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Approaches being used in the national schistosomiasis elimination programme in China: a review

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Abstract

Schistosomiasis japonica, caused by the human blood fluke *Schistosoma japonicum*, remains a major public health problem in China, although great success has been achieved. The control efforts during the past half-decade, notably the wide implementation of the new integrated strategy with emphasis on control of the source of *S. japonicum* infection across the country since 2004, has greatly reduced *S. japonicum* in humans, livestock, and intermediate host *Oncomelania hupensis* snails, and transmission control of schistosomiasis was achieved in China in 2015. A two-stage roadmap was therefore proposed for schistosomiasis elimination in 2015, with aims to achieve transmission interruption by 2020 and achieve disease elimination by 2025 in the country. During the last two decades, a variety of approaches, which target the epidemiological factors of schistosomiasis japonica have been developed, in order to block the transmission cycle of the parasite. These approaches have been employed in the national or local schistosomiasis control activities, and facilitated, at least in part, the progress of the schistosomiasis elimination programs. Here, we present an approach to control the source of *S. japonicum* infection, three new tools for snail control, three approaches for detecting and monitoring *S. japonicum* infection, and a novel model for health education. These approaches are considered to play a great role in the stage moving towards transmission interruption and elimination of schistosomiasis in China.

Keywords: Schistosomiasis japonica, *Schistosoma japonicum*, *Oncomelania hupensis*, Elimination, Snail control, Source of infection, Health education, China

Multilingual abstracts

Please see Additional file 1 for translations of the abstract into the six official working languages of the United Nations.

Introduction

Schistosomiasis japonica, caused by the human blood fluke *Schistosoma japonicum*, remains endemic in China, the Philippines and parts of Indonesia [1–3]. In China, the description of schistosomiasis dates back more than two millennia [4, 5]. After the founding of the People's Republic of China, schistosomiasis was once recognized as "God of plague", since the disease caused huge social, economic and disease burdens in the country [6]. At the initial stage of the national schistosomiasis control programme in 1950s, over 11 million people were estimated to have the disease in China [7, 8]. Then, the integrated control activities [9–15], together with strong political will and sufficient financial support [16, 17], had resulted in a remarkable decline in both the prevalence and intensity of *S. japonicum* infection [18–23].

However, there was a resurgence of schistosomiasis in China at the early 2000s [24–28], due to the termination of the World Bank Loan Project (WBLP) for Chinese Schistosomiasis Control Program [29, 30], the continuous flooding along the Yangtze River basin [31], and changes of other natural, social and economic factors [32, 33]. Since 2004, schistosomiasis

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has been defined as one of the top four priorities for communicable disease control by the central government [34], and a new national strategy was proposed aiming to control the transmission of *S. japonicum* in China [7]. The new strategy integrates management of the sources of *S. japonicum* infection, chemotherapy, snail control, health education, and improved sanitation and access to safe water [35–37]. The implementation of this integrated strategy has achieved great success in controlling the transmission of *S. japonicum* in the country [38–44]. By 2015, only 77.2 thousand people were estimated to have the disease in China [45], which reduced by 90.8% as compared to that in 2004 when the new integrated strategy was initiated [46], and no *S. japonicum* infection was identified in *Oncomelania hupensis* snails since 2014 [47]. Based on the control achievements, a two-stage roadmap was therefore proposed for schistosomiasis elimination in China in 2015, with aims to achieve transmission interruption by 2020 and disease elimination by 2025 [48, 49].

During the past two decades, a variety of approaches, which target the epidemiological factors of schistosomiasis japonica, have been developed, in order to block the transmission cycle of the disease. These approaches have been employed in national or local schistosomiasis control activities, and facilitated, at least in part, the progress of the schistosomiasis elimination programs. Here, we present some approaches that have shown effective to control the transmission of *S. japonicum* in China, so as to provide choice of interventions for the national schistosomiasis elimination program.

An approach to control the source of *S. japonicum* infection

Boatman and fisherman have a high frequency of contacting *S. japonicum*-infested water, and play a dual role in the transmission of schistosomiasis [50–52]. They act as both victims (health-harming after being infected) and transmitter of schistosomiasis (source of *S. japoncum* infection) [53–55]. Since the boatman and fishermen are characterized by frequent mobility and have relatively stable anchor sites [50–52], public toilets with three-cell septic tanks had been built on the marshlands besides the anchor sites along the Yangtze River basin (Fig. 1). The public toilets were used to collect the excrements from the boatman and fishermen, and all schistosome eggs in the night soil were killed, so as to reduce the contamination of the Yangtze River by schistosome eggs derived from the boatman and fishermen [56–58].

