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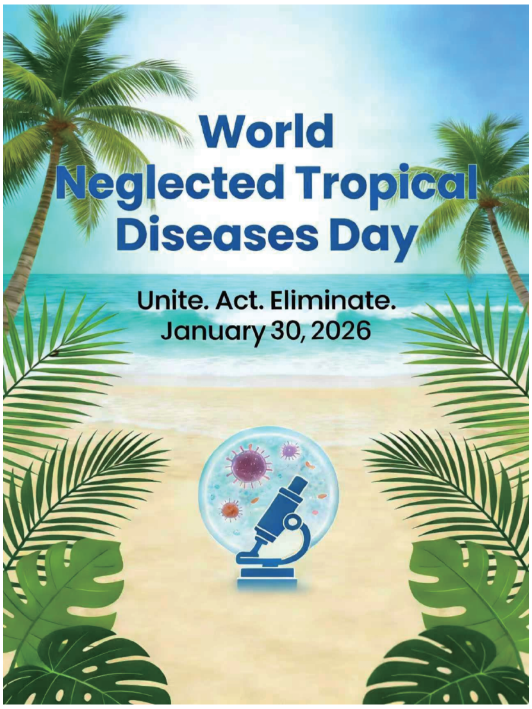

NEGLECTED TROPICAL DISEASE ISSUE

Preplanned Studies

Outbreak Reports

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Cover Image: adapted from Doubao image generation.
This week's issue were organized by Guest Editors Xiaonong Zhou and Shizhu Li.

Preplanned Studies

Epidemiological Transition and Spatial Expansion of Mountain-Type Zoonotic Visceral Leishmaniasis — China, 2010–2024

Lulu Huang[1]; Yanfeng Gong[2]; Zhengbin Zhou[1]; Jingshu Liu[1]; Peijun Zhang[3]; Shizhu Li[1,#]

Summary

What is already known about this topic?

Mountain-type zoonotic visceral leishmaniasis (MT-ZVL) remains endemic in China and has re-emerged in recent years, with its geographic distribution demonstrating signs of progressive expansion.

What is added by this report?

Drawing on 15 years of national surveillance data, this study demonstrates a clear resurgence after 2015, a shift in high-risk populations from scattered children to farmers and older adults, and eastward and northward expansion of transmission risk areas.

What are the implications for public health practice?

These findings provide evidence that control strategies should prioritize interventions targeting farmers and elderly-focused interventions, strengthen surveillance in newly affected counties, and implement geographically targeted vector and reservoir control measures.

ABSTRACT

Introduction: Mountain-type zoonotic visceral leishmaniasis (MT-ZVL) has re-emerged in China with shifting demographic patterns and expanding geographical distribution. This study aimed to characterize its epidemiological and spatial-temporal dynamics to guide targeted control strategies.

Methods: Case data from 2010–2024 were analyzed using χ^2 tests and proportional analyses. Temporal trends were assessed by Joinpoint regression, projections by autoregressive integrated moving average (ARIMA) models, spatial clustering and directional tendency by *Moran's I* and Standard Deviational Ellipse (SDE) analyses.

Results: A total of 2,260 cases were reported, showing a bimodal age distribution (<5 years and 60–75 years) with marked male predominance and a shifting occupational risk toward adults. Affected counties expanded from 19 to 69 and after a decline in 2010–2015, incidence increased and spread eastward during 2015–2024, with projections indicating continued growth by 2030 without strengthened control.

Conclusions: MT-ZVL in China shows expanding risk areas and changing occupational patterns, highlighting the need for strengthened surveillance and targeted control interventions in the regions.

Visceral leishmaniasis (VL), also known as kala-azar, is a neglected tropical disease that is fatal in over 95% of untreated cases (*1*). Mountain-type zoonotic visceral leishmaniasis (MT-ZVL) represents the predominant form of VL in China, accounting for more than 95% of reported cases. The disease is transmitted by *P. chinensis*, with dogs and certain wild animals serving as the primary reservoir hosts (*2*). Following large-scale control efforts initiated in the 1950s, MT-ZVL incidence declined substantially and was largely controlled by the 1960s. However, re-emergence and geographic expansion of MT-ZVL have been observed across multiple provinces in northern and central China over the past decade, raising concerns about the sustainability of previous control achievements (*3*–*5*). Recent surveillance data from China's National Notifiable Diseases Reporting System (NNDRS) reveal shifts in the demographic and occupational profiles of MT-ZVL cases, with increasing involvement of farmers and older adults and a corresponding decline among young children. Concurrently, indigenous cases have been reported in an increasing number of counties, including areas previously not considered endemic, suggesting gradual expansion of transmission zones. These evolving patterns challenge traditional control approaches that focus primarily on historically endemic foci. This study characterizes the demographic features, occupational distribution, temporal trends, and geographic expansion of MT-ZVL transmission in China, providing evidence to inform targeted and adaptive public health interventions.

MT-ZVL surveillance data were obtained from the NNDRS from January 1, 2010, to December 31, 2024, covering 7 endemic provincial-level administrative divisions (PLADs): Beijing Municipality and 6 provinces (Shanxi, Shaanxi, Gansu, Sichuan, Henan, and Hebei). Population denominators were derived from China's 6th (2010) and 7th (2020) National Population Censuses, with age-specific populations estimated using averaged census data to ensure temporal comparability. Incidence rates were calculated using the age and sex composition of each PLAD. Age- and sex-specific incidence rates were computed, and sex differences were assessed using χ^2 tests. Occupational categories were consolidated into standardized groups, and proportional distributions across these groups were analyzed to identify temporal shifts in case demographics. Temporal trends in MT-ZVL incidence were evaluated using Joinpoint regression analysis to identify significant inflection points and estimate annual percent changes (APC). Future incidence rates and projected case numbers for 2025–2030 were estimated using autoregressive integrated moving average (ARIMA) models. Spatial autocorrelation was assessed at the county level using Global Moran's *I* statistic to evaluate overall clustering patterns. Standard Deviational Ellipse (SDE) analysis was applied to describe the spatial center, dispersion, and directional tendency of disease distribution. Data analysis was performed using R version 4.3.3 (R Foundation for Statistical Computing, Vienna, Austria), ArcGIS version 10.7 (Environmental Systems Research Institute, Redlands, CA, USA), and the Joinpoint Regression Program version 5.0.0 (Surveillance Research Program, National Cancer Institute, Bethesda, MD, USA).

Between 2010 and 2024, a total of 2,260 MT-ZVL cases were reported across the seven endemic provinces. The age-specific incidence demonstrated a bimodal distribution, with peak rates observed among children younger than 5 years and adults aged 60–75 years. Male predominance was statistically significant in infants <1 year (χ^2=4.455, *P*=0.035) and adults aged 35–79 years (all *P*<0.01). The annual average number of cases per million population increased progressively with age after 30 years, reaching the highest levels in the 65–74-year age group, thereby identifying older adults as a primary high-risk population for MT-ZVL (Table 1). Throughout 2010–2024, MT-ZVL exhibited substantial temporal and seasonal variation. Following a steady decline from 2010 to 2014, both incidence and case numbers increased continuously from 2015 onward, reaching 226 indigenous cases in 2024, corresponding to an incidence rate of 0.608 per 1,000,000 population. Joinpoint regression analysis revealed a clear reversal in temporal trends around 2015. MT-ZVL incidence declined significantly during 2010–2015 [APC=−15.7%, 95% confidence interval (*CI*): −23.6 to −10.1, *P*<0.001], followed by a sustained and significant increase during 2015–2024 (APC=13.1%, 95% *CI*: 10.0 to 17.1, *P*<0.001). ARIMA projections indicate that without intensified control strategies, incidence will continue to rise, reaching 0.801 per 1,000,000 (95% *CI*: 0.081 to 1.520) by 2030, with an estimated 1,607 additional cases (95% *CI*: 660 to 2,554) expected between 2025 and 2030 (Figure 1A). The geographic distribution of MT-ZVL expanded substantially during this period, with the number of counties reporting local cases increasing from 19 in 2010 to 69 in 2024, highlighting progressive transmission spread and an expanding at-risk population (Figure 1B). Seasonal analysis revealed year-round case occurrence, with a pronounced peak from March to August and the highest monthly incidence in April, accounting for over 12% of the annual total (Figure 1C). Occupational analysis (Supplementary Table S1, available at https://weekly.chinacdc.cn/) demonstrated that farmers and scattered children were the primary affected groups, accounting for 40.1% and 30.9% of cases, respectively. Over time, the proportion of cases among scattered children declined markedly from 42.3% in 2010 to 14.6% in 2024, whereas the proportion among farmers increased from 23.6% to 54.4% (Figure 1D).

