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Integrated control programmes for schistosomiasis and other helminth infections in P.R. China

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ABSTRACT

The prevalence of human schistosomiasis and soil-transmitted helminthiasis (STH) has decreased significantly in the People's Republic of China (P.R. China), particularly after 2005 when the national control programmes were reinforced by forming of integrated control strategies. Furthermore, social-economic development also contributed to the decrease of schistosome and soil-transmitted helminth infections. The prevalence of the zoonotic helminthiasis, including clonorchiasis and echinococcosis, on the other hand, is either underestimated or has in fact increased due to changes in social and environmental factors. In comparison with the control strategies in force and their effects on those four kinds of helminthiasis, the challenges and control priorities for the potential transfer from control to elimination of each disease is reviewed, to provide evidence for policy-makers to act upon.

1. Introduction

As one of the most widespread diseases affecting human beings, human helminthiasis is caused by helminth parasites from the family of phyla Nematoda (roundworms) and Platyhelminths (flatworms). These diseases are mainly found in poor and rural areas of the developing countries. Among 17 parasitic and bacterial infections known as neglected tropical diseases (NTD) by the World Health Organization (WHO), eight are helminthiasis including soil-transmitted helminthiasis (STH) (ascariasis, hookworm infection, and trichuriasis), food-borne trematodes, lymphatic filariasis, onchocerciasis, dracunculiasis, cysticercosis, echinococcosis, and schistosomiasis (WHO, 2010). As estimated, about 1 billion people living in poverty were infected with one or more helminth parasites mainly distributed in sub-Saharan Africa, Asia, and the Americas (Hotez et al., 2008).

The People's Republic of China (P.R. China) has experienced rapid industrialization during the past decades but large gaps were found between different areas. The underdeveloped regions are now still suffering from the endemicity of many different helminthiasis in spite of the fact that they were already socially and economically left behind (Yu et al., 1992). From the first year after the foundation of P.R. China, central and local governments started to pay attention to the prevailing parasitic diseases and implement control activities with special targeting to schistosomiasis and filariasis which had resulted in high morbidity and mortality (Wu, 2005). With the sustained commitment to suitable control strategies based on local resources and political will, the morbidity and prevalence of helminthiasis decreased significantly in the past 50 years in P.R. China which was regarded as one of most successful countries in controlling helminthiasis especially in schistosomiasis and filariasis (Chen et al., 2012; Sudomo et al., 2010; Utzinger et al., 2005; Sun et al., 2013). However, due to the increasing migrant population and the changes in environment and diet habits, schistosomiasis rebounded in controlled endemic areas while the number of clonorchiasis and echinococcosis cases increased at the beginning of new millennium (Fang et al., 2008; Wang et al., 2010; Zhao et al., 2005; Zhou et al., 2005; Qian et al., 2013).

Recognizing the huge public health and economic significance of helminthiasis, the Chinese government has recently reemphasized the importance of rigorous control. A series of action plan for schistosomiasis, major parasitic diseases and echinococcosis control, were drafted during the "eleventh five-year plan" period. Comprehensive strategy suitable for each helminthiasis was

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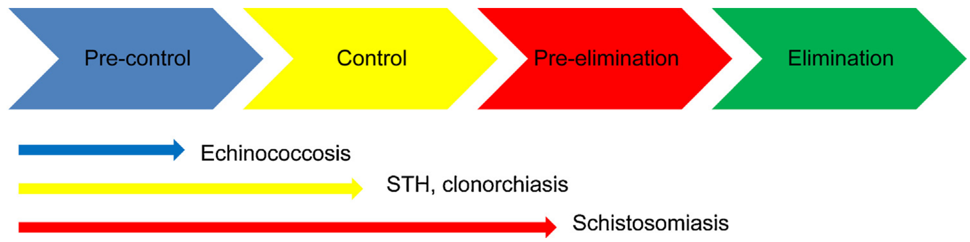

Fig. 1. Control status of major helminthiasis in P.R. China showing the four helminthiasis are located in different stages of the national control or elimination programme.

conducted during the implementation of national control programmes (Lei and Wang, 2012). New achievements were gained through this new round that, besides further general progress, resulted in the elimination of filariasis in P.R. China, which was recognized by WHO (Sudomo et al., 2010; Sun et al., 2013). In addition, the endemicity of schistosomiasis and STH decreased to the lowest level in history while the integrated control activities accelerated the decrease of morbidity and prevalence caused by clonorchiasis and echinococcosis. This paper describes the control strategies implemented in national Chinese programmes through reviewing the control progress with respect to the major helminthiasis focusing on schistosomiasis, STH, clonorchiasis, and echinococcosis, which are all in different control stages towards elimination and therefore require different approaches (Fig. 1). Challenges to control or eliminate helminthiasis are analyzed to supply information to policy makers and scientists.

2. Schistosomiasis and its control in P.R. China

2.1. Endemic status and achievements on schistosomiasis control

Schistosomiasis is endemic in 76 countries and territories which are mainly located in tropic and subtropics (Steinmann et al., 2006). Among the three major schistosome species infecting humans, *Schistosoma japonicum* is the only endemic species in P.R. China. Human beings and more than 40 mammalian animals could serve as its definite hosts while *Oncomelania hupensis* is its only intermediate host. The infection of *S. japonicum* often leads to severe and substantial morbidity including wasting, weakness, retarded growth and intellectual development, and sometimes even death (Chen and Feng, 1999).