The public toilets have two types, 2-seat with an area of 6 m^2 and 4-seat with an area of 13 m^2 [56]. A total of 53 public toilets had been built in the anchor sites along the Yangtze River basin and an estimated 79.62% rate of use was observed [58]. Currently, this approach has been widely employed in the major schistosomiasis-endemic foci of China, and has become an effective tool for the management of the feces excreted from boatman and fishermen [59]. Such an approach provides a novel measure for schistosomiasis elimination in the country.

Approaches for snail control

A machine simultaneously integrating mechanized environmental cleaning and automatic molluscicide treatment

Environmental vegetation is a primary factor affecting the efficiency and quality of *O. hupensis* snail control [60, 61].

Fig. 1 A public toilet with three-cell septic tanks built in the anchor site along the Yangtze River basin

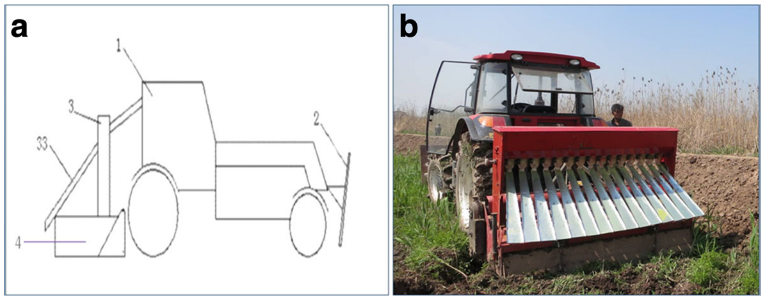

Fig. 2 Structure diagram (**a**) and working field of the machine simultaneously integrating mechanized environmental cleaning and automatic molluscicide treatment (**b**). 1, tractor; 2, vegetation-pressing plate; 3, automatic molluscicide-releasing device; 33, comb-like molluscicide spraying retainer; 4, plough machine

A machine simultaneously integrating mechanized environmental cleaning and automatic molluscicide treatment (Fig. 2), which contains three systems including power traction, cutting up and plough, and automatic molluscicide treatment, was developed. The machine simultaneously completes the procedures of getting vegetations down and cutting vegetations into pieces, ploughing the land and molluscicide treatment with niclosamide formulations [62]. In the complicated marshland regions with vegetations, the device can complete a 3 000 m^2 area of environmental cleaning and molluscicide treatment per working hour, and have a working efficiency similar to 56 workers; however, the economic cost is equal to approximately 1/6 human power [62]. In addition, the machine exhibit a snail control efficacy that is comparative to artificially environmental cleaning plus chemical molluscicide treatment (86.58% vs. 84.37%) [62]. It is therefore considered that this device provides a feasible tool for snail control in the large marshland regions endemic for *S. japonicum*.

A rapid niclosamide detector

Currently, niclosamide remains the most widely used chemical molluscicide for snail control in the endemic field of schistosomiasis worldwide [63, 64], and a real-time determination of the active niclosamide concentration is of great importance to achieve the molluscicidal efficacy and reduce the environmental toxicity [65, 66]. A niclosamide detector was developed for the rapid determination of the niclosamide concentration in the endemic field (Fig. 3). The detector has a linear range of 0 to 8 g/m^3 and a detection limit of 0.015 g/m^3, and it is easy to carry, which measures 2.5 cm × 9 cm × 24 cm [67]. In addition, this detector is very convenient and rapid, and has a high sensitivity for the field detection of the niclosamide concentration [67]. To date, this tool has been widely applied for the quality control of molluscicide treatment in the schistosomiasis-endemic regions of Jiangsu Province. This device is believed to provide an effective tool to support the elimination of schistosomiasis in China.