Spatial autocorrelation analysis revealed significant clustering of MT-ZVL incidence in most years, particularly after 2020, with consistently positive Moran's *I* values (Supplementary Table S2, available at https://weekly.chinacdc.cn/), indicating intensifying geographic aggregation. The SDE analysis demonstrated a significant northeastward shift of the mean center from (104.86°, 33.39°) to (111.89°, 36.40°) and the area enlarged from core regions in Gansu and Sichuan to Shaanxi, Shanxi, Henan, and Hebei. Directional anisotropy peaked in 2015–2019 (Ratio=7.32), indicating a pronounced corridor expansion, and declined in 2020–2024 (Ratio=3.42), suggesting a transition toward areal diffusion. The consistently stable orientation (62.82°–66.13°) reflected a persistent southwest–northeast expansion trajectory (Table 2).

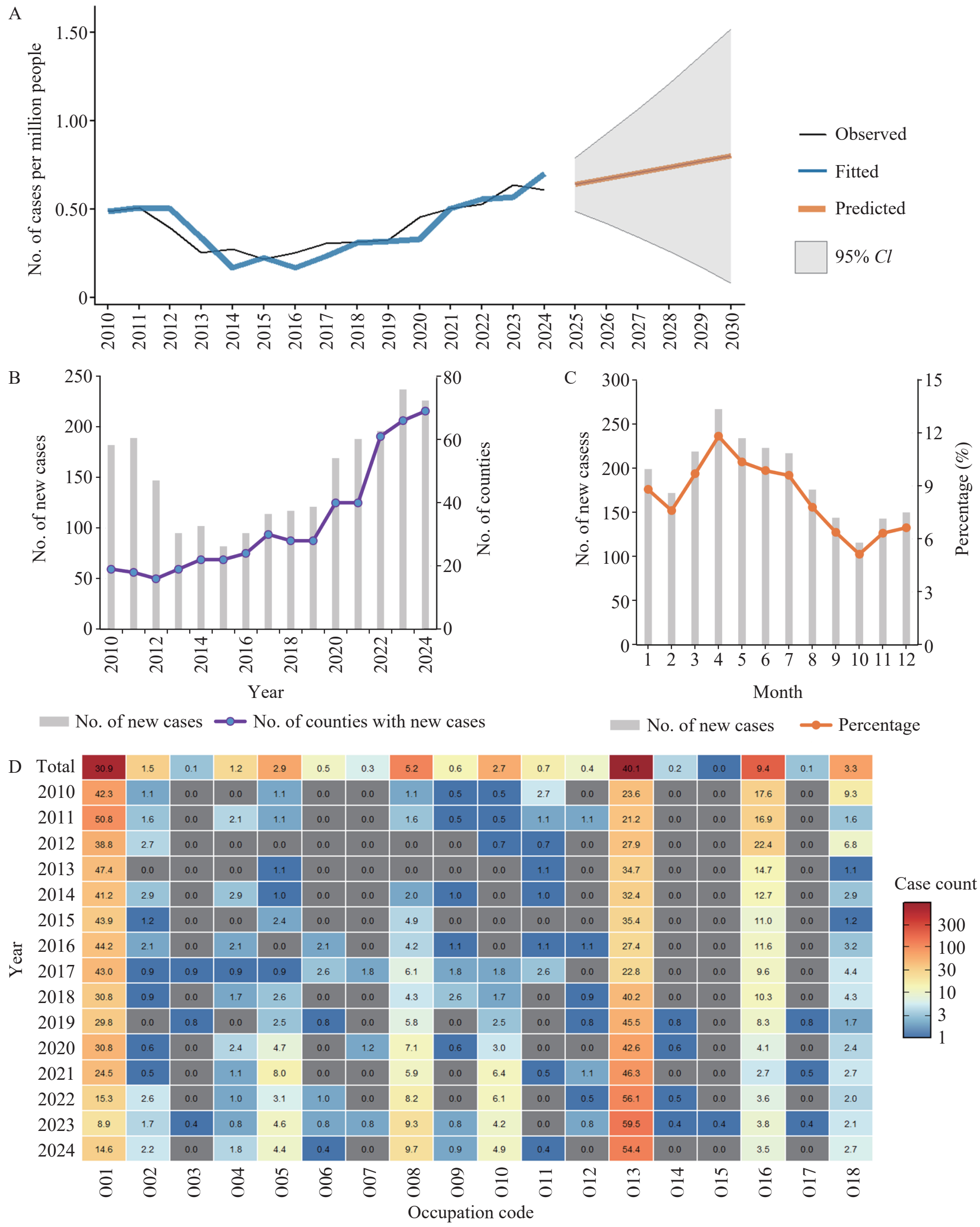
TABLE 1. Sex and age characteristics of MT-ZVL in China, 2010–2024.

Age (years)	Total			Male			Female			χ^2 test	
	No. of accumulated cases	Population in endemic province (million)	Annual average number of cases per million people	No. of accumulated cases	Population in endemic province (million)	Annual average number of cases per million people	No. of accumulated cases	Population in endemic province (million)	Annual average number of cases per million people	χ^2	*P*
<1	103	3.48	1.98	65	1.83	2.36	38	1.64	1.54	4.455	0.0348
1–4	607	18.03	2.24	338	9.57	2.36	269	8.46	2.12	1.683	0.1945
5–9	162	22.94	0.47	84	12.24	0.46	78	10.69	0.49	0.153	0.6961
10–14	68	24.64	0.18	32	12.88	0.17	36	11.76	0.20	0.741	0.3895
15–19	63	23.04	0.18	29	12.31	0.16	34	10.74	0.21	1.377	0.2407
20–24	58	27.44	0.14	29	13.83	0.14	29	13.60	0.14	0.004	0.9485
25–29	58	25.12	0.15	33	12.65	0.17	25	12.48	0.13	1.000	0.3174
30–34	86	28.62	0.20	53	14.43	0.24	33	14.19	0.16	4.327	0.0375
35–39	104	28.20	0.25	74	14.28	0.35	30	13.92	0.14	17.532	<0.0001
40–44	87	28.05	0.21	59	14.19	0.28	28	13.86	0.13	10.328	0.0013
45–49	148	29.04	0.34	104	14.62	0.47	44	14.42	0.20	23.476	<0.0001
50–54	168	26.85	0.42	132	13.51	0.65	36	13.34	0.18	53.679	<0.0001
55–59	127	24.99	0.34	100	12.46	0.53	27	12.52	0.14	42.303	<0.0001
60–64	128	18.30	0.47	96	9.24	0.69	32	9.06	0.24	30.801	<0.0001
65–69	143	16.47	0.58	107	8.15	0.87	36	8.31	0.29	36.657	<0.0001
70–74	104	11.59	0.60	75	5.70	0.88	29	5.89	0.33	21.891	<0.0001
75–79	38	7.61	0.33	31	3.60	0.57	7	4.00	0.12	17.826	0.0000
80–84	8	4.47	0.12	6	2.01	0.20	2	2.46	0.05	2.916	0.0877

Note: Population in endemic province (million) = (Population of the corresponding age group from the 6th National Population Census in 2010 + Population of the corresponding age group from the 7th National Population Census in 2020) / 2 / 1,000,000. Annual average number of cases per million people = (Age-specific number of accumulated cases / Age-specific population in endemic province × 1,000,000) / 15.

DISCUSSION

This nationwide analysis demonstrates that the epidemiology of MT-ZVL in China has undergone a substantial transition over the past 15 years. The most notable findings include a shift in high-risk populations from scattered children to farmers and older adults, a clear reversal in incidence trends after 2015, and persistent spatial clustering with geographic expansion into previously unaffected areas. Together, these patterns reflect evolving transmission dynamics and mounting challenges for disease control. Historically, MT-ZVL in China disproportionately affected young children, likely due to peri-domestic exposure to *P. chinensis*. Our findings indicate a declining proportion of cases among scattered children and a growing burden among farmers, who now represent the primary high-risk group. This shift may be driven by sustained occupational exposure to *P. chinensis* habitats linked to agricultural activities, livestock shelters, and rural living environments (*6*). The increasing incidence among older adults further suggests cumulative exposure and potential age-related susceptibility. Similar occupational risk patterns have been reported in other endemic regions globally, where rural and agricultural populations bear the highest disease burden (*7*). However, the underlying causes of this epidemiological shift remain unclear; further studies are therefore needed to clarify the determinants of these changes and to inform more targeted control interventions. The observed resurgence of MT-ZVL after 2015 suggests that earlier control gains have not been fully sustained (*4*,*8*). Multiple factors may contribute to this resurgence, including reduced intensity of vector and reservoir control, ecological changes, rural land-use transformation, and increased human mobility (*8*–*9*). The pronounced seasonal peak from spring to summer aligns with *P. chinensis* activity



Cell values show proportion (%), color intensity represents counts
Proportion (%)=Number of cases reported in a certain occupation/total number of cases in the year ×100%.