Large-scale surveys carried out in the 1950s after the foundation of P.R. China showed that schistosomiasis japonica was endemic in 10 provinces, one autonomous region and one municipality city mainly along the Yangtze River in the southern part of P.R. China (Chen and Feng, 1999). It was estimated that about 11.6 million people were infected with schistosomes while 100 million were at risk (Zhou et al., 2005). After more than 60 years of endeavor, P.R. China became one of the most successful countries in the world with regard to controlling schistosomiasis (Chitsulo et al., 2000; Engels et al., 2002; Wang et al., 2008). By the end of 2011, out of 454 endemic counties in 12 provinces which were subjected to enhanced control activities, 103 reached the criteria of transmission control and 274 had interrupted the transmission completely. The leftover 77 counties, mainly located at lake regions of Hubei, Hunan, Jiangxi, and Anhui Provinces, were still at the stage of infection control (Fig. 2) (Zheng et al., 2012). The number of estimated infected population was 286,800, with a reduction of about 97.53% in comparison to the number of that in the early 1950s (Zheng et al., 2012; Zhou et al., 2005) while the number of infected cattle and the size of snail-infested areas had decreased more than 99 and 74%, respectively (Zheng et al., 2012; Zhou et al., 2005).

2.2. National control programmes for schistosomiasis control

The schistosomiasis control in P.R. China could be divided into three phases emphasizing on different control strategies according to the economic situation and technology at that time (Collins et al., 2012; Zhou et al., 2013).

2.2.1. Elimination strategy emphasized on snail control (1950s–early 1980s)

During this period, a nationwide control programme aiming at the elimination of schistosomiasis was initiated. Snail control with environmental modification and mollusciciding was the major strategy used to prevent infection and reduce prevalence due to serious adverse effect of antimony compound before praziquantel was available (Chen, 1999). In addition, other control measures such as self-protection with chemical repellent or niclosamide-impregnated clothes, safe water supply, construction of latrines, and methane-producing ponds plus preliminary health education were provided as complementary methods. However, the effects were somehow limited by the poverty and scarce health resource at that time in P.R. China. On the other hand, as results of the effective interventions, the snail-breeding areas had decreased from 14.3 thousand km^2 in 1950s to 3.6 thousand km^2 in 1989, and 4 out of 12 endemic provinces including Guangdong, Guangxi, Shanghai, and Fujian had eliminated the disease (no new local infection found in man or domestic animals during five successive years) by the end of 1980s (Chen, 1999). However, as snail control with molluscicides or environmental modification is expensive and complex, the implementation of this strategy was hampered not only in the swamp and lake regions but also in the hilly and mountainous areas owning to the reasons of complicated environments and under-developed economic situation.

2.2.2. Morbidity control based on chemotherapy (mid 1980s–2003)

After the recommendation from WHO expert committee of taking chemotherapy as the main strategy for schistosomiasis control in 1985, Chinese government adjusted the strategy and objective for schistosomiasis control from transmission interruption and/or elimination to morbidity control. Hence, P.R. China carried out pilot studies based on the new strategy since 1985 and implemented it further at national level in the 10-year World Bank Loan Project (WBLP, 1992–2001) (Chen et al., 2005). Praziquantel was administered to population at risk and livestock concurrently to reduce infection rate and transmission (Hu et al., 2005; Yuan et al., 2000). Health education through different types of materials was implemented to decrease the water contamination among population at risk and improve their compliance to receive screening and treatment (Guo et al., 2005; Hu et al., 2005; Yuan et al., 2005). Snail control was also carried out complementarily at the same time (Chen et al., 2005). The chemotherapy-based strategy facilitated morbidity control and contributed to the decrease in number of schistosomiasis cases in P.R. China from 1.7 million in 1992 to 828,000 in 2001 (Jiang et al., 2002). Among the 219 counties covered by

