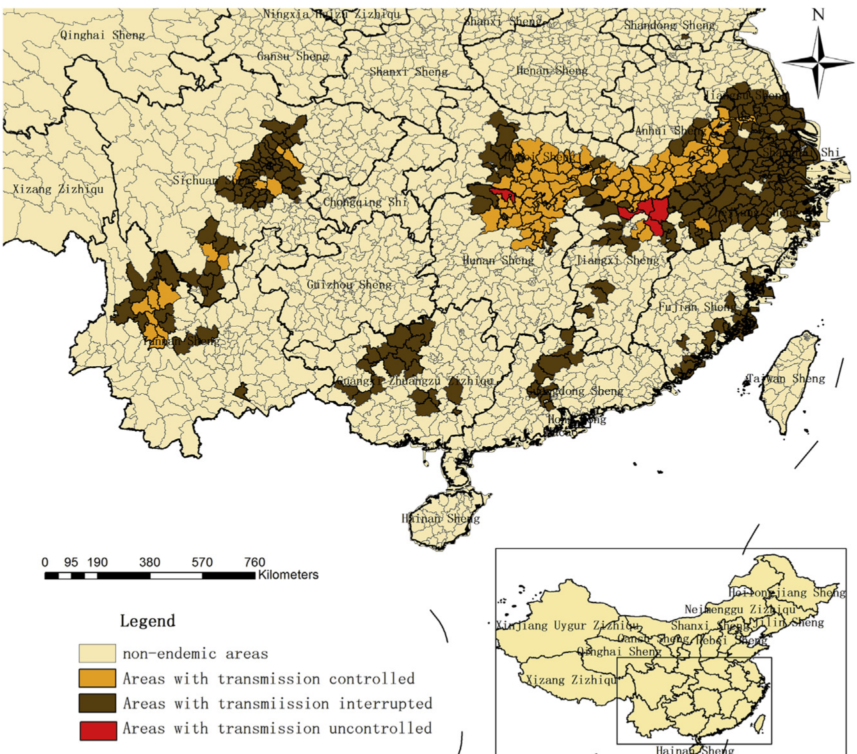

Figure 1 Distribution of counties with endemic schistosomiasis in The People's Republic of China, 2014.

Although schistosomiasis distribution is focal, transmission is complex and difficulties include identifying and managing the infection source, high number of patients and livestock and controlling intermediate host snails. The potential infection or reinfection risk in controlled areas has been recognized for a long time due to the multiple infection sources, frequent floods and human behavioural factors (Utzinger et al., 2005). New cases of cattle or human infection and the re-emergence and distribution of infected snail hosts have been reported in regions where transmission has previously been interrupted or controlled (Wang et al., 2004; Wu et al., 2004). Therefore, it is important to improve and strengthen the surveillance and monitoring system. Since 2010, studies on the construction of sensitive monitoring networks and early warning systems have become a priority in the field of schistosomiasis control in The People's Republic of China (Xu et al., 2014; Yang et al., 2014).

This article systematically reviews the history of the establishment and development of the schistosomiasis surveillance system in The People's Republic of China. The different prevention and control stages, as well as the endemic areas in The People's Republic of China are described. In addition, problems associated with the current Chinese schistosomiasis surveillance systems are also discussed and analyzed.

2. SURVEILLANCE OF SCHISTOSOMIASIS

2.1 Purposes and framework

The definition of surveillance in epidemiology is "the monitoring of activities with an approach that include some characteristics for long-term, continuous, systematic information collection and analysis on the dynamic distribution of disease and its impact factors, to provide scientific basis for implementation of the diseases control programme and intervention measures" (Jiang, 2003).

The main purpose of schistosomiasis surveillance is to better understand the changing patterns of epidemiological characteristics of schistosomiasis and its related impact factors, elucidate the transmission patterns and potential transmission risk of schistosomiasis and adopt the intervention measures for schistosomiasis control in response (Yang et al., 2006). In addition, it helps provide results for effective evaluation of schistosomiasis control strategies and measures.

However, the frame of schistosomiasis surveillance in transmission-controlled areas is different from transmission-interrupted areas. In transmission-controlled areas, the major tasks are to identify and treat patients with schistosomiasis and infected livestock, as well as application of molluscicides for vector snail control in areas where transmission still persists (Zhou et al., 2005). Furthermore, factors associated with schistosomiasis epidemiology are also monitored in these areas (Cao et al., 2016; Liu et al., 2016; Shi et al., 2016; Zhang et al., 2016). In transmission-interrupted areas, there are no patients with schistosomiasis or infected livestock but vector snails inhabit the areas. The major surveillance tasks in transmission-interrupted areas are snail detection, molluscicidal application, monitoring imported infection sources and control of other potential risk factors (Wen et al., 2011; Wu et al., 2005; Zhu et al., 2009).

2.2 Contents and indicators

The surveillance indicators for schistosomiasis mainly included schistosomiasis cases, infected domestic animals, vector snails and the related epidemic factors (Xu et al., 2014).