FIGURE 1. Temporal-spatial trends, seasonal patterns, and occupational distribution of MT-ZVL cases in endemic PLADs of China, 2010–2024, with incidence projections to 2030. (A) Time-trend analysis of incidence with observed, fitted, and predicted values of MT-ZVL. (B) Annual number of new indigenous cases and counties reporting cases of MT-ZVL. (C) Monthly distribution of MT-ZVL cases. (D) Heat map of the occupational distribution of MT-ZVL cases.
Note: “Observed” indicates the reported annual incidence (cases per million population) from the NNDRS; “Fitted” indicates the Joinpoint regression-based fitted trend; “Predicted” indicates the ARIMA model-based projected incidence for 2025–2030. Incidence was calculated as the number of reported cases per million population. In panel B, bars represent the number of newly reported cases, and the line represents the number of counties reporting at least one MT-ZVL case each year. In panel C, bars represent the monthly number of new cases, and the line represents the percentage of cases occurring in each month. In panel D, cell values show the proportion (%) of cases in each occupational category by year, calculated as (number of cases in a given occupation / total number of cases in that year) × 100; color intensity represents the absolute number of cases. Occupational codes (O01–O18) correspond to the standardized occupational classification used in NNDRS.
Abbreviation: MT-ZVL=mountain-type zoonotic visceral leishmaniasis; PLADs=provincial-level administrative divisions; *CI*=confidence interval; NNDRS=National Notifiable Diseases Reporting System.

TABLE 2. Standard deviation ellipse of distribution of MT-ZVL in China from 2010–2024.

Year	CenterX	CenterY	XStdDist	YStdDist	Rotation	Ratio
2010–2014	104.86	33.39	2.51	0.81	62.82	3.11
2015–2019	107.24	34.64	5.88	0.80	66.13	7.32
2020–2024	111.89	36.40	4.49	1.31	63.75	3.42

Note: MT-ZVL cases were grouped into three consecutive five-year periods (2010–2014, 2015–2019, and 2020–2024). The SDE was applied to characterize the spatial centrality, dispersion, and directional pattern of MT-ZVL. CenterX and CenterY denote the longitude and latitude of the mean center, indicating the overall geographic location of cases. XStdDist and YStdDist represent the standard distances along the major and minor axes of the ellipse, describing the extent of spatial dispersion in the principal expansion direction and its perpendicular direction, respectively. Rotation indicates the orientation angle (in degrees) of the major axis, reflecting the dominant direction of spatial spread. Ratio is the ratio of the major to the minor axis, representing the strength of directional anisotropy in the spatial distribution.

Abbreviation: SDE =Standard Deviational Ellipse.

and highlights the importance of timely, preseason interventions for vector control (*10*). Forecasting results underscore the likelihood of continued resurgence in the absence of strengthened, targeted control measures.

Spatial analyses revealed persistent clustering of MT-ZVL incidence that has intensified in recent years. Although some years exhibited weaker spatial dependence, this pattern likely reflects low overall incidence or sporadic case distribution rather than a genuine absence of clustering. The northeastward expansion indicates that MT-ZVL transmission is no longer confined to traditional endemic foci (*3*). These findings underscore the urgent need to extend surveillance and control efforts to newly affected areas and to allocate resources strategically based on spatiotemporal risk patterns.

Based on these findings, several public health actions are warranted. Control strategies should prioritize farmers and older adults through targeted health education, personal protective measures, and improved access to early diagnosis and treatment. Integrated approaches that combine sustained vector surveillance, dog reservoir management, and rapid response to emerging hotspots are essential to interrupt transmission cycles. This study has several limitations, including potential underreporting in surveillance data, broad occupational classifications, and the absence of analyses of environmental and socioeconomic drivers. Furthermore, the role of other reservoir hosts, such as wild animals, was not assessed and may be underestimated. Nevertheless, the extended 15-year study period and nationwide coverage provide robust evidence to inform future public health practice and policy development.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Occupational codes (O01–O18) correspond to the standardized occupational classification used in NNDRS.

Occupational code	Standardized occupational classification in NNDRS
O01	Scattered children
O02	Unknown
O03	Catering or food industry staff
O04	Public servant
O05	Worker
O06	Business service personnel
O07	Seafarer / Long-distance driver
O08	Household / Unemployed personnel
O09	Teacher
O10	Retiree
O11	Migrant worker
O12	Herdsmen
O13	Farmer
O14	Individual business owners
O15	Soldier
O16	Students
O17	Medical worker
O18	Preschool care children

Abbreviation: NNDRS= National Notifiable Disease Reporting System.

SUPPLEMENTARY TABLE S2. Annual Moran's *I* for MT-ZVL in China, 2010–2024.

Year	Moran's *I*	Expected Moran's *I*	Variance	Z value	*P*
2010	0.199207	−0.055556	0.007169	3.008891	0.002622
2011	0.115745	−0.058824	0.007738	1.984564	0.047193
2012	−0.010381	−0.076923	0.008036	0.742313	0.457898
2013	0.018307	−0.055556	0.007083	0.877634	0.380143
2014	0.462370	−0.047619	0.017123	3.897345	0.000097
2015	0.239765	−0.047619	0.011142	2.722587	0.006477
2016	0.198821	−0.043478	0.011625	2.247288	0.024622
2017	0.148021	−0.035714	0.008758	1.963371	0.049603
2018	0.217221	−0.034483	0.021843	1.703061	0.088557
2019	0.129253	−0.033333	0.034376	0.876910	0.380535
2020	0.816739	−0.025641	0.008262	9.267503	0.000000
2021	1.298336	−0.027778	0.018219	9.824665	0.000000
2022	0.446089	−0.017544	0.004211	7.144700	0.000000
2023	0.075549	−0.000345	0.000010	24.178686	0.000000
2024	0.328612	−0.014706	0.007249	4.032223	0.000055

Preplanned Studies

Effectiveness of an Integrated One Health Intervention on *Schistosoma japonicum* Infection in Wild Rodents — Anhui Province, China, 2022–2024

Suying Guo[1]; Chao Lyu[1]; Lijuan Zhang[1]; Wangping Deng[1]; Jing Xu[1,#]; Shizhu Li[1]; Xiaonong Zhou[1]

Summary

What is already known about this topic?

Schistosomiasis represents a natural focal disease in which wild rodents function as critical reservoir hosts for *Schistosoma japonicum* transmission within specific endemic regions of China.

What is added by this report?

Implementation of a comprehensive 2-year One Health intervention package demonstrated a significant reduction in *S. japonicum* infection rates among wild rodents, declining from 69.15% to 22.09%, with intervention villages showing an 88.46% decrease in infection odds compared to control villages.

What are the implications for public health practice?

Integrating One Health intervention measures into schistosomiasis control programs could effectively reduce infection risk among environmental reservoir hosts and mitigate transmission risks to human populations.

ABSTRACT

Introduction: Wild rodents serve as important reservoir hosts of *Schistosoma japonicum* in certain endemic regions. Although a One Health strategy integrating human, animal, and environmental health measures has been proposed, evidence demonstrating its effectiveness in reducing wildlife reservoir infection remains limited.

Methods: A preplanned intervention study was conducted from 2022 to 2024 across 12 villages in two endemic counties of Anhui Province. Villages were assigned to receive either routine control measures or an enhanced One Health intervention package that included deratization, drone-based surveillance, microenvironment modification, and health education. Annual rodent surveys were conducted using trap-night methods, and multiple diagnostic tests were employed to detect *S. japonicum* infection.

Results: A total of 2,084 rodents were captured and examined. The *S. japonicum* infection rate in intervention villages decreased from 69.15% (278/402) at baseline to 22.09% (146/661) after two years of intervention (χ^2=230.950, *P*<0.01), whereas the infection rate in control villages increased from 39.07% (143/366) to 45.65% (299/655) (χ^2=4.138, *P*=0.04). Adjusted analysis demonstrated an 88.46% reduction in infection odds within the intervention group [adjusted odds ratio (a*OR*)=0.115, 95% confidence interval (*CI*): 0.078, 0.172].

Conclusion: A comprehensive One Health intervention package is significantly associated with reduced *S. japonicum* infection in wild rodents. Integrating rodent-targeted measures into schistosomiasis control programs may substantially decrease transmission risk and accelerate progress toward nationwide schistosomiasis elimination.

Schistosomiasis japonica is a snail-borne neglected tropical disease caused by *Schistosoma japonicum* infection, which produces complex intestinal manifestations in chronically infected individuals (*1*). Classified as a class B infectious disease in China, schistosomiasis is currently progressing toward national elimination. However, *S. japonicum* maintains a broad host range, infecting over 40 mammalian species. Among these, wild rodents have emerged as increasingly important transmission reservoirs in specific ecological settings, particularly mountainous and hilly regions where human-wildlife interfaces are common (*2–3*). Addressing this zoonotic transmission cycle requires interventions that span human, animal, and environmental health sectors — an approach embodied by the One Health framework (*4*). Despite growing recognition of wild rodents as key reservoir hosts, rigorous field evidence demonstrating the effectiveness of integrated control measures targeting these populations remains limited. To address this knowledge gap, we designed a preplanned intervention study to evaluate whether a comprehensive One Health package could effectively reduce *S. japonicum* infection prevalence in wild rodent populations within high-risk areas of Anhui Province, thereby mitigating spillover transmission to humans and livestock.