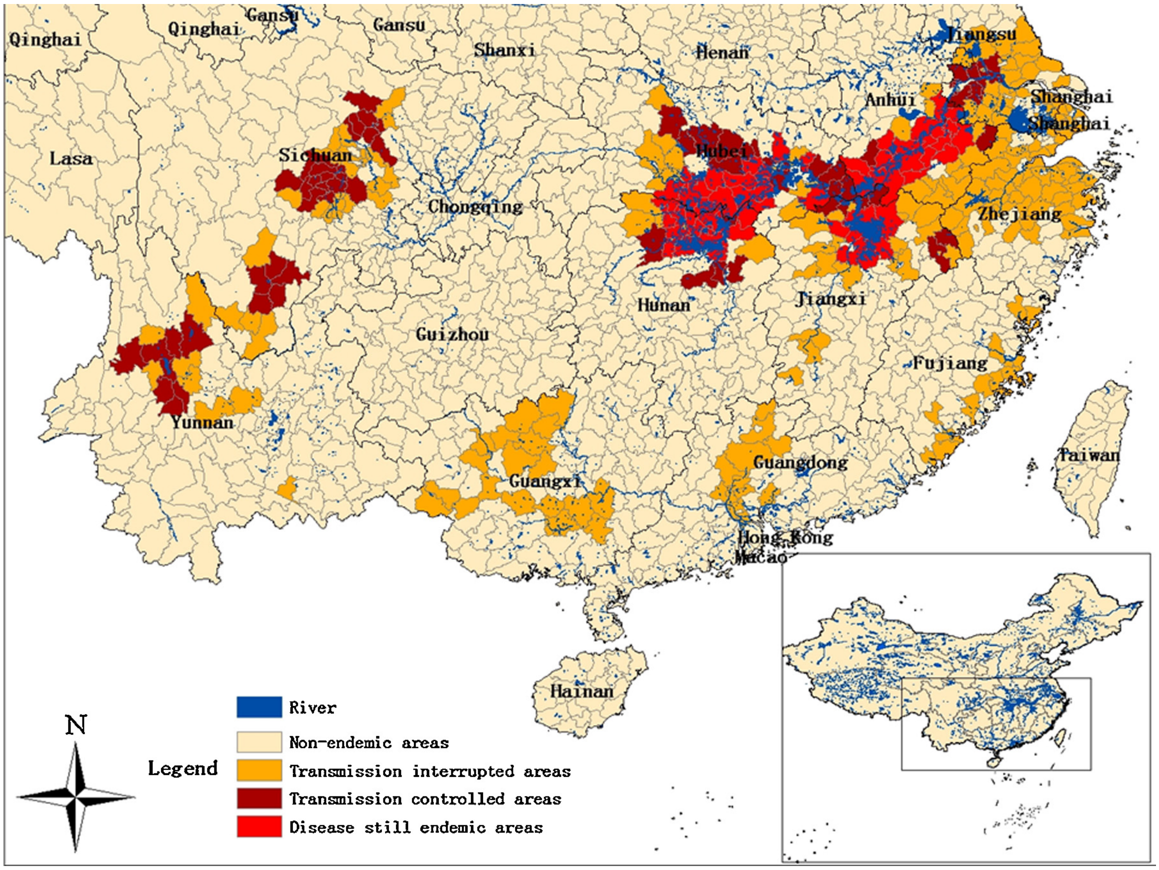

Fig. 2. Endemic status of Schistosomiasis japonica in 2011 showing transmission patterns and geographic distribution of schistosomiasis in P.R. China.

the WBLP, 47 had met the criteria of transmission control and 82 had interrupted the transmission of schistosomiasis by 2001(Chen et al., 2005). However, the consolidation task is arduous with the implementation of this strategy since the areas where snail habitats were still extensive, and the reinfections in human beings and livestock were very common (Balen et al., 2007; Guo et al., 2006). Furthermore, the resurgence of schistosomiasis in some endemic regions made it once more a major public health concerns at the beginning of the new millennium (Liang et al., 2006; Wang et al., 2004; Zhao et al., 2005).

2.2.3. Integrated control strategy aimed at transmission interruption (2004–until now).

To overcome the problem of re-infection in both humans and livestock, a new integrated control strategy focusing on interrupting the infection of eggs from feces of cattle and humans to snails was introduced in the new round of national control activities launched since 2004 (Wang et al., 2008; Zhou et al., 2007). Except routine control approaches such as chemotherapy, molluscicide treatment of snail habitats, and health education, other major interventions including agriculture mechanization (phasing out the cattle for ploughing and other field work), prohibiting pasture in the grasslands along lake and rivers, raising livestock in herds, building safe grassland for grazing, improving sanitations through supplying safe water, building lavatories and latrines, constructing marsh-gas pools, and providing fecal-matter containers for fishermen's boats, etc., were integrated into schistosomiasis control. Even at the pilot stage, the results showed that this strategy could decrease the prevalence of schistosomiasis to a very low level after several transmission seasons (Wang et al., 2009; Wang et al., 2008; Zhang et al., 2009). Enlarged pilot studies further proved that the new strategy was highly effective to reduce the transmission of schistosomiasis (Hong et al., 2013; Sun et al., 2011). After nearly 10 years' implementation of this integrated control strategy nationwide, considerable achievements were obtained. As such, the medium term goal of reaching infection control by 2008 was already achieved. The number of estimated infected population and acute cases in 2011 decreased to 286.8 thousand and 13 cases, with a reduction rate of 61.35 and 99.73%, respectively, as compared to 2003 (Fig. 3). The prevalence of schistosomiasis in cattle decreased from 4% in 2003 to 0.7% in 2011 (Zheng et al., 2012; Zhou et al., 2005). These data suggested that transmission interruption or elimination of schistosomiasis is feasible in P.R. China and expected to be reached within the next decade (Zhou et al., 2011b and c).

3. Soil-transmitted helminthiasis and its control in P.R. China

3.1. Endemic status and achievements on STH control

The soil-transmitted helminthiasis (STH) is a group of diseases caused by the ingestion of eggs of *Ascaris lumbricoides* and *Trichuris trichiura* or by active penetration from the skin by their larvae in the soil such as different species of hookworms (Vandemark et al., 2010). Although, STH is globally distributed and more than 1 billion people are affected with 300 million of them are suffering from severe morbidity; it remains as one of the most neglected tropical diseases due to its low mortality, insidious, and chronic consequence including anemia, diarrhea, abdominal pain, cognitive impairment, and growth retardation (Bethony et al., 2006; de Silva et al., 2003; Hotez et al., 2008; Hotez et al., 2007).