2.2.1 Schistosomiasis cases

According to the diagnostic criteria issued in 2006, schistosomiasis cases are classified into the following categories: acute schistosomiasis, chronic schistosomiasis and advanced schistosomiasis. Acute schistosomiasis is one of the important indexes to measure the severity of the schistosomiasis epidemic situation in a certain area (Lin et al., 2007). Therefore, surveillance is focused on acute cases where uncontrolled transmission occurs.

2.2.2 Domestic animals

Livestock are a major reservoir host. The surveillance on domestic animals mainly includes cattle, sheep, pigs and horses (Dang et al., 2006), with cattle being the main surveillance focus, as they play a major role in schistosomiasis transmission (Guo et al., 2001).

2.2.3 Snail intermediate hosts

Oncomelania hupensis is the only intermediate host involved in the transmission of *Schistosoma japonicum*, which plays a key role in schistosomiasis transmission (Yang et al., 2009; Zhou et al., 2010). The snail's geographic distribution is consistent with that of schistosomiasis strictly (Li et al., 2016). Therefore, snail monitoring is an important component of the surveillance system including the snail-ridden areas, density and infection rate of snail hosts.

2.2.4 Related epidemic factors

The surveillance on related epidemic factors mainly included surveillance on water level, rainfall, temperature (Wang et al., 2015b; Zhou et al., 2008), the residents' occupational activities and lifestyle and the implementation of schistosomiasis prevention and control measures (Liu et al., 2014; Salam et al., 2014).

3. IMPLEMENTATION AND ACHIEVEMENTS OF SCHISTOSOMIASIS SURVEILLANCE

In general, surveillance can be classified into passive surveillance and active surveillance. In passive surveillance, the subordinate unit routinely reports to the superior unit with surveillance data and information, and the superior unit passively accepts those data. In The People's Republic of China, routine statutory infectious disease reports belong to passive surveillance. Schistosomiasis is categorized as a Class B infectious disease in The People's Republic of China, and the statutory report of schistosomiasis began in 2004 (Jin et al., 2006). So far, most of the reported cases are acute schistosomiasis. In active surveillance, the superior unit conducts special investigations or the subordinate unit collects information in strict accordance to meet special needs. In line with different monitoring purposes, the active surveillance for schistosomiasis in The People's Republic of China can be divided into three categories: (1) repetitive cross-sectional sampling survey, ie, national surveys on schistosomiasis endemicity; (2) longitudinal monitoring of fixed sentinel surveillance, ie, surveillance on sentinel sites. The narrow sense of surveillance usually refers to sentinel surveillance (3) risk surveillance, ie, consolidated surveillance in areas where schistosomiasis transmission has been interrupted.

Specific to the surveillance on schistosomiasis, it usually includes the following types.

3.1 Routine surveillance and emergency endemic surveillance

In The People's Republic of China, the routine surveillance and emergency endemic surveillance on schistosomiasis began in 2005. The routine surveillance of schistosomiasis covers 32 provinces/autonomous regions/municipalities (P/A/M) (excluding Hong Kong, Macao and Taiwan), with main efforts in areas endemic with schistosomiasis, this includes 12 southern P/A/M. The routine surveillance mainly included case reports, case surveys and acute schistosomiasis warnings.

3.1.1 Case report

All levels of medical institutions, disease prevention and control centres, health quarantine institutions and other medical-related institutions are required to report within 24 h after a schistosomiasis case is diagnosed according to the Law of The People's Republic of China on the prevention and treatment of infectious diseases. Schistosomiasis cases are reported through the Web-based Information System of Diseases Prevention and Control. Contents of this report system include name, gender, age, address, contact information, occupation and case classification coded as acute schistosomiasis, chronic schistosomiasis and not classified.

From 2004 to 2014, a total of 1874 acute schistosomiasis cases were reported (Fig. 2). With the significant decrease in acute schistosomiasis cases resulting from the effective schistosomiasis control programme in The People's Republic of China, more attention has been paid to chronic cases.

3.1.2 Case survey

Case surveying investigates the detailed information of the schistosomiasis cases. The focus of case surveying differs at the different control stages of schistosomiasis and with The People's Republic of China's approaches to schistosomiasis control goal of elimination, every schistosomiasis case, including acute, chronic and advanced schistosomiasis cases, was investigated. Information collected in the case survey mainly included name, gender, age, address, contact information, occupation, history of schistosomiasis, history of schistosomiasis treatment, time of diagnosis, diagnostic results, clinical symptoms, results from sera test and stool examination and characteristics of infection sites.

3.1.3 Emergency epidemic surveillance

In 2003, the emergency disposal plan for schistosomiasis (trial) was issued, which defined emergency epidemics that require emergency disposal.