Snail control with black plastic film coverage

The approximate temperature for snail breeding and reproduction is 15 to 25 °C; snails cannot survive at > 29 °C, and may die within several hours at > 40 °C [61]. To achieve snail control in mountainous and hilly regions, a snail control approach with black plastic film coverage has been developed (Fig. 4). In the mountainous regions, the density of living snails reduced by 67.71%, 93.06% and 100% after 7, 10 and 30 days of coverage with the black plastic film [68], and in the marshland and lake regions, the density of

Fig. 3 The package for the field niclosamide detector (**a**) and the field niclosamide detector (**b**)

Fig. 4 Control of the intermediate host snails through coverage with the black plastic film

living snails reduced by 20.77% and 96.92% following 15 and 30 days of coverage with the black plastic film, respectively [69]. More importantly, the plastic film coverage is nontoxic to aquacultures and is active against snails and snail eggs in the soil layer, which is effective to inhibit the reproduction and breeding of the offspring snails [70]. This snail control approach is applicable for the snail control in specific snail habitats, such as fish ponds [71]. Such a method was employed as the major snail control measures for achieving the elimination of schistosomiasis in Sichuan Province in 2015, where mountainous and hilly regions are the predominant endemic areas [72]. Currently, this approach is recommended by the Ministry of Health, China, as an effective snail control intervention in the marshland and lake, and plain regions of China during the stage moving towards elimination of schistosomiasis.

Tools for detection and monitoring of *S. japonicum* infection

An intelligent device for detecting S. japonicum-infested water

According to the biological feature of *S. japonicum* cercariae that float on water surface and cannot migrate actively [73], an intelligent device was developed for detecting *S. japonicum*-infested water with a mouse bioassay (Fig. 5). This device increases the likelihood of detection of *S. japonicum* cercariae through the remote-controlled movement in the water body. Field test showed that the detector reduced the detection from 8 h to 1 h, and increased *S. japonicum* infection from 15 to 40% in sentinel mice, and the intensity of infection (worm burden) from 0.25 to 2.55 worms per mouse [74]. The intelligent detector greatly enhances the efficiency for the field detection of the infested water, and has played a critical role in the surveillance-response system for schistosomiasis along the lower reaches of the Yangtze River basin [75].

A kit for detecting S. japonicum DNA in O. hupensis snails

To achieve early detection of *S. japonicum* in snails, a rapid extraction of snail genomic DNA combined with loop-mediated isothermal amplification (LAMP) assay was developed [76], which greatly reduces the identification of infected snails from 60 days (dissection of snails) to approximately one week [77]. As compared to currently available commercial imported reagents, this kit (Fig. 6) has comparable detection efficiency, but showing an over 50% reduction in cost [77], which has been integrated in the national schistosomiasis control programs of China. During the process towards transmission interruption and elimination of schistosomiasis, this assay, which greatly improves the sensitivity for detection of *S. japonicum* infection in snails in relative to conventional microscopic approaches, may provide an effective approach for the rapid identification and timely elimination of the risk of schistosomiasis transmission [78, 79].

Web- and Google Earth-based surveillance-response system

In the field schistosomiasis control, the rapid release and sharing of the monitoring information is the prerequisite to the rapid response [80]. A surveillance-response system of schistosomiasis was developed based on Web and Google Earth (Fig. 7), which

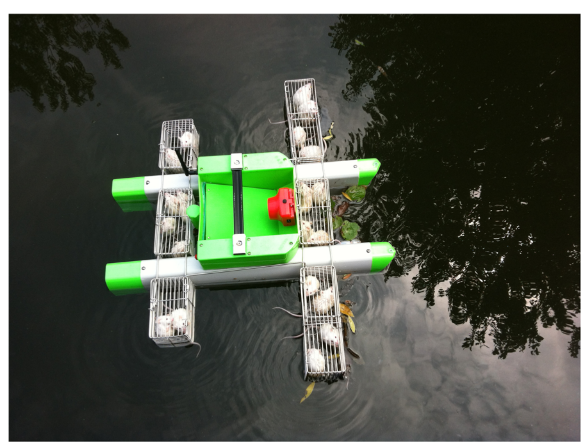

Fig. 5 An intelligent device for detecting *S. japonicum*-infested water with sentinel mice

Fig. 6 A kit for detecting genomic *S. japonicum* DNA in *O. hupensis* snails

effectively enhances the use of the monitoring information and achieves the synchronous visualization of the monitoring information [81, 82]. This system displays the graphs and texts directly and clearly, and is easy and simple to perform [83], which plays a critical role in the elimination of schistosomiasis in China, notably in the stage moving towards schistosomiasis elimination.