This study was conducted from 2022 to 2024 in two historically high-endemic counties in Anhui Province: Dongzhi County and Dangtu County. Site selection was based on a comprehensive review of recent epidemiological data, including human infection prevalence, distribution of *Oncomelania hupensis* snail habitats, and livestock density, combined with an assessment of operational feasibility. Twelve administrative villages were selected from endemic areas: six from hilly regions in Dongzhi County and six from swamp and lake regions in Dangtu County. These villages were evenly assigned to either the intervention group or the control group (three per county in each group). To minimize potential spillover effects, villages in different study groups were geographically separated. Baseline surveys were conducted in 2022, followed by implementation of intervention measures in 2023 and 2024. Control villages received only routine schistosomiasis control measures, including regular health education, screening and treatment of infected humans and livestock, and conventional molluscicide application. In addition to these routine measures, intervention villages received a comprehensive One Health intervention package beginning in January 2023 (Supplementary Table S1, available at https://weekly.chinacdc.cn/).

Annual cross-sectional surveys of wild rodents were conducted each autumn (September through November) from 2022 to 2024. In each study village, rodents were captured over three consecutive nights using the standard trap-night method. A minimum of 200 wire traps were deployed per night in *O. hupensis* snail habitats along linear transects, including irrigation ditches, field borders, and residential peripheries. All captured rodents were identified to species level. Infection with *S. japonicum* was determined using a parallel diagnostic approach comprising three methods: visual examination for adult worms in the hepatic portal and mesenteric veins, microscopic examination of liver homogenate, and Kato-Katz thick smear technique for fecal egg detection. A rodent was classified as positive if *S. japonicum* adult worms or eggs were identified by any of these methods (*5*).

Descriptive statistics were calculated to summarize baseline characteristics and annual trends in *S. japonicum* infection rates among wild rodents at the county level. Infection rates from 2023 and 2024 were pooled to represent the intervention period. Pearson's chi-square test was employed to assess changes within each group from baseline to the intervention period. To control for potential confounding from baseline prevalence differences and county-level heterogeneity, we constructed a multivariable logistic regression model. This model incorporated main effects for study group (intervention *vs*. control), time period (baseline *vs*. post-intervention), and county, as well as an interaction term between study group and time period. The exponentiated coefficient of this interaction term yields the adjusted odds ratio (a*OR*) quantifying the intervention effect. All statistical analyses were conducted using R software (version 4.3.0, The R Foundation), with two-sided $P<0.05$ considered statistically significant.

A total of 2,084 wild rodents were captured and examined over the three-year study period, with 1,063 from the intervention villages and 1,021 from the control villages. At baseline, the infection rate in the intervention group (69.15%, 278/402) was substantially higher than that in the control group (39.07%, 143/366) (χ^2=70.001, $P<0.01$). Following the two-year intervention period, the pooled infection rate in the intervention group significantly decreased to 22.09% (146/661), representing an absolute reduction of 47.06 percentage points (χ^2=230.950, $P<0.01$). In contrast, the infection rate in the control group significantly increased to 45.65% (299/655), representing an absolute increase of 6.58 percentage points (χ^2=4.138, P=0.04); this increase was particularly pronounced in Dangtu County (Table 1). As shown in Table 2, county type, time period, and study group were all significantly associated with *S. japonicum* infection in wild rodents. After adjusting for county-level effects and time period, the a*OR* for the intervention effect was 0.115 (95% *CI*: 0.078, 0.172), indicating an 88.46% reduction in the odds of *S. japonicum* infection among rodents in intervention villages compared to control villages following the two-year One Health intervention.

DISCUSSION

This study demonstrates that a comprehensive One Health intervention approach is significantly associated with reduced *S. japonicum* infection rates in wild

TABLE 1. Infection rates of *Schistosoma japonicum* in wild rodents across intervention and control groups, 2022–2024.

Year	Infection rate in intervention groups, % (*n*/*N*)					Infection rate in control groups, % (*n*/*N*)				
	Dongzhi County	Dangtu County	Total	χ^2	*P*	Dongzhi County	Dangtu County	Total	χ^2	*P*
Baseline										
2022	77.46 (268/346)	17.86 (10/56)	69.15 (278/402)	−	−	52.65 (119/226)	17.14 (24/140)	39.07 (143/366)	−	−
After intervention										
2023	36.76 (50/136)	13.42 (20/149)	24.56 (70/285)	132.672	<0.01	55.51 (141/254)	25.55 (35/137)	45.01 (176/391)	2.737	<0.01
2024	24.83 (73/294)	3.66 (3/82)	20.21 (76/376)	187.663	<0.01	46.41 (84/181)	46.99 (39/83)	46.59 (123/264)	3.555	0.06
Two-year pooled	28.60 (123/430)	9.96 (23/231)	22.09 (146/661)	230.950	<0.01	51.72 (225/435)	33.64 (74/220)	45.65 (299/655)	4.138	0.04
Total	50.39 (391/776)	11.50 (33/287)	39.89 (424/1,063)	232.228	<0.01	52.04 (344/661)	27.22 (98/360)	43.29 (442/1,021)	4.298	0.12

Note: "−" means reference.

TABLE 2. Multivariable binary logistic regression coefficients for *S. japonicum* infection in wild rodents.

Parameters	B	SE	*aOR* (95% *CI*)	*P*
County (ref: Dongzhi)	−1.328	0.116	0.265 (0.211, 0.333)	<0.01
Study group (ref: control group)	1.011	0.158	2.749 (2.016, 3.749)	<0.01
Time period (ref: baseline)	0.232	0.139	1.261 (0.961, 1.656)	0.09
Study group * time period interaction	−2.159	0.202	0.115 (0.078, 0.172)	<0.01

Abbreviation: *aOR*=adjusted odds ratio; *CI*=confidence interval.

rodent populations. These findings complement and extend prevalence data from previous rodent surveillance studies (*6*–*7*). In theory, integrating simultaneous data on snail infection rates and schistosomiasis incidence in humans and livestock would allow for a more comprehensive assessment of intervention effectiveness. However, prevalence in these hosts has remained at extremely low levels for years when measured by traditional detection methods, thereby limiting their utility for estimating environmental transmission risk. As wild animals increasingly serve as the primary reservoir hosts, surveillance and effective infection control in these populations appear crucial during the transmission interruption and post-elimination phases (*8*).

The results indicate that a targeted package of environmental, rodent-focused, and community-based measures was associated with a marked decline in rodent infection prevalence within intervention villages. In contrast, the increased prevalence observed in control villages may be explained by the limited effectiveness of routine control measures against wildlife reservoirs. This pattern underscores the persistent intensity of zoonotic transmission and suggests potential for escalation without targeted reservoir management. The observed 88.46% reduction in adjusted infection odds is notable in field-based zoonotic disease research, suggesting that the intervention may have disrupted critical links in the local transmission cycle — potentially by reducing rodent-snail habitat overlap, decreasing rodent density and infection pressure, and limiting environmental contamination with parasite eggs. However, it should be noted that potential confounders — including ecological heterogeneity, rodent species composition, and operational variations — were not explicitly controlled for, and residual confounding cannot be fully ruled out. Future studies could enhance interpretability by clarifying covariate selection and more thoroughly addressing these limitations. The increased infection rate in control villages further implies that transmission risk may continue to escalate in the absence of tailored interventions. Although rodent infection is not included as an indicator in the national criteria for schistosomiasis elimination, it can serve as a valuable risk indicator, signaling the persistence of the complete *S. japonicum* life cycle in nature. Further research is needed to clarify the spillover risk from infected wildlife populations and their role in sustaining current transmission dynamics.

This study has several important limitations. First, the non-randomized village assignment may not fully eliminate residual confounding from unmeasured ecological or epidemiological factors, despite statistical adjustment for county-level effects and baseline prevalence. Second, variations in rodent trapping efficiency and diagnostic sensitivity across sites could introduce bias into prevalence estimates, potentially affecting the magnitude of observed intervention effects. Third, the substantial baseline imbalance in infection rates between intervention and control villages (69.15% *vs*. 39.07%) complicates causal attribution of the observed decline, as regression to the mean or unmeasured site-specific factors could partially explain the differential trends. The underlying drivers of this baseline heterogeneity were not systematically investigated.

This study demonstrates that a comprehensive, integrated One Health intervention strategy can substantially reduce *S. japonicum* prevalence in wild rodent populations — a reservoir host that has proven notoriously difficult to manage. The intervention package provides an evidence-based model for schistosomiasis control in areas where wildlife reservoirs sustain ongoing transmission. For endemic regions approaching elimination or maintaining post-elimination status, public health programs should consider integrating environmental modification and targeted reservoir host management into their long-term control strategies. Successful implementation of such measures requires sustained cross-sectoral collaboration spanning health, agriculture, water resources, forestry, and natural resource management agencies. The observed prevalence increase in control villages (from 39.07% to 45.65%) underscores the critical need for proactive, ecologically informed interventions in high-risk areas to prevent transmission resurgence and accelerate progress toward national schistosomiasis elimination goals.