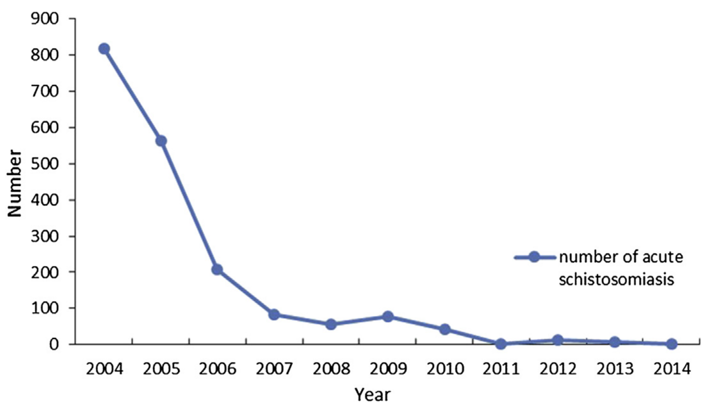

Figure 2 Annual reported cases of acute schistosomiasis from 2004 to 2014, The People's Republic of China (excluding Hong Kong, Macao and Taiwan).

In areas where schistosomiasis transmission is not controlled, detection of 10 or more acute cases in one village within 2 weeks, or five or more acute cases in the same environment within 1 week are considered as emergency epidemic. In areas where schistosomiasis transmission is controlled, detection of five or more acute schistosomiasis cases in one village within 2 weeks, or three or more acute schistosomiasis cases in the same environment within 1 week are considered as emergency epidemic. In areas where schistosomiasis transmission has been interrupted, detected schistosomiasis infection in local residents, livestock or vector snails is considered as an emergency epidemic. However, it is considered as emergency epidemic too if the snail, local infected patients or livestock are detected in areas without schistosomiasis.

Once an emergency epidemic is confirmed, all acute cases were investigated, and the people who had contact with the same infected water were followed up within 2 weeks. The scope of the infection sites can be determined using information collected by the case surveys. In those areas, surveys were conducted to collect data on vector snails, as well as other related natural and social factors including water level, rainfall, temperature, natural disasters, movement of humans and livestock, activities and lifestyle of residents. There were 18 emergency epidemics since the plan was initiated, with 6 emergency epidemics in 2004 and 12 emergency epidemics in 2005 (Hao et al., 2006; Xiao et al., 2004).

3.2 Cross-sectional sampling survey

Three rounds of national sampling surveys on the prevalence of schistosomiasis were successively organized and conducted in 1989, 1995 and 2004. The results not only showed the national dynamic situation of schistosomiasis but also provided an important scientific basis for developing strategies for schistosomiasis control at different stages.

The results from the 1989 survey revealed that there were 1,638,000 patients and 200,000 infected cattle in uncontrolled areas, with infection rates at 10.20% and 13.29%, respectively. This survey provided a scientific basis for the formulation of the eighth "five-year plan" on schistosomiasis control, and also provided systematic and reliable data for the approval of the World Bank Loan Programme for Schistosomiasis Control (WBLPSC) project.

The second national sampling survey of schistosomiasis was conducted in 1995 after the conclusion of the WBLPSC (Zhu et al., 2016). Results from this survey showed 865,084 patients with schistosomiasis and 100,251 infected cattle, and the infection rates were 4.89% and 9.06%, respectively. There were reductions of 47.19% and 49.87% in case numbers compared with that of the first round survey. This survey comprehensively evaluated the effect of the eighth "five-year plan" on schistosomiasis control and the WBLPSC with the results providing guidance for the ninth "five-year control plan" on schistosomiasis in The People's Republic of China.

In 2004, the third national sampling survey of schistosomiasis was conducted in seven P/A/M where schistosomiasis transmission was still uncontrolled. Survey results suggested that the infection rate of residents and cattle were 2.50% and 4.36%, respectively, and there were 726,112 patients from the seven P/A/M. The results of this survey highlighted the important role of livestock as an infection source in the transmission of schistosomiasis in The People's Republic of China. In addition, this survey exposed the challenges in schistosomiasis control: (1) apparent diffusion of *Oncomelania* snails; (2) the relatively high number of schistosomiasis cases and the rising number of acute cases; (3) new or re-emerging endemic foci rising in areas where transmission has already been controlled or interrupted. These observations supported the development of new comprehensive schistosomiasis control strategies with emphasis on infection source control, and the issuing of the National Medium and Long Term Plan on Schistosomiasis Control from 2004 to 2015.

3.3 Sentinel surveillance

Sentinel surveillance is the core of the schistosomiasis surveillance system. It is an encompassing component of schistosomiasis surveillance and it simply implies that, surveillance on schistosomiasis mainly means sentinel surveillance. Generally, sentinel surveillance on schistosomiasis in The People's Republic of China has experienced four stages.

3.3.1 First stage (from 1990 to 1998)

In the eighties, efforts on schistosomiasis control were faced with severe challenges: schistosomiasis epidemics seriously rebounded in some areas, the number of patients with schistosomiasis was high and outbreaks of acute schistosomiasis occurred from time to time (Mao, 1986). Therefore, the Chinese Ministry of Health decided to set up sentinels for schistosomiasis surveillance. A total of 14 surveillance sentinels were established in eight provinces. Sentinel surveillance was designated in each administrative village (county) and the chosen sites represented different endemic types and levels during that period. The sentinel sites were distributed as follows: three sentinel sites in Hunan and Hubei provinces, two sites in Jiangxi and Sichuan provinces and one site in Anhui, Yunnan, Jiangsu provinces and Shanghai municipality. The main contents of the systematic surveillance included collecting schistosomiasis infection rates of permanent residents and livestock, and surveying snails during spring and autumn. Results from the surveillance indicated schistosomiasis endemicity status and the implementation of the systematic surveillance improved the quality of the schistosomiasis control programme. In addition, the surveillance system also provided information that helped in evaluating the performance of WBLPSC.