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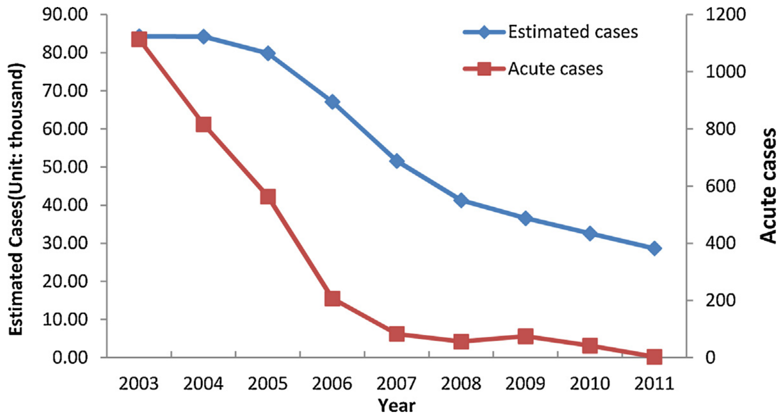

Fig. 3. The number of estimated schitosomiasis cases and acute cases from 2003–2011.

Historically, P.R. China has a wide-spread problem of soil-transmitted helminth infections but the real status and distribution of STH were not clear until the 1980s. The first nationwide survey, organized by Ministry of Health and conducted in the period of 1988–1992, showed that the prevalence of *A. lumbricoides*, *T. trichiura*, and hookworm infections were 47.0, 18.8, and 17.2%, respectively with a total prevalence of STH over 53% (Xu et al., 1995). Among those, the former two infections are distributed nationwide while hookworm only existed in 26 provinces out of the 30 surveyed provinces (Yu et al., 1994a). The prevalence of STH had decreased to about 19% according to the second national parasitic diseases survey which was conducted between 2001 and 2004 (Fig. 4). The infection rate of *A. lumbricoides*, hookworm, and *T. trichiura* decreased dramatically to 12.7, 6.1, and 4.6%, respectively (Chen et al., 2008). Meanwhile, the prevalence and infection intensity of STH continuously decreased year by year according to the national surveillance results after the initiation of the national control programme since 2006 (Chen et al., 2011b).

3.2. National control programmes for STH control

3.2.1. STH control focused on individual treatment

The earliest stage of the national STH control activity could be traced back to the early 1950s. Control of hookworm infection along with malaria, schistosomiasis, lymphatic filariasis, and leishmaniasis were listed as priorities in the "national programme of agriculture development from 1956 to 1967" issued by the State Council in 1956. The "barefoot doctor system" supported the STH control activities during 1960s and 1970s by offering free treatment for common diseases and health education (Wang et al., 2012). Unfortunately, with the collapse of the "barefoot doctor system" at the end of 1980s, STH were neglected, during the following 20 years; the control activities with respect to STH were intermittent and only implemented in regional level according to the different endemic status and policy commitment. Treatment with anthelmintic drugs was mainly delivered to the soil-transmitted helminth infected cases with symptoms. Furthermore, improved living conditions and better health awareness among villagers living in poverty have made great contribution to the decrease of soil-transmitted helminth infections in P.R. China especially in the latest two decades (Zheng et al., 2009). The number of estimated STH cases decreased by 75.93% from 536 million to 129 million according to two nationwide surveys (Chen et al., 2008). But STH was still serious endemic in middle and south part of P.R. China with a prevalence ranging from 20.07 to 56.22% since safe water and sanitation were not fully accessible, and re-infections were still very common in these regions (Chen et al., 2008).

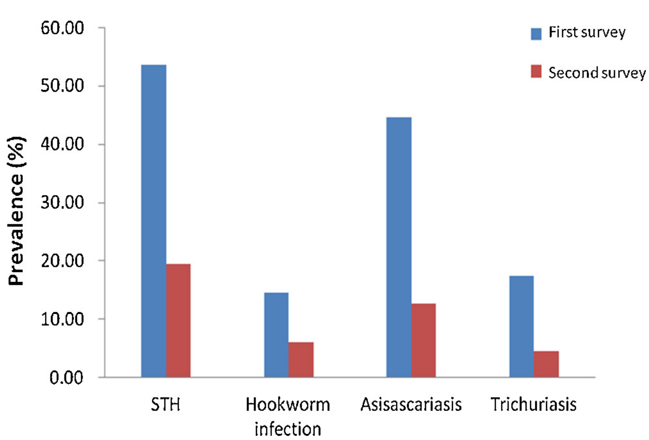

Fig. 4. Comparsion of prevalence of STH between two nationwide surveys (data from Chen Y.D., 2008), showing the reduction patterns of each soil-transmitted helminthiasis, including hookworm infection, ascariasis, and trichuriasis.