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Ethical statement: Approved by the Ethical Review Committee of the National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention (Chinese Center for Tropical Diseases Research) (approval number 20211019).

Conflicts of interest: The authors declare no conflicts of interest.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. One Health intervention measures implemented in intervention and control villages, 2023–2024.

One Health Approach	Intervention Villages	Control Villages
Human Health	1. Chemotherapy 2. Common health education 3. Key population management 4. Intelligent surveillance system 5. Health education via WeChat (a new media) platform 6. Incentive-based campaigns	1. Chemotherapy 2. Common health education
Animal Health	1. Livestock screening and treatment 2. Drone monitoring for open grazing of livestock in the snail habitats 3. Wild rodent survey and deratization	1. Livestock screening and treatment
Environmental Health	1. Survey of wild feces and snails 2. Molluscicide 3. Water body surveillance 4. Environmental molecular biology surveys 5. Safe disposal of wild animal feces in snail habitats 6. Drone-based snail control 7. Plastic film mulching 8. Micro-environment modification for snail control	1. Survey of wild feces and snails 2. Molluscicide

Preplanned Studies

Knowledge, Attitudes, and Practices of Dog Owners Toward a Smart Health Education Pillbox for Controlling Echinococcosis — Western China, 2023–2024

Shijie Yang[1]; Chenqing Sun[1]; Ning Xiao[1]; Shizhu Li[1]; Shuai Han[1]; Liying Wang[1]; Ying Wang[1]; Jiangshan Zhao[2]; Shanglin Wu[3]; Xiao Ma[4]; Yu Feng[5]; Benfu Li[6]; Tongmin Wang[7]; Kaisaier Tuerxunjiang[2]; Xiaonong Zhou[1,#]

Summary

What is already known about this topic?

Echinococcosis remains a critical public health challenge in western China. Conventional routine health education (RHE) strategies have consistently proven insufficient in achieving the sustained behavioral modifications necessary to reduce disease transmission and burden.

What is added by this report?

This study provides the first large-scale experimental evidence that a Smart Health Education Pillbox (SHEP) significantly enhances knowledge, corrects misconceptions, and improves practice conversion efficiency regarding echinococcosis control among dog owners in endemic pastoral areas. These findings demonstrate the substantial value of precise, automated health education tools in controlling zoonotic diseases.

What are the implications for public health practice?

The SHEP represents a scalable, precise health education tool that effectively bridges the knowledge-practice gap in resource-limited settings. Its demonstrated efficacy supports integration into national echinococcosis control programs as a cost-effective digital intervention that promotes sustainable behavior change and reduces zoonotic disease transmission.

ABSTRACT

Introduction: Echinococcosis, a neglected zoonotic disease, imposes a substantial global health burden. Enhancing health literacy and facilitating practice changes among pastoral communities through innovative technological interventions are essential for reducing disease transmission and impact. We evaluated the effectiveness of the Smart Health Education Pillbox (SHEP) on the knowledge, attitudes, and practices (KAP) of dog owners in controlling echinococcosis.

Methods: We conducted a cluster-randomized trial among 2,700 dog owners across nine endemic counties in western China, selecting two townships per county. Within each township, 150 enrolled dog owners were randomly allocated in equal numbers to either the Smart Health Education Pillbox (SHEP) or routine health education (RHE) group. Data were collected through a validated online questionnaire (Cronbach's α=0.85) distributed via the Wenjuanxing platform. Primary outcomes included knowledge, attitude, and practice rates, as well as practice conversion efficiency. Statistical analyses were performed to calculate absolute risk reduction (ARR), relative risk (RR), relative risk reduction (RRR), protective efficacy (1/RR), and conversion efficiency index (η).

Results: Implementation of the SHEP significantly enhanced dog owners' knowledge, attitudes, and practices by 6.78%, 3.30%, and 7.50%, respectively, while reducing misconceptions, negative attitudes, and improper practices by 43.92%, 28.60%, and 13.74% compared to RHE (all P<0.001). The intervention demonstrated protective efficacy ratios of 1.82, 1.40, and 1.16 across these domains and increased the overall conversion efficiency index by 7.88% (all P<0.001).

Conclusion: The SHEP represents a superior intervention for improving echinococcosis-related knowledge, attitudes, and practices (KAP), demonstrating particular strength in enhancing knowledge-to-practice conversion. As an innovative solution addressing health education challenges in plateau pastoral areas, the SHEP is recommended for integration into the national echinococcosis control program.

Echinococcosis, a neglected tropical zoonosis with cross-species transmission potential, manifests primarily as cystic echinococcosis (CE) and alveolar echinococcosis (AE), caused by *Echinococcus granulosus sensu lato* and *E. multilocularis*, respectively. These forms are endemic across 370 counties in northwestern China, with 115 experiencing co-endemicity (*1*). Annually, CE accounts for approximately 18,800 new cases and 1 million disability-adjusted life years (DALYs), with China bearing 40% of this global burden. AE is responsible for an estimated 18,200 cases and 666,000 DALYs annually, over 90% occurring within China. The combined annual economic burden reaches approximately 3 billion US dollar (USD), predominantly borne by China (*2*–*3*). Consequently, echinococcosis has been designated a priority infectious disease for control within China's One Health framework (*4*).

Health education represents a cost-effective foundational intervention for echinococcosis control. New Zealand achieved elimination through legislative measures enforcing "canine management+public health education." South American nations including Argentina and Chile achieved human incidence reductions exceeding 60% through sustained "dog deworming+community education" campaigns (*5*). In China, the National Echinococcosis Control Program (2010–2015) and subsequent implementation plan (2024–2030) emphasize integrated strategies combining source control, health education, intermediate host management, and case treatment, prioritizing culturally tailored health materials for pastoral areas (*6*). After two decades of sustained efforts, improvements in knowledge, attitudes, and practices (KAP) among residents have contributed to reduced transmission (*7*–*8*). However, conventional health education approaches — including pamphlets, lectures, social media, and targeted training — face persistent challenges from low literacy levels, linguistic diversity, sporadic outreach, and coverage disparities (*6*,*9*). Lower awareness of echinococcosis control ($P<0.01$) was observed among high-altitude pastoral residents compared to urban/peri-urban residents (*9*). Addressing these gaps requires smart, precise, digitalized health education tools ensuring sustainable, equitable, and effective delivery of control messages to reduce disease burden.

Between 2021 and 2023, we developed an AI and IoT-enabled SHEP with a dedicated anthelmintic bait compartment, two reminder lights, a liquid-crystal display, six function buttons, and an integrated speaker and charging port (Figure 1). Core functions include

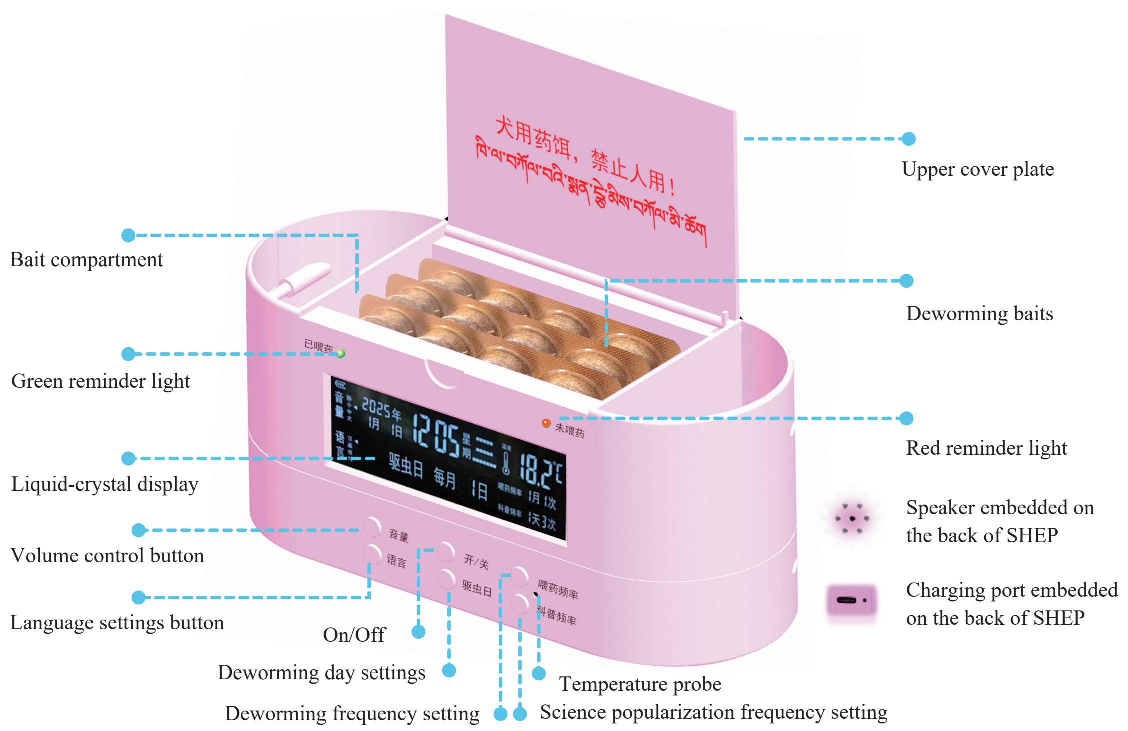

FIGURE 1. Structure and functionalities of Smart Health Education Pillbox.
Abbreviation: SHEP=Smart Health Education Pillbox.

automated deworming reminders and delivery of at least three daily health education broadcasts per household. We conducted a 12-month cluster-randomized trial from 2023 to 2024 across nine endemic counties (*10*). Within each county, two townships were randomly assigned to intervention arms using a computer-generated random number table. The SHEP group received automated intervention with digitized core knowledge delivery, while the routine health education (RHE) group received standard health education through pamphlets, WeChat, and conventional methods. Sample size calculations determined that 150 eligible dog owners per township would provide 90% power to detect significant differences at the two-sided 5% significance level.