Taking into account the four counties in Jiangxi (Duchang and Xinjian counties) and Sichuan province (Xichang and Lushan counties) for instance, which belong to the lake and marshland type (Jiangxi province) and hilly/mountainous type (Sichuan province), respectively. The infection rate of populations in Duchang county had declined significantly, while the infection rate in the other three counties fluctuated during the nine surveillance years, especially in Lushan county with signs of re-emergence (Fig. 3).

3.3.2 Second stage (from 2000 to 2004)

The scope of surveillance for schistosomiasis during the first stage was narrow; however, the surveillance contents were simple. In 2000, the Chinese Ministry of Health made adjustment to the national surveillance programme and set up a total of 21 sentinel sites in eight P/A/M. In addition to the epidemiological information, the surveillance contents also included local control measures and implementation intensity. After 5 years of surveillance, the infection rate of residents decreased yearly in six sites,

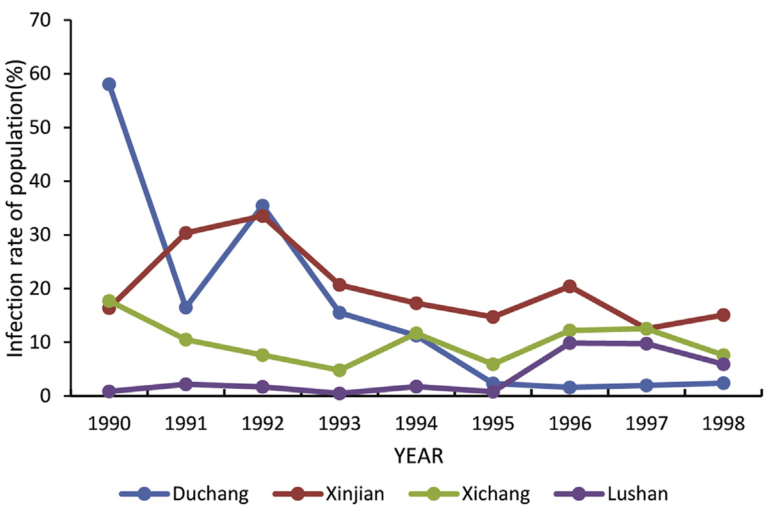

Figure 3 Infection rates of four surveillance sites from 1990 to 1998.

increased yearly in one site and fluctuated in the rest of the sites (Zhao et al., 2006).

The first two stages lasted 15 years, with focus on epidemic information of schistosomiasis. The surveillance results reflected the changes of schistosomiasis endemicity, and provided a basis for the evaluation of schistosomiasis prevention and control measures in The People's Republic of China. Data collected during these 15 years also exposed certain problems, such as limitations of implementing simple chemotherapy measures, difficulties in controlling schistosomiasis reinfection, the inadequate knowledge on the role of cattle in schistosomiasis transmission and the increasing number of imported cases in transmission-controlled or transmission-interrupted areas. Those analyses provided guidance for future improvement of schistosomiasis prevention and control strategies.

However, the sentinel surveillance during the first two stages covered only eight P/A/M that are endemic with schistosomiasis, the number of the surveillance sites in each P/A/M were not more than three and there was no sentinel surveillance in areas with potential transmission risk of schistosomiasis.

3.3.3 Third stage (from 2005 to 2014)

In 2005, 81 national schistosomiasis surveillance sites were established in 11 P/A/M where schistosomiasis transmission was ongoing (Fig. 4). Of particular interest is the surveillance site in Chongqing around the Three Gorges Dam (TGD) to monitor the potential risk for schistosomiasis transmission after the construction of TGD. The contents of the surveillance included usual infection rates of humans, livestock and snails, and natural and social factors such as economic, meteorological and hydrological data were added compared with the first two stages.

This stage lasted 10 years and the scope of the sentinel surveillance covered all P/A/M endemic areas with schistosomiasis except Fujian province. The number of surveillance sites in each province increased; there were 16 surveillance sites in the Hunan and Hubei provinces. The results of the surveillance reflected the epidemic situation at that time. The infection rates of residents and livestock declined significantly during the 10 years (Fig. 5).