3.2.2. National control programme implemented integrated control strategy

As the endemic status of STH infections became clarified through the two nationwide surveys and the significance of STH with regard to public health and economic development was realized, STH control was involved in the "national control programme on important parasitic diseases from 2006 to 2015" issued by the Ministry of Health in 2005. The medium- and long-term goals were to reduce the prevalence of STH at least 30% by 2010 and over 60% by 2015 at provincial level in comparison with that in 2004. This programme was combined with the national health promotion project (2006–2010) which was initiated by nine ministries in 2006 and benefited hundreds of millions of farmers; health education which emphasized on washing hands before eating and after toilet, diet and drinking safety, and avoiding cultivating with barefoot etc., was conducted to disseminate protection knowledge. Construction of sanitary latrines and environment modification in rural areas were accelerated to reduce the contamination of parasite eggs in the environment (Zhou et al., 2011a). Deworming strategies including mass drug administration to population above 3 years old, selective chemotherapy on high-risk population and individual treatment were implemented according to the prevalence of soil-transmitted infections in different endemic areas. The pilot studies in eight counties from heavily endemic provinces proved that the integrated control strategy could decrease the prevalence of STH significantly and increase the awareness of health knowledge in population (Chen et al., 2011a; Zhang et al., 2011). Cohort surveillance in 22 sites with different endemicity showed that the total prevalence of STH decreased from 21% in 2006 to 13% in 2009 with a reduction rate of about 36% (Chen et al., 2011b). The third national survey is now under planning to be expected to assess the effectiveness of integrated control strategies on parasitic diseases control nationwide.

4. Clonorchiasis and its control in P.R. China

4.1. Endemic status of clonorchiasis

Clonorchis sinensis infection is widely endemic in east of Asia, mainly in P.R. China, Japan, Korea, and Vietnam (Lustigman et al., 2012b; Qian et al., 2012). It was estimated that there were about 35 million people with clonorchiasis in the world, and most of them are living in P.R. China (Lun et al., 2005). Clonorchiasis is transmitted via snails to freshwater fish or shrimps, and then to definitive hosts including humans and other mammals that consume fish or crustaceans (Gao and Lin, 2010; Lun et al., 2005; Zhou et al., 2008). For humans, clonorchiasis could lead to hepatic diseases such as periductal inflammation, pyogenic cholangitis, biliary calculi, cholecystitis, and liver fibrosis as well as liver cirrhosis and pancreatitis in the end (Choi et al., 2004). There is a large body of evidence showing the association between gallstone formation and *C. sinensis* infection. Moreover, the link between clonorchiasis and malignant cholangiocarcinoma in humans was also observed although the mechanisms involved are not completely understood (An et al., 1999; Choi et al., 2004; Gao et al., 1994; Qiao et al., 2012; Rana et al., 2007).

Clonorchiasis had been endemic in P.R. China for more than 2000 years which was proved by detection of *C. sinensis* eggs in the fecal remains from an ancient corpse buried during the West Han dynasty (Wei et al., 1980). As most clonorchiasis cases are asymptomatic and is endemic locally, an estimation of the accurate number of infected cases nationwide is really difficult. Due to the continuous preference of raw freshwater fish consumption and lack of effective strategy on clonorchiasis control, the prevalence of clonorchiasis increased by 75% (from 0.33 to 0.58% of the population) based on the two national surveys even though great economic development was witnessed during this period (Fang et al., 2008). The estimated number of clonorchiasis cases was 12.5 million in P.R. China at the beginning of 21th century mainly distributed in Guangdong, Guangxi, Jilin, Liaoning, and Heilongjiang provinces (Chen et al., 2012; Gao and Lin, 2010; Lun et al., 2005; Tang et al., 2005; Yu et al., 2003; Zhou et al., 2008). Several surveys show that the prevalence of clonorchiasis in the endemic areas could be as high as 70% (Chen and Chen, 2003; Fang et al., 2000; Pan et al., 2000; Qian et al., 2011). Instead, with the effective control activities conducted by health and education departments, the prevalence of clonorchiasis decreased significantly in some areas (Huang et al., 2011; Qian et al., 2013; Wan et al., 2005). These surveys and studies provided an incentive for conducting control strategies and interventions against clonorchiasis in P.R. China.