A baseline survey was conducted in 2023 using a questionnaire with satisfactory internal consistency (Cronbach's α=0.85) through face-to-face, in-home interviews with all 2,700 eligible dog owners. One year later, a follow-up assessment was administered to both randomized groups of 1,350 participants each. Data were collected using a validated online questionnaire on the Wenjuanxing platform, capturing demographic characteristics, socioeconomic status, and KAP related to echinococcosis. A pilot survey was conducted and multilingual versions were provided to ensure data quality. Blinding was maintained through separate surveyors for each group and independent WeChat groups for survey administration.

Data from the Wenjuanxing platform were entered into MS-Excel and analyzed using SPSS software (version 27.0, IBM Corp., NY, USA). Categorical variables were reported as counts (*n*) and percentages (%). Primary outcomes included knowledge, attitude, and practice rates related to echinococcosis control, and conversion efficiency. These were assessed using absolute risk reduction (ARR), relative risk (RR), relative risk reduction (RRR), protective efficacy (1/RR), and conversion efficiency index (η). Between-group comparisons used the chi-square test or Fisher's exact test, with two-tailed testing and statistical significance at $P<0.05$.

At baseline, all 2,700 dog owners completed the survey. At one-year follow-up, retention rates were 75.63% (*n*=1,021) in SHEPG and 68.89% (*n*=930) in RHEG. The survey employed a nine-item knowledge questionnaire across five domains: basic knowledge, policy awareness, transmission routes, key practices, and livestock management. The knowledge rate in SHEPG reached 91.35%, significantly exceeding both RHEG and baseline by 6.78% [*ARR*=6.78%; 95% confidence interval (*CI*): 5.95, 7.61; $P<0.001$] and 6.50% (*ARR*=6.50%; 95% *CI*: 5.71, 7.29; $P<0.001$), respectively. SHEP intervention substantially reduced the risk of knowledge gaps and misconceptions compared to both groups. The relative risk reduction was 43.92% (*RRR*, 95% *CI*: 40.23, 47.61; $P<0.001$) versus RHEG and 42.97% (*RRR*, 95% *CI*: 39.38, 46.56; $P<0.001$) versus Baseline. Relative probabilities of incomplete or incorrect knowledge were reduced to 0.55 times RHEG (*RR*, 95% *CI*: 0.51, 0.59; $P<0.001$) and 0.57 times Baseline (*RR*, 95% *CI*: 0.53, 0.61; $P<0.001$). SHEP demonstrated protective efficacy of 1.82-fold against knowledge inaccuracies relative to RHE (1/*RR*, 95% *CI*: 1.70, 1.96; $P<0.001$) and 1.75-fold relative to Baseline (1/*RR*, 95% *CI*: 1.64, 1.88; $P<0.001$) (Table 1; Supplementary Table S1, available at https://weekly.chinacdc.cn/). RHEG showed marginal, non-significant decrease in knowledge rate versus Baseline (*ARR*=−1.85; 95% *CI*: −8.32 to 4.62; $P=0.575$; *RR*=1.02; 95% *CI*: 0.96–1.08; $P=0.569$) (Supplementary Table S2, available at https://weekly.chinacdc.cn/). Detailed knowledge rates and response frequencies for questions 1–9 are in Table 1 and Supplementary Tables S1–S2.

The attitude questionnaire evaluated participants' willingness to adopt eight key control measures: handwashing, dog tethering, deworming, safe fecal disposal, centralized slaughtering, abstaining from feeding viscera to dogs, lamb vaccination, and health screening. Participants demonstrated overwhelmingly positive attitudes at all time points (Baseline: 89.97%; SHEPG: 91.76%; RHEG: 88.46%). One year post-initiation, SHEPG showed substantial improvements versus both controls. The absolute risk reduction was 3.30% (95% *CI*: 2.28–4.32; $P<0.001$) versus RHEG and 1.79% (95% *CI*: 0.95–2.63; $P<0.0001$) versus Baseline. These improvements corresponded to meaningful reductions in negative attitudes: *RRR* was 28.60% (95% *CI*: 19.76–37.38; $P<0.001$) versus RHEG and 17.85% (95% *CI*: 9.48–26.22; $P<0.0001$) versus Baseline. The *RR* of negative attitudes decreased to 0.71 (95% *CI*: 0.65–0.78; $P<0.001$) versus RHEG and 0.82 (95% *CI*: 0.76–0.89; $P<0.0001$) versus Baseline. Consequently, SHEP provided protective effects against unfavorable attitudes that were 1.40-fold (1/*RR*, 95% *CI*: 1.28–1.54; $P<0.001$) and 1.22-fold (1/*RR*, 95% *CI*: 1.12–1.32; $P<0.0001$) stronger than RHEG and Baseline, respectively (Table 2 and Supplementary Table S3, available at https://weekly.chinacdc.cn/). Conversely, RHEG showed significant

TABLE 1. Knowledge rates from Baseline, SHEPG, and RHEG; *ARR*, *RRR*, *RR*, and *1/RR* between SHEPG and RHEG after the 12-month follow-up, 2023–2024.

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	CHEG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
					95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
Q1. Have you heard of echinococcosis?	Yes (correct)	93.89 (2,535/2,700)	96.87 (989/1,021)	90.97 (846/930)	5.90 (3.56, 8.24)	<0.001	65.33 (39.41, 91.24)	<0.001				
	No	3.96 (107/2,700)	0.59 (6/1,021)	4.95 (46/930)	4.36 (3.07, 5.65)	<0.001	88.08 (72.96, 95.04)	<0.001	0.12 (0.05, 0.28)	<0.001	8.47 (3.57, 20.08)	<0.001
	Not sure	2.15 (58/2,700)	2.55 (26/1,021)	4.09 (38/930)	1.54 (0.19, 2.89)	0.026	37.65 (3.59, 61.52)	0.026	0.62 (0.38, 1.02)	0.058	1.61 (0.98, 2.63)	0.058
Q2. How do people get echinococcosis?	Get infected if they accidentally ingest worm eggs excreted by dogs or foxes (correct)	66.33 (1,791/2,700)	71.69 (732/1,021)	66.92 (615/919)†	4.77 (0.90, 8.64)	0.016	14.43 (2.73, 26.14)	0.016				
	By eating unclean internal organs of cattle or sheep	29.67 (801/2,700)	27.23 (278/1,021)	30.47 (280/919)†	3.24 (−0.57, 7.05)	0.095	14.43 (2.73, 26.14)	0.016	0.89 (0.78, 1.03)	0.126	1.12 (0.97, 1.28)	0.126
	Human-to-human	4.00 (108/2,700)	1.08 (11/1,021)	2.61 (24/919)†	1.53 (0.41, 2.65)	0.007	58.62 (17.30, 79.86)	0.007	0.41 (0.21, 0.83)	0.013	2.44 (1.20, 4.76)	0.013
Q3. How do dogs get infected with *Echinococcus*?	By consuming the diseased internal organs of cattle or sheep (correct)	93.03 (1,976/2,124)†	98.53 (1,006/1,021)	96.34 (896/930)	2.19 (0.87, 3.51,)	0.001	59.46 (23.64, 95.28)	0.001				
	Dog-to-dog	6.50 (138/2,124)†	0.98 (10/1,021)	2.15 (20/930)	1.17 (0.20, 2.14)	0.018	54.42 (5.26-79.63)	0.018	0.45 (0.22-0.95)	0.036	2.22 (1.05-4.55)	0.036
	Human-to-dog	0.47 (10/2,124)†	0.49 (5/1,021)	1.51 (14/930)	1.02 (0.22, 1.82)	0.012	67.55 (12.33, 87.80)	0.012	0.32 (0.12, 0.88)	0.028	3.13 (1.14, 8.33)	0.028
Q4. Are you aware of the national policies for echinococcosis patients?	Fully aware (correct)	43.85 (1,184/2,700)	73.16 (747/1,021)	49.13 (450/916)†	24.03 (20.32, 27.74)	<0.001	47.30 (39.98, 54.61)	<0.001				
	Partially aware	46.33 (1,251/2,700)	25.86 (264/1,021)	41.48 (380/916)†	15.62 (11.48, 19.76)	<0.001	37.66 (27.68, 47.63)	<0.001	0.62 (0.55, 0.71)	<0.001	1.60 (1.41, 1.82)	<0.001
	Not aware	9.81 (265/2,700)	0.98 (10/1,021)	9.39 (86/916)†	8.41 (6.73, 10.09)	<0.001	89.56 (82.71, 94.99)	<0.001	0.10 (0.05, 0.20)	<0.001	9.58 (5.01, 18.33)	<0.001