3.3.4 Fourth stage (from 2015 to present)

With schistosomiasis control in The People's Republic of China gradually approaching the stage of transmission control, the control work in The People's Republic of China is focused on surveillance. The number of

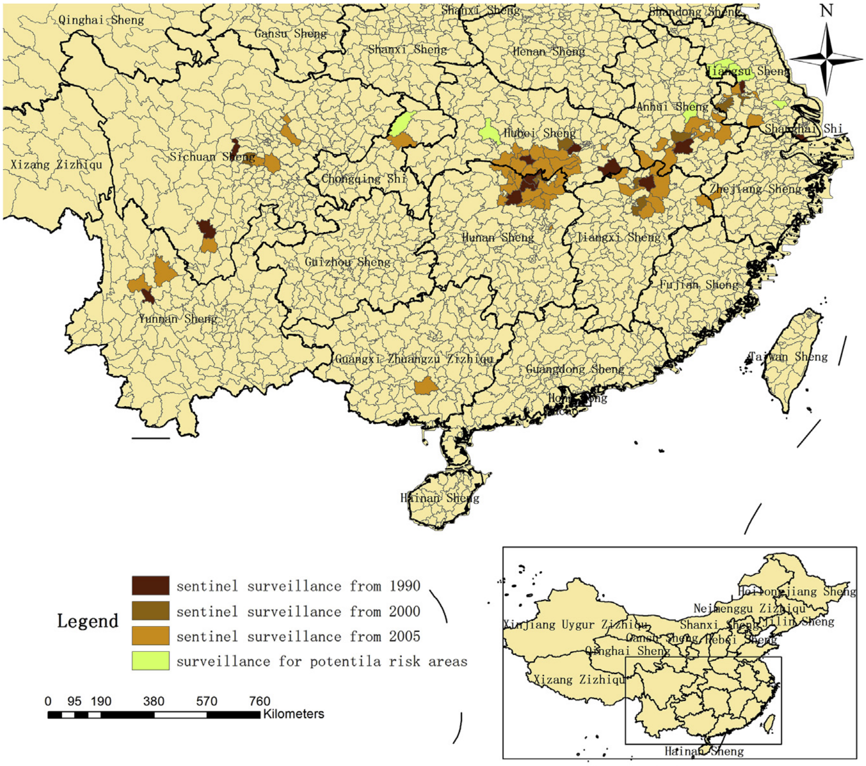

Figure 4 Distribution of the surveillance sites at the first three stages.

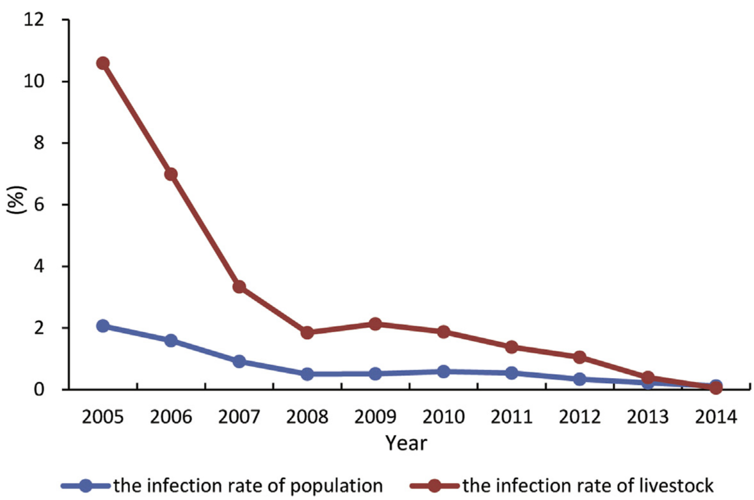

Figure 5 Infection rates of residents and livestock from 2005 to 2014.

surveillance sites falls short of the surveillance needs, and especially in counties with transmission interruption, surveillance work requires strengthening to prevent the rebound of schistosomiasis epidemic. In 2014, 458 national surveillance sites were established in 13 P/A/M, with complete coverage of counties endemic with schistosomiasis and extension to areas with potential transmission risk around TGD.

The development of schistosomiasis sentinel surveillance especially the surveillance from 2015 has presented several characteristics of the changing trend on schistosomiasis sentinel surveillance in The People's Republic of China.

3.3.4.1 Scope of schistosomiasis sentinel surveillance

The scope of schistosomiasis sentinel surveillance has been continuously expanding. The coverage of the surveillance programme has extended from 6 P/A/M in 1990 to 13 P/A/M in 2015 and the number of surveillance sites has increased from 14 to 458, covering all schistosomiasis endemic counties. In addition, four surveillance sites with potential schistosomiasis transmission risk have been added around TGD areas (Fig. 6).

3.3.4.2 Contents of schistosomiasis sentinel surveillance

The protocol of schistosomiasis sentinel surveillance has been constantly improved and adjusted based on the demands of schistosomiasis control; these include case investigation, early warning, serological examination, adoption of the loop-mediated isothermal amplification (LAMP) technology and examination of wildlife faeces.