4.2. National control programme for clonorchiasis control

Before 21th century, clonorchiasis was acknowledged as a serious health problem in its endemic areas with no effective strategies being found to control it even though local government had given great attention on the disease. Therefore, a series of field research organized by different facilities was conducted to explore effective control strategies (Chen et al., 1995; Ruan et al., 1999; Wan et al., 2005). With the notice of increasing number of clonorchiasis cases and understanding of its disease burden, clonorchiasis was listed as one of the diseases required control in the national programme for major parasitic diseases launched in 2006. The medium- and long-term goals were set as achieving a reduction rate of 30% by 2010 and 50% by 2015 at provincial level in comparison with the prevalence in 2004 with especial focus on Guangdong, Guangxi, Jilin, and Heilongjiang provinces. With the policy of "prevention first and control with integrated approaches", control strategies integrated with several intervention approaches such as deworming, health education, and construction of safe lavatories etc., (Ministry of Health, 2006) were put forward with specific adaption to different context according to the prevalence rates, infection intensity, resources available, and compliance of the residents in receiving treatment or changing of diet habits in different endemic areas (Choi et al., 2010). Moreover, inter-sectoral cooperation between Ministry of Health and Food Safety Departments worked through regulating the food processing with the aim of decreasing the risk of contamination to ensure the safety of diet. Meanwhile, supply of safe lavatories was another complementary approach for control of clonorchiasis since it helped interrupt the spread of *C. sinensis* eggs to fish pond through fecal treatment. Demonstration pilot studies including five pronged approaches, namely mass drug administration (MDA), water supply, improvement of latrine and environmental sanitation, and health education showed a drop of infection rate of *C. sinensis* from over 41% in 2006 to 7% in 2009 with a reduction rate of 83% (Chen et al., 2011a; Zhang et al., 2011) but the efficacies of the various chemotherapy strategies varied with respect to prevalence, incidence and re-infection (Choi et al., 2010). Based on the experience gained from these demonstration pilot studies, the national programme amended its deworming strategy according to the endemic status of the local settings (Fig. 5).

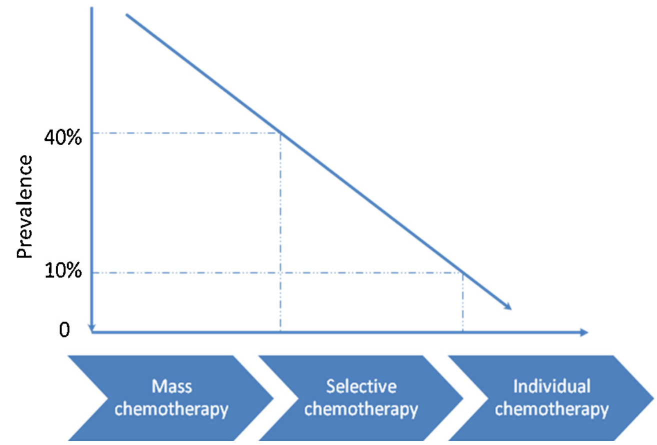

Fig. 5. Chemotherapy strategies conducted in different endemic areas for clonorchiasis control in P.R. China, showing the threshold of each chemotherapy strategy for *Clonorchis sinensis* infection.

5. Echinococcosis and its control in P.R. China

5.1. Endemic status of echinococcosis in P.R. China

Echinococcosis (hydatidosis or hydatid disease) is a group of infectious diseases caused by the larval stage of tapeworms of the genus *Echinococcus*. It is estimated that there are more than three million people in the world who are infected with echinococcosis while 0.38 million cases exist in P.R. China (McManus et al., 2003; Zhang et al., 2008). Among the reported *Echinococcus* species, *E. granulosus* leads to cystic echinococcosis (CE) and *E. multilocularis* causes alveolar echinococcosis (AE), and both are of significant public health importance in P.R. China. Humans are accidental intermediate host when ingesting eggs contaminated food or water. Infection with *E. granulosus* results in the development of one or several unilocular hydatid cysts which develop mostly in the liver (70%) and the lungs (20%) (Grosso et al., 2012). CE also causes great loss of animal husbandry as sheep, goats, and cattle. *E. multilocularis* metacestodes develop as a series of small interconnected cysts growing as a metastasising lesion almost exclusively in the liver (98–100%). The mortality of AE is normally higher than that of CE.

Echinococcosis has a wide geographical distribution in P.R. China, mainly in the pastoral and semi-pastoral western provinces and regions. According to the reporting system on diseases control and prevention established by China CDC, there are 27 provinces (autonomous regions, municipalities) reported echinococcosis cases (Wang et al., 2010), and Xinjiang, Qinghai, Gansu, Ningxia, Tibet, Inner Mongolia, and Sichuan Provinces were reported with a relatively high prevalence (Cai et al., 2012; Chi et al., 1990; Craig et al., 2000; Jiang, 2005; Li et al., 2010; Pleydell et al., 2008; Schantz et al., 2003; Wang et al., 2010; Xiao et al., 2006; Yang et al., 2006; Yang et al., 2005; Yu et al., 2008; Zhou et al., 2000). Regional distribution of AE is not as extensive as that of CE which is mainly distributed in Gansu, Xinjiang, Ningxia, and Qinghai Provinces or autonomous regions in P.R. China overlapping with the endemic regions of CE. A high prevalence of AE is reported from the Tibetan pastoral communities of northwest Sichuan (Li et al., 2010). As no national control activities were conducted before 2000, the second national survey on parasitic diseases implemented in 2002–2004 found the increase of the number of echinococcosis cases in P.R. China. It was reported that the sero-prevalence of echinococcosis reached 12% and the morbidity was 1% in 12 provinces (Major Human Parasitic Diseases Office, 2005).