Continued

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	CHEG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
					95% CI	*P*	*95% CI*	*P*	*95% CI*	*P*	*95% CI*	*P*
Q5. Is deworming dogs a preventive measure for echinococcosis?	Yes (correct)	96.96 (2,618/2,700)	99.80 (1,019/1,021)	95.46 (799/837)†	4.34 (2.92, 5.76)	<0.001	95.45 (64.10, 126.80)	<0.001				
	No	1.56 (42/2,700)	0.00 (0/1,021)	2.03 (17/837)†	2.03 (1.01, 3.05)	<0.001	100.00 (58.04, 100.00)*	<0.001	0.05 (0.00, 0.79)*	0.033	19.61 (1.27, ∞)*	0.033
	Not sure	1.48 (40/2,700)	0.20 (2/1,021)	2.51 (21/837)†	2.31 (1.30, 3.32)	<0.001	92.03 (67.18, 98.48)	<0.001	0.08 (0.02, 0.33)	<0.001	12.82 (3.03, 50.00)	<0.001
Q6. Is the safe disposal (deep burial) of dog feces a preventive measure for echinococcosis?	Yes (correct)	90.70 (2,449/2,700)	93.83 (958/1,021)	89.35 (831/930)	4.48 (2.16, 6.80)	<0.001	42.11 (20.32, 63.90)	<0.001				
	No	5.15 (139/2,700)	4.80 (49/1,021)	4.19 (39/930)	−0.61 (−2.46, 1.24)	0.518	−14.56 (−71.49, 42.37)	0.518	1.15 (0.77, 1.71)	0.498	0.87 (0.58, 1.30)	0.498
	Not sure	4.15 (112/2,700)	1.37 (14/1,021)	6.45 (60/930)	5.08 (3.55, 6.61)	<0.001	78.76 (63.45, 88.12)	<0.001	0.21 (0.12, 0.37)	<0.001	4.76 (2.70, 8.33)	<0.001
Q7. Is not feeding raw livestock internal organs to dogs a preventive measure for echinococcosis?	Yes (correct)	90.74 (2,450/2,700)	92.26 (942/1,021)	86.56 (805/930)	5.70 (3.10, 8.30)	<0.001	42.54 (23.13, 61.94)	<0.001				
	No	6.26 (169/2,700)	6.95 (71/1,021)	6.02 (56/930)	−0.93 (−3.24, 1.38)	0.430	−15.45 (−53.76, 22.86)	0.430	1.15 (0.77, 1.71, 0.498)	0.498	0.87 (0.58, 1.30)	0.498
	Not sure	3.00 (81/2,700)	0.78 (8/1,021)	7.42 (69/930)	6.64 (4.96, 8.32)	<0.001	89.49 (78.22, 94.97)	<0.001	0.11 (0.05, 0.22)	<0.001	9.09 (4.55, 20.00)	<0.001
Q8. Is not playing with dogs a preventive measure for echinococcosis?	Yes (correct)	93.30 (2,519/2,700)	96.57 (986/1,021)	90.32 (840/930)	6.25 (4.17, 8.33)	<0.001	64.52 (43.02, 86.02)	<0.001				
	No	4.04 (109/2,700)	2.84 (29/1,021)	4.84 (45/930)	2.00 (0.41, 3.59)	0.014	41.32 (8.97, 62.45)	0.014	0.59 (0.38, 0.91)	0.018	1.70 (1.10, 2.63)	0.018
	Not sure	2.67 (72/2,700)	0.59 (6/1,021)	4.84 (45/930)	4.25 (2.85, 5.65)	<0.001	87.81 (71.43, 94.74)	<0.001	0.12 (0.05, 0.27)	<0.001	8.26 (3.70, 20.00)	<0.001

Continued

Question	Response	Baseline [% (n/N)]	SHEPG [% (n/N)]	CHEG [% (n/N)]	ARR 95% CI	ARR P	RRR 95% CI	RRR P	RR 95% CI	RR P	1/RR 95% CI	1/RR P
Q9. Is washing hands before meals a preventive measure for echinococcosis?	Yes (correct)	96.56 (2,607/2,700)	99.41 (1,015/1,021)	90.65 (843/930)	8.76 (6.92, 10.60)	<0.001	93.75 (74.07, 113.44)	<0.001				
	No	1.22 (33/2,700)	0.49 (5/1,021)	5.16 (48/930)	4.67 (3.22, 6.12)	<0.001	90.50 (77.91, 96.15)	<0.001	0.09 (0.04, 0.23)	<0.001	11.11 (4.35, 25.00)	<0.001
	Not sure	2.22 (60/2,700)	0.10 (1/1,021)	4.19 (39/930)	4.09 (2.94, 5.24)	<0.001	97.61 (85.00, 99.85)	<0.001	0.02 (0.00, 0.15)	<0.001	50.00 (6.67, ∞)*	<0.001
Total (Q1–Q9)	Yes (correct)	84.85 (20,129/23,724)	91.35 (8,394/9,189)	84.57 (6,925/8,252)	6.78 (5.95, 7.61)	<0.001	43.92 (40.23, 47.61)	<0.001				
	Other responses (incorrect)	15.15 (3,595/23,724)	8.65 (795/9,189)	15.43 (1,327/8,252)	6.78 (5.95, 7.61)	<0.002	43.92 (40.23, 47.61)	<0.001	0.55 (0.51, 0.59)	<0.001	1.82 (1.70, 1.96)	<0.001

Abbreviation: *ARR*=absolute risk reduction; *RR*=relative risk; *RRR*=relative risk reduction; 1/*RR*=protective efficacy; *CI*=confidence interval; SHEPG=smart health education pillbox group; RHEG =routine health education group.

*For cells containing zero counts (Q5-No, Q9-Not sure), the Haldane-Anscombe correction was implemented by adding 0.5 to each cell. The *RRR* for Q5-No was set at 100% when the intervention group risk equaled 0; the corresponding *CI* was calculated using this correction.

†All responses were considered valid except for 576 logical errors in Q3 at baseline and 11, 14, and 93 logical errors in Q2, Q4, and Q5 in RHEG, respectively.

Note: Chi-square tests were employed for all comparisons; however, Fisher's exact test was applied when the expected frequency of any cell fell below 5. Blank cells indicate values that were not calculated (with no need for calculation).

TABLE 2. Attitude rates from Baseline, SHEPG, and RHEG; *ARR*, *RRR*, *RR*, and 1/*RR* between SHEPG and RHEG after the 12-month follow-up, 2023–2024.

Question	Response	Baseline [% (n/N)]	SHEPG [% (n/N)]	CHEG [% (n/N)]	ARR 95% CI	ARR P	RRR 95% CI	RRR P	RR 95% CI	RR P	1/RR 95% CI	1/RR P
Q1. Would you like to wash your hands before meals?	Yes	97.30 (2,627/2,700)	98.33 (1,004/1,021)	97.74 (909/930)	0.59 (−0.49, 1.67)	0.288	25.93 (−21.67, 73.52)	0.288				
	No	2.70 (73/2,700)	1.67 (17/1,021)	2.26 (21/930)	0.59 (−0.49, 1.67)	0.288	26.11 (−21.74, 73.96)	0.288	0.74 (0.40, 1.37)	0.336	1.35 (0.73, 2.50)	0.336
Q2. Would you agree to tether all your dogs?	Yes	95.63 (2,582/2,700)	97.16 (992/1,021)	95.94 (803/837)*	1.22 (−0.40, 2.84)	0.137	29.76 (−9.76, 69.29)	0.137				
	No	4.37 (118/2,700)	2.84 (29/1,021)	4.06 (34/837)*	1.22 (−0.40, 2.84)	0.137	30.05 (−9.85, 69.95)	0.137	0.70 (0.44, 1.12)	0.139	1.43 (0.89, 2.27)	0.139
Q3. Would you agree to free regular dog deworming?	Yes	97.22 (2,625/2,700)	98.82 (1,009/1,021)	98.17 (913/930)*	0.65 (−0.47, 1.77)	0.208	35.71 (−25.81, 97.22)	0.208				
	No	2.78 (75/2,700)	1.18 (12/1,021)	1.83 (17/930)	0.65 (−0.47, 1.77)	0.208	35.52 (−25.81, 97.22)	0.208	0.64 (0.32, 1.30)	0.218	1.56 (0.77, 3.13)	0.218
Q4. Would you agree to bury dog waste deeply after deworming?	Yes	92.70 (2,503/2,700)	96.38 (984/1,021)	92.95 (778/837)*	3.43 (1.37, 5.49)	<0.001	48.57 (19.42, 77.72)	<0.001				
	No	7.30 (197/2,700)	3.62 (37/1,021)	7.05 (59/837)*	3.43 (1.37, 5.49)	<0.001	48.65 (19.42, 77.72)	<0.001	0.51 (0.35, 0.75)	<0.001	1.96 (1.33, 2.86)	<0.001
Q5. Would you support centralized slaughter?	Yes	49.74 (939/1,888)*	61.76 (533/863)*	50.32 (419/852)*	11.44 (6.30, 16.58)	<0.001	22.73 (12.52, 32.94)	<0.001				
	No	50.26 (949/1,888)*	38.24 (330/863)*	49.68 (433/852)*	11.44 (6.30, 16.58)	<0.001	23.03 (12.68, 33.33)	<0.001	0.77 (0.69, 0.86)	<0.001	1.30 (1.16, 1.45)	<0.001