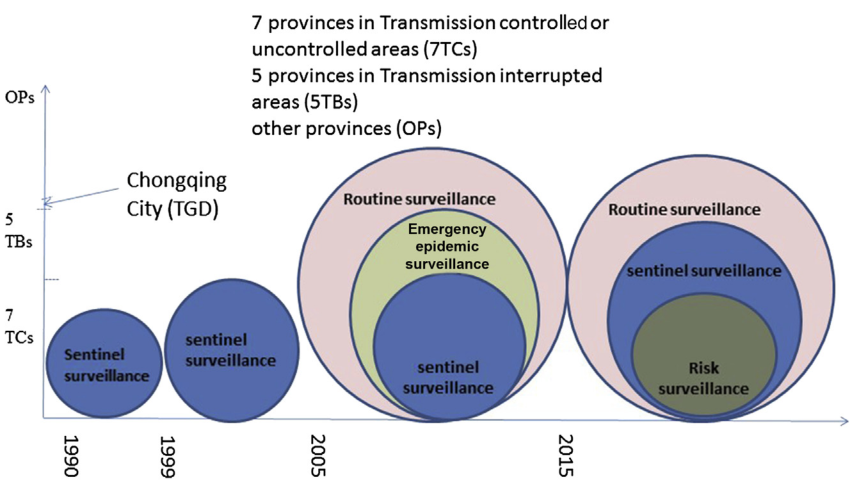

Figure 6 Scope of the schistosomiasis surveillance system at different stages in The People's Republic of China.

At the fourth stage of the sentinel surveillance, case investigation has been extended to cover those confirmed schistosomiasis cases, so as to trace the infection source aiding the gradual elimination of infection sources. This measurement of case management is very important during the process of transiting from transmission control to schistosomiasis elimination in The People's Republic of China. The early warning system has been strengthened to monitor acute schistosomiasis cases, which could feature sudden onset and possible mass outbreak. The early warning system can also help identify, investigate and respond to the epidemics as well as ensure early treatment. In the new surveillance programme the measurements of antibody titre has become much stricter. Antibody level reflects the level of population exposure during a certain period of time, and dynamic changes of the geometric mean and positive antibody titre are important to analyze the changes of local schistosomiasis prevalence (Xie et al., 2012). Traditional methods such as dissection and microscopic examination can only find sporocysts and cercariae in snails. However, it usually takes more than 2 months for miracidia-infected snails to shed cercariae. To solve this issue, LAMP technology targeting nucleic acid has been adopted for snail testing. Moreover, the LAMP technology can also detect DNA markers during the early developmental stages of schistosome parasites in snails, in addition to detecting the biological information of sporocysts and cercariae in snails, thus helping to improve the detection rate of infected snails (Tong et al., 2015). Wildlife faeces investigations can detect environmental infection risks and improve the sensitivity of the surveillance system.

3.3.4.3 Surveillance methods

At the new surveillance stage, based upon different epidemic levels and characteristics, the surveillance areas are divided into areas with transmission control, areas with transmission interruption and potential risk areas around the Three Gorge Reservoir. The transmission-interrupted areas are further divided into areas with and without snails. Different areas can adapt different surveillance items and methods to meet their specific prevention and control needs.

At the fourth stage of surveillance, the floating population is monitored by both active and passive surveillance. Active surveillance is developed in chosen villages to obtain epidemiological information. However, active surveillance has limited ranges and effectiveness, especially when the infection rate is low. Establishing a proper passive surveillance system and setting up sentinel hospitals and institutions are necessary to supplement the active surveillance system. Fixed and mobile surveillance sites have been set up in different areas that are endemic with schistosomiasis. For transmission-interrupted areas without snails, surveillance is focused on detecting cases especially imported cases and identifying potential transmission risk. The mobile surveillance sites can increase surveillance range and relatively improve sensitivity. Table 1 summarizes the surveillance coverage, items and methods used in the national schistosomiasis surveillance system at the four different stages.

3.4 Risk surveillance

Risk surveillance enables early warning and prevention. The choice of risk surveillance sites mainly relies on the results from routine surveillance. Risk surveillance mainly covers the following areas: areas with epidemic rebound and areas with environmental changes due to natural disasters, water conservancy or transportation. Risk surveillance focuses on imported snails, infected wildlife faeces survey and infected water detection using sentinel mice, which were left in the cell cages on the water surface from 10:00 am to 2:00 pm for two consecutive days in each month during the period May to September, and 17 and 6 infected foci in 2010 and 2012 were detected by this way, respectively (Zheng et al., 2012a, 2013a). In a broad sense, risk surveillance can also include schistosomiasis surveillance in potential endemic areas. In order to avoid the spread of possible schistosomiasis transmission that may arise through climate warming and/or water conservancy, the Chinese Ministry of Health in 2008 established 10 fixed surveillance sites and 30 mobile sentinel sites across 10 counties that are not endemic with schistosomiasis in Jiangsu, Shandong, Anhui and Hubei provinces and Chongqing municipality (Dang et al., 2014). The surveillance in potential endemic areas was mainly implemented by investigating susceptible cases, monitoring the floating population and livestock.