5.2. National control programme for echinococcosis control

After the founding of P.R. China, no national control programme was conducted before 1990s since people knew little about the significance of echinococcosis either to public health or to economic development. In 1992, the first national programme "1992–1995 national programme for hydatid disease control" was initiated by the Ministry of Health. During this programme, professional institutes, and monitoring systems were established in endemic regions and epidemiological surveys were conducted. Extensive health education, sanitation of slaughtering methods, management, and deworming of dogs were implemented as the major control measures. Unfortunately, control activities were sustained due to lack of funding and professional staffs. In 2006, the Chinese government listed echinococcosis as one of major parasitic diseases to control in the national programme. In 2007, echinococcosis was listed as one of major parasitic diseases which can be treated free. In 2010, to strengthen and propel the control of this zoonosis, the action plan for Echinococcus control programme (2010–2015) with the policy of "prevention first, control scientifically" was drafted by the Ministry of Health in collaboration with other 14 ministries. The medium-term goals by 2012 and long term goals by 2015 were listed in Table 1. With financial support from the central government, the coverage of echinococcosis control programme had expanded from 10 counties in Sichuan Province in 2006 to 170 counties in 7 provinces including the construction corps in Xinjiang in 2011. The comprehensive control strategy which was integrated in the action plan included health education, free treatment of patients, deworming of dogs and management of livestock slaughtering etc. Health education which focused on "washing hands", "don't drink water without boiling", and "do not use internal organs of infected animals as dog food" is conducted in order to form healthy diet habits and change unhealthy behaviors. Treatment for echinococcosis patients through active screening were carried out to alleviate the pain of patients. The collaboration between health sector and other government sectors including agriculture, husbandry, and police strengthened the control and management of dogs through a series of methods like deworming of dogs, handling of dogs without hosts through effective measures, decreasing the number of dogs, etc. Overall, the management of livestock was strengthened through salvaging in group, health quarantine, and innocent treatment of animals' internal organs. As the action plan for echinococcosis control is still in its initial period, therefore the effectiveness of integrated control strategy might be only assessed and seen several years after the implementation (Zhou, 2012). Recently, the field work of a national epidemiological survey on echinococcosis organized by Ministry of Health just finished. It is expected that the data from this survey will provide information to policy makers to improve or adjust their future control strategies.

6. Analysis and conclusion

6.1. Experience for helminthiasis control

Although the four kind of helminthiasis described in this paper are in different stages toward elimination, P.R. China accumulated a significant amount of experience for helminthiasis control especially on schistosomiasis which could be concluded as follows: (1) The strong policy wills of Chinese government on control and/or eliminate helminthiasis ensured the sustainability and the success of national control programmes with the support of organization, funds, legislation, technique and human resource. (2) The well-developed disease control system and well-trained technical staffs from national to township level guaranteed the feasibility and quality of routine control activities (Huntington, 2012). (3) The development of technology and researches conducted on helminthiasis provided sensitive diagnostic tools and effective intervention measures in each control stages. (4) Good mechanism of inner and/or inter-sector collaboration at county level made it effective to manage and implement disease control activities (Collins et al., 2012; Zhou et al., 2011b).

6.2. Challenges for helminthiasis control

Although P.R. China gained great achievement on schistosomiasis and other helminthiasis control through more than 60 years of endeavor, there are still considerable challenges in consolidating the achievements and recognizing the definite goals to control or eliminate helminthiasis due to the varied epidemiological and biological characteristics of different helminth diseases and the fact that they were in different stages toward control and/or elimination.

For schistosomiasis, with the decrease of infection intensity and prevalence, lack of sensitive surveillance capacity and monitoring tools would lead to underestimation of the endemic status in areas with low prevalence. Although the screening system which was based on serological tests with follow-up parasitological examinations (mainly Kato-Katz) for sero-positive cases could increase the compliance among screening population, the low sensitivity of Kato-Katz method will increasingly underestimate the actual endemic situation (Lin et al., 2008; Xu et al., 2007; Zhou et al., 2011c). As the transmission of schistosomiasis is a very complex process and the biological and social factors related to transmission still existed, it is plausible to assume that the incidence of schistosomiasis is highly possible to rebound if the work and endeavors on control is overlooked in the future (Zhou et al., 2010; Zhou et al., 2007). As ecological factors may change and lead to resurgence of the disease (Butler, 2012; Zhou et al., 2002), long-term surveillance system considering all potential risk factors needs to be established immediately since large water conservancy projects such as Three Gorges Dam and the south-to-north water conversion project etc., will change the ecological surrounding and affect schistosomiasis transmission eventually (Xu et al., 2012; Zheng et al., 2002).

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Table 1
Goals of action plan for echinococcosis control in P.R. China (2010–2015).

Index	Qinghai-Tibet Plateau		Other endemic areas	
	By 2012	By 2015	By 2012	By 2015
To understand the endemic areas and endemic status[a]	yes	–	yes	–
Prevalence of dogs (%)[b]	<15%	<8%	<10%	<5%
Morbidity of livestock aged less than 2 years (%)[b]	<20%	<15%	<15%	<10%
Sero-prevalence of children aged 6–12 years (%)[b]	<10%	<8%	<8%	<5%

[a] Based on county level.
[b] Based on township level.