A novel model for health education

As described above, boatman and fisherman have a high likelihood and a high prevalence of *S. japonicum* infection [50–52], and they are recognized as the key target population of health education for schistosomiasis control [53]. However, the health education materials are usually not reached to the boatman and fisherman due to their high motility. A new model

Fig. 7 Web- and Google Earth-based surveillance-response system

was therefore developed of schistosomiasis control health education. Firstly, a group of active, respected boatman and fishermen with high education levels are selected as health education volunteers. Then, the volunteers receive training pertaining to schistosomiasis prevention and control by professional staff from local CDC, and the volunteers are ensured to seize the techniques of health education regarding schistosomiasis prevention and control knowledge. Subsequently, the volunteers transmit the schistosomiasis prevention and control knowledge to the massive boatman and fishermen (one volunteer is responsible for boatmen and fishermen living in 10 boats), and participate in the health education interventions targeting the boatman and fishermen. In addition, the volunteers help professional staff to alter the incorrect behaviors, remind the implementation of self-protective measures and prohibit the pouring of the contaminated feces into water. They also help to record the use of feces container in boats and the use of harmless public toilets at the anchor sites. To evaluate the effectiveness of this health education model on schistosomiasis control, a questionnaire survey was conducted among the boatmen and fishermen. The results showed that the 3-year (2005 to 2007) implementation of this health education model increased the awareness of schistosomiasis control knowledge from 23.85 to 95.7% and percentage of correct schistosomiasis control behavior from 6.59 to 53.42%, the use of public toilets from 0 to 80.21% and the use of on-boat fecal container from 0 to 54.52%, respectively, and the sero-prevalence of *S. japonicum* infection decreased from 27.95% in 2004 to 19.24% in 2005, 12.27% in 2006 and 8.15% in 2007, respectively [84]. The results demonstrate that this new health education model improves the awareness of schistosomiasis prevention and control knowledge and may correct the incorrect health behaviors, which play an active role in the prevention and control of schistosomiasis among the boatman and fishermen.

Conclusions

In this study, we present several approaches that had been developed during the past 2 decades, and they have been proved to effectively facilitate the progress towards the elimination of schistosomiasis in China. Actually, there are many other diagnostics, therapeutics, information, education and communication (IEC) materials, and snail control interventions developed in China, which are not presented in this review. Further systematic reviews to describe the role of all approaches in the national schistosomisis elimination program of China are required.

With the agenda set for global schistosomiasis elimination [85], Africa, the most severely afflicted regions due to schistosomiasis [86, 87], is also striving to eliminate this neglected tropical disease [88]. However, it is almost impossible to achieve schistosomiasis elimination depending on mass drug administration (MDA) with praziquantel alone, which remains the primary strategy for schistosomiasis control until now [89–91]. Currently, China is aiding the elimination of schistosomiasis from mainland Africa [92, 93]. The approaches, which have been proved to be effective to block the transmission cycle of *S. japonicum* in China, may be effective to control the transmission of other *Schistosoma* species, with adaption to local epidemiological profiles. Further studies to assess the feasibility and effectiveness of these approaches in regions endemic for *S. mansoni* and *S. haematobium* seem justified.

Additional file

Additional file 1: Multilingual abstracts in the six official working languages of the United Nations. (PDF 603 kb)

Abbreviations

CDC: Center for disease control and prevention; IEC: Information, education and communication; LAMP: Loop-mediated isothermal amplification; MDA: Mass drug administration; WBLP: World bank loan project.

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Availability of data and materials

The data supporting the findings in this paper can be found in Jiangsu Institute of Parasitic Diseases.

Authors' contributions

LPS, WW and XNZ conceived and designed the study. LPS collected publications. WW prepared the first version of the manuscript. QBH, SZL, YSL and HTY provided suggestive comments on the revision of the manuscript. XNZ revised and finalized the manuscript. All authors read and approved the final version of the manuscript.

Competing interests

Part of the materials described in the manuscript was reported in the Third Symposium on Surveillance Response System Leading to Tropical Diseases Elimination. The corresponding author, Xiao-Nong Zhou, is the Editor-in-Chief of *Infectious Diseases of Poverty*.

Consent for publication

All authors provided consent for publication.

Ethics approval and consent to participate

Not applicable.

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