4. CHALLENGES AND FUTURE DIRECTIONS

4.1 Challenges

4.1.1 Low sensitivity of schistosomiasis diagnostics

Before 2005, the Kato-Katz technique was used to identify schistosome eggs in human stool samples and stool hatching methods were carried out to identify infected cattle during the national surveillance programme (Zhao et al., 2005). After 2005, populations were first screened using sera

Table 1 Surveillance coverage, items and methods listed in the national schistosomiasis surveillance system at the four different stages

	First stage	Second stage	Third stage		Fourth stage			
						Counties with transmission interrupted		
Surveillance items	Areas with severe endemic	Areas with severe endemic	Counties with transmission not interrupted	Counties with transmission interrupted (including the Three Gorged Reservoir)	Counties with transmission not interrupted	With snails	Without snails	The Three Gorged Reservoir
Number of sites	14	21	80–81		458			
Number of P/A/M	6	7	12		13			
Setting	Fixed village	Fixed village	Fixed village		Fixed village	Fixed village	Flow village	Fixed village
Examination methods for local residents	Stool examination with Kato-Katz	Screening by sera examination and stool examination with Kato-Katz or only stool examination	Screening by sera examination and stool examination with Kato-Katz	Screening by sera examination and stool examination with Kato-Katz (every other year)	Screening by sera examination and stool examination with Kato-Katz and stool hatching method	Screening by sera examination and stool examination with Kato-katz and stool hatching method	—	—
Examination methods for floating population	None	None	Active surveillance: ≥30 persons	Active surveillance: ≥100 persons	Active and passive surveillance:≥200 persons			Active and passive surveillance: ≥200 persons
Examination methods for livestock	Stool examination	Stool examination	Stool examination	—	Stool examination	Stool examination on imported livestock		

Snail survey	Environment with snails	Environment with snails	Environment with snails or suspected	Environment with snails in history or suspected	Environment with snails or suspected	Environment with snails or suspected	Environment with snails in history or with imported risk	Environment with snails imported risk, more than 5 environments and flotage examination (more than five water areas)
	Microscopic examination	Microscopic examination	Microscopic examination	Microscopic examination	Microscopic examination and LAMP	Microscopic examination and LAMP (if possible)	Microscopic examination and LAMP (if possible)	
Wild faeces investigation	None	None	None	None	Area with snails and human or livestock	None		
Related factors	None	None	Natural and social factors	Natural and social factors	None	None	None	None
	Control measures	Control measures	Control measures	Control measures	Control measures	Control measures	Control measures	Control measures

LAMP, Loop-mediated isothermal amplification; *P/A/M*, provinces/autonomous regions/municipalities.

examination and positive cases were confirmed by Kato-Katz examination (Dang et al., 2008). Some studies showed that the false-negative rate of the Kato-Katz technique was 5.56–89.47%; especially in areas with infection rates less than 3%, the false-negative rate was as high as 30% (Zhu et al., 2005). Effective evaluation of the field application for four serological diagnosis methods showed that the sensitivity of the four methods were all significantly higher than that of the pathogen-detecting methods, but the specificity of serological test was low and this method cannot exclude previous infections (Xu et al., 2007). However, because of the effective schistosomiasis control in The People's Republic of China, the infection rate in most villages was less than 1% (Lei et al., 2014); therefore, using serological diagnostic methods for screening and then Kato-Katz technique for clarification was still unable to avoid the problems of false-positive and false-negative results, which decreased the reliability of surveillance results. Therefore, both stool hatching and Kato-Katz techniques should be used for screening positive results to increase the sensitivity of the results.

4.1.2 Traditional snail survey technology

At present, snail surveys are conducted manually, and the survey quality can be influenced by many factors such as season, climate, light and vegetation (Huang et al., 2010). Therefore the traditional method of snail surveying is unable to meet the requirements of current monitoring work (Zheng et al., 2013b); new technologies such as Geographic Information System and remote sensing, and special analysis methods, can be applied on snail surveillance (Hu et al., 2015; Qiu et al., 2014; Yang et al., 2005; Zhou et al., 2015). Furthermore, easy and rapid detection methods for infected snails should be developed for epidemics and outbreaks of acute schistosomiasis.

4.1.3 Deficiency in the surveillance technology on imported schistosomiasis cases

With the increase in trade and communication between The People's Republic of China and Africa, returning travellers or workers with African schistosomiasis have been frequently reported in The People's Republic of China (Xu et al., 2016a,b). Reports of imported cases of urogenital schistosomiasis, caused by infection with *Schistosoma haematobium,* to The People's Republic of China can be traced back to the 1970s, when The People's Republic of China sent technicians and workers to support infrastructure construction in African countries (Lu et al., 2014). Major clinical manifestations of *S. haematobium* include hematuresis, bladder irritation and urinary tract obstruction. Those cases are often erroneously diagnosed as sexually transmitted diseases, cystitis, tuberculosis or tumours because the symptoms of *S. haematobium* infection are quite different from that of *S. japonicum*. Due to the lack of diagnostic tools and related knowledge of *S. haematobium*, it is difficult for hospitals or institutions to diagnose and control *S. haematobium* in The People's Republic of China. The current surveillance system mainly focuses on *S. japonicum* (Clerinx and Van Gompel, 2011; Hua et al., 2013). Reports of the imported cases were included in the routine case report surveillance; however, most cases were missed.

4.1.4 Lack of effective monitoring network evaluation system

The main function of the current surveillance network largely relies on data collection, which determines the sensitivity, functionality, effectiveness, quality control and cost-effectiveness of the surveillance system. However, there is no systematic evaluation system in place to monitor the surveillance network.