For STH, re-infection after effective deworming is still common in the areas that are seriously contaminated with soil-transmitted helminth eggs or larvae which makes further progress difficult (Chen et al., 2011b; Jia et al., 2012; Singer and de Castro, 2007). Meanwhile, the intensification of mass drug administration (MDA) has caused the serious problem of resistance to anthelminthic drug which is now irreversible (Behnke et al., 2008; Geerts and Gryseels, 2000). This has resulted in mass chemotherapy being challenged with respect to optimizing community involvement and participation and monitoring/evaluating the effectiveness of MDA (Prichard et al., 2012). As poverty, lack of sanitation, and eating habits are highly related to soil-transmitted helminth infections (Spiegel et al., 2010; Wang et al., 2008; Zhou et al., 2011a; Zhou, 2011), lack of technical staffs and funding would make the STH more difficult to control especially in the endemic areas which are located in the poor and rural areas of P.R. China. Inter-sectoral cooperation between the departments of health, education, and engineering also needs to be strengthened to improve awareness of health knowledge and improve access to clean water and adequate sanitation in those under-developed places (Utzinger et al., 2009; Ziegelbauer et al., 2012).

Being a zoonotic parasite, *C. sinensis* has a very complicated life cycle involving two intermediate hosts and many mammals definitive hosts especially dogs and cats (Lun et al., 2005). Epidemiological studies showed that intermediate hosts and the most common definite hosts have a very high prevalence in endemic areas (Jiang and Sun, 2001; Lin et al., 2011; Zhou et al., 1994) which contributes to the contamination of surrounding environment and makes the control of clonorchiasis more difficult. As the customs of eating raw fish and crustaceans is a tradition in endemic areas since long time ago, and this type of food is considered delicious, it is very difficult to eliminate the consumption of raw, uncooked fresh fish or shrimps, although this is considered to be the simplest way to prevent infection. Furthermore, as the clinical symptoms of clonorchiasis are non-specific and the diagnosis of infection is mainly based on microscopic detection which suffers from a high possibility of false negativity, misdiagnosis, and missed diagnosis are fairly common. In addition, since the disease burden is not clear and the medical staff often lacks a thorough understanding of this disease, it is urgently required that the training of staffs and health education for residents in endemic areas should be strengthened.

As echinococcosis is mainly endemic in pastoral or semi-pastoral areas, control of echinococcosis remains a great challenge due to the complicated environment, various cultural and religious customs, lack of control work, the large amount of animal hosts in endemic areas etc (Xiao et al., 2013). Since most of information on echionococcosis in animals is based on reports from limited areas and clinical case studies are only found in humans; therefore, there is a paucity of data on the overall prevalence of CE in the whole country.

6.3. *Recommendations for helminthiasis control*

In conclusion, with the economic development and the raise of consciousness on burden of parasitic diseases, the Chinese government has been paying great attention to control of parasitic diseases. The scientific control policies and effective control approaches adapted to different eco-epidemiological settings during national control activities assured the great achievements on helminthiasis control. To achieve a new round of achievements for helminthiasis control, sustainable financial resources and political commitments need to be assured. Enhanced efforts should be required to integrate measures to control helminthiasis. Preventative chemotherapy can be integrated for control of several helminthiasis since praziquental, mebendazole, and albendazole are belonging to broad-spectrum anthelminthics, and there is extensive overlap and co-endemicity among these parasitic diseases (Chen et al., 2012; Shang et al., 2010; Yu et al., 1994b). To reach the long term goals to reduce or interrupt transmission of helminthiasis, improvement of hygiene, housing, and sanitation conditions will help to consolidate and gain further achievements for parasitic disease control (Prichard et al., 2012). Supplying of safe water and latrine, disposing adequately of excreta and solid waste, and environmental modification will improve the sanitation to decrease STH contamination of surroundings being effective against many helminthic diseases (Utzinger et al., 2003; Utzinger et al., 2009; Wang et al., 2008). Collaboration with the Departments of Water Conservancy, Agriculture, Husbandry, and Education should be strengthened to accelerate the progress of national control programme (Zhou, 2012).

Although scientific advances accelerate our understanding of the biology and epidemiology of helminth infection, and significant decrease in prevalence and infection intensity of helminthiasis was attained during past several decades, there are still a lot of obstacles ahead if we want to reach the aim of controlling morbidity or eliminating infections of helminthiasis (Hotez et al., 2008). In 2012, the diseases reference group on helminth infections (DRG4), established in 2009 by the Special Programme for Research and Training in Tropical Diseases (TDR), conducted a gap analysis on helminthiasis control. Meanwhile, the research and development agenda for helminthiasis control, covering seven topics including interventions, diagnostics, basic biology, mathematical modeling, social, and environmental determinants and capacity building etc., were put forward (Basanez et al., 2012; Boatin et al., 2012; Gazzinelli et al., 2012; Lustigman et al., 2012a; Lustigman et al., 2012b; McCarthy et al., 2012; Osei-Atweneboana et al., 2012; Prichard et al., 2012). As such, firstly more funding needs to be invested to support further studies on helminthiasis and in the end, the potential scientific advancements in turn need to be translated into improved or novel interventions to accelerate the control of helminthiasis.

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Authors' contributions

XJ and ZXN participated in the initial design of the paper. XJ and XJF participated in the literature review and contributed equally to the writing. ZLJ, WQ, and ZHH did the data collection and figure drawing. ZXN and LSZ participated in the writing of the paper. All the authors reviewed and approved the final version.

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