4.2 Future directions

4.2.1 Effective evaluation of schistosomiasis surveillance

The implementation of schistosomiasis surveillance systems is helpful for schistosomiasis control. In areas with schistosomiasis interrupted status, the improvement of surveillance capacity is helpful to detect imported cases and potential outbreaks. For instance, there were imported acute and chronic schistosomiasis cases reported from Shanghai municipality and Zhejiang province, although these two areas reached the level of transmission interruption in 1984 and 1995, respectively (Lei et al., 2014; Wang et al., 2015a; Zheng et al., 2012a,b, 2013b) (Fig. 7).

4.2.2 Sensitivity indexes of schistosomiasis surveillance

The transmission of schistosomiasis is influenced by many factors, including biological, natural and social factors, which reflect the occurrence and development of schistosomiasis epidemics. The indicators for schistosomiasis epidemics include infection rate of humans and livestock, and density/infection rates of vector snails. These indexes are traditional indicators for schistosomiasis surveillance, which can directly reflect the epidemic status. Natural factors mainly refer to factors related to the environment, such as water level, vegetation and rainfall. Survival and reproduction of vector snails are closely related to environmental factors; these include temperature, rainfall,

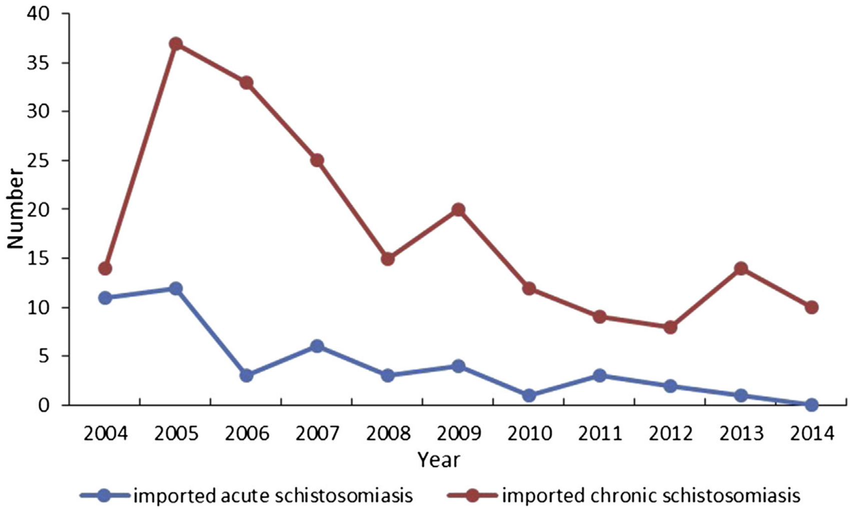

Figure 7 Reported cases from provinces with schistosomiasis transmission interrupted or nonendemic.

vegetation and soil moisture (Bavia et al., 2001; Gomes et al., 2012; Guimaraes et al., 2008; Hu et al., 2013). Social and economic indicators usually include lifestyle factors, population production activities and population mobility.

5. CONCLUSIONS AND RECOMMENDATIONS

At present, The People's Republic of China has established a nationwide schistosomiasis surveillance system and the sentinel surveillance covers all the counties that are endemic with schistosomiasis, as well as potential risk areas (Feng et al., 2016). All the schistosomiasis cases should be reported through the web-based information system including acute, chronic and imported schistosomiasis cases. The design is set up to ensure timely detection, monitoring and treatment of every schistosomiasis case, as well as determine its infection source and transmission route, to prevent potential transmission.

However, with the fast development of economy and technology sectors in The People's Republic of China, improving schistosomiasis surveillance systems is quickly becoming an important task for effective schistosomiasis prevention and control. Since the disease surveillance is gradually transiting from epidemic surveillance to public health surveillance, more attention should be paid to the factors related to schistosomiasis epidemics. Currently, related factor surveillance is still a supplement to epidemic surveillance with uneven surveillance quality; hence, it is difficult to use the data collected effectively. In the future, quantitative data collection of natural, social and behavioural factors will be improved upon the comprehensive related factor surveillance, so as to achieve accurate prediction and detect early warning signs of schistosomiasis transmission or resurgence.

Although the current schistosomiasis surveillance is mainly focused on collecting and summarizing data from previous epidemics, in the future, a schistosomiasis monitoring network is required to enable epidemic forecast, and provide evidence for targeted preventive and control measures (Tambo et al., 2014; Zhou et al., 2011).

COMPETING INTERESTS

The authors declare that they do not have competing interests.

AUTHORS' CONTRIBUTIONS

L.-J. Zhang, S.-Z. Li and X.-N. Zhou conceived the study; L.-J. Zhang, S.-Z. Li wrote the manuscript; L.-Y. Wen, D.-D. Lin, R. Zhu, Y. Du, S. Lv, J. Xu, E.M. Abe, B. L. Webster, D. Rollinson and X.-N. Zhou revised the manuscript and gave approval of the version to be published. All the authors read and approved the final version of the manuscript.

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