Continued

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	CHEG [% (*n*/*N*)]	ARR 95% *CI*	ARR *P*	RRR 95% *CI*	RRR *P*	RR 95% *CI*	RR *P*	1/RR 95% *CI*	1/RR *P*
Q6. Would you agree to free lamb vaccination?	Yes	87.16 (1, 147/1, 316)*	88.02 (507/576)*	86.81 (553/637)*	1.21 (−2.78, 5.20)	0.490	8.75 (−20.08, 37.58)	0.490				
	No	12.84 (169/1, 316)*	11.98 (69/576)*	13.19 (84/637)*	1.21 (−2.78, 5.20)	0.490	9.17 (−21.08, 39.42)	0.490	0.91 (0.68, 1.21)	0.509	1.10 (0.83, 1.47)	0.509
Q7. Would you avoid feeding dogs raw livestock organs?	Yes	86.86 (1, 342/1, 545)*	90.70 (634/699)*	85.53 (668/781)*	5.17 (1.66, 8.68)	0.001	35.71 (11.46, 59.96)	0.001				
	No	13.14 (203/1, 545)*	9.30 (65/699)*	14.47 (113/781)*	5.17 (1.66, 8.68)	0.001	35.73 (11.46, 59.96)	0.001	0.64 (0.49, 0.84)	0.001	1.56 (1.19, 2.04)	0.001
Q8. Would you agree to free regular check-ups (screening)?	Yes	98.26 (2, 653/2,700)	98.33 (1, 004/1,021)	98.28 (914/930)	0.05 (−0.91, 1.01)	0.901	2.78 (−50.00, 55.56)	0.901				
	No	1.74 (47/2,700)	1.67 (17/1,021)	1.72 (16/930)	0.05 (−0.91, 1.01)	0.901	2.91 (−55.56, 55.56)	0.901	0.97 (0.50, 1.88)	0.929	1.03 (0.53, 1.99)	0.929
Q9. Would you use our Smart Health Education Pillbox?	Yes	N/A	89.72 (916/1,021)**	N/A	N/A		N/A		N/A		N/A	
	No	N/A	10.28 (105/1,021)**	N/A	N/A		N/A		N/A		N/A	
Total (Q1-8)	Yes	89.97 (16, 418/18, 249)	91.76 (7, 583/8, 264)	88.46 (5, 957/6, 734)	3.30 (2.28, 4.32)	<0.001	28.57 (19.76, 37.38)	<0.001				
	No	10.03 (1, 831/18, 249)	8.24 (681/8, 264)	11.54 (777/6, 734)	3.30 (2.28, 4.32)	<0.001	28.60 (19.76, 37.38)	<0.001	0.71 (0.65, 0.78)	<0.001	1.40 (1.28, 1.54)	<0.001

Note: Chi-square tests were applied for all comparisons; however, Fisher's exact test was employed when the expected frequency of any cell fell below 5. Blank cells indicate "not calculated (with no need for calculation)".

Abbreviation: *ARR*=absolute risk reduction; *RR*=relative risk; *RRR*=relative risk reduction; 1/*RR*=protective efficacy; *CI*=confidence interval; SHEPG=smart health education pillbox group; RHEG=routine health education group; N/A=not applicable.

* *N*=2,700 at baseline. At the one-year follow-up, SHEPG (*N*=1,021) and RHEG (*N*=930). Valid response counts in RHEG for Q2 and Q4 totaled 837. For Q5, valid response counts among households raising livestock were 1,888,863, and 852 across the three groups, respectively; for Q6, among households raising sheep, counts were 1,316,576, and 637, respectively; for Q7, among households raising livestock, counts were 1,545,699, and 781, respectively.

** The attitude survey regarding SHEP usage was administered exclusively in the SHEPG.

TABLE 3. Practice rates from Baseline, SHEPG, and RHEG; *ARR*, *RRR*, *RR*, and *1/RR* between SHEPG and RHEG after the 12-month follow-up, 2023–2024.

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	CHEG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
					95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
1. Do you wash your hands before meals?	Three times a day or more (correct)	53.89 (1, 455/2,700)	59.94 (612/1,021)	54.73 (509/930)	5.21 (1.37, 9.05)	0.015	11.52 (3.03, 20.01)	0.015				
	1-2 times a day (partly)	23.96 (6, 47/2,700)	27.13 (277/1,021)	24.95 (232/930)	−2.18 (−6.35, 1.99)	0.250	−8.74 (−25.45, 7.97)	0.250	1.09 (0.94, 1.26)	0.250	0.92 (0.79, 1.07)	0.250
	Occasionally (incorrect)	22.15 (598/2,700)	12.93 (132/1,021)	20.32 (189/930)	7.39 (4.35, 10.43)	<0.001	36.36 (21.41, 51.33)	<0.001	0.64 (0.52-0.78, *P*<0.001)		1.57 (1.28, 1.92)	<0.001
2. How is your dog typically restrained?	Always tethered (correct)	27.89 (753/2,700)	31.73 (324/1,021)	28.84 (265/919)	2.89 (−0.97, 6.75)	0.150	4.06 (−1.36, 9.49)	0.150				
	Tethered during the day, free at night (partly)	14.96 (404/2,700)	13.22 (135/1,021)	14.79 (136/919)	1.57 (−2.18, 5.32)	0.330	10.62 (−14.74, 35.97)	0.330	0.89 (0.72, 1.11)	0.300	1.12 (0.90, 1.39)	0.300
	Tethered in settlements, free during migration (partly)	47.78 (1, 290/2,700)	48.09 (491/1,021)	48.42 (445/919)	0.33 (−3.69, 4.35)	0.900	0.68 (−7.62, 8.98)	0.900	0.99 (0.90, 1.10)	0.90	1.01 (0.91, 1.11)	0.900
	Never tethered (incorrect)	9.37 (253/2,700)	6.95 (71/1,021)	7.94 (73/919)	0.99 (−1.30, 3.28)	0.400	12.47 (−16.37, 41.31)	0.400	0.87 (0.65, 1.18)	0.380	1.15 (0.85, 1.55)	0.380
3. Do you often pet or hug your dog?	Never (correct)	8.24 (175/2, 124)	10.19 (104/1,021)	9.25 (86/930)	0.94 (−1.96, 3.84)	0.480	1.04 (−2.16, 4.23)	0.480				
	Occasionally (partly)	53.95 (1, 146/2, 124)	52.69 (538/1,021)	53.01 (493/930)	0.32 (−3.71, 4.35)	0.880	0.60 (−7.00, 8.21)	0.880	0.99 (0.91, 1.09)	0.880	1.01 (0.92, 1.10)	0.880
	Often (incorrect)	37.81 (803/2, 124)	37.12 (379/1,021)	37.74 (351/930)	0.62 (−3.73, 4.97)	0.750	1.64 (−9.88, 13.17)	0.750	0.98 (0.87, 1.11)	0.750	1.02 (0.90, 1.15)	0.750
4. Do you deworm your dog regularly?	Yes (correct; 9-12 times/yr)	61.00 (1, 647/2,700)	91.38 (933/1,021)	59.89 (557/930)	31.49 (28.17, 34.81)	<0.001	78.57 (70.15, 86.99)	<0.001				
	Frequently (4-8 times/yr) (partly)	18.11 (489/2,700)	7.44 (76/1,021)	16.88 (157/930)	9.44 (6.67-12.21, *P*)	<0.001	55.92 (39.51, 72.34)	<0.001	0.44 (0.34, 0.57)	<0.001	2.27 (1.75, 2.94)	<0.001
	Occasionally (1-3 times/year) (partly)	17.19 (464/2,700)	0.69 (7/1,021)	20.65 (192/930)	19.96 (18.06, 21.86)	<0.001	96.66 (87.48, 105.83)	<0.001	0.03 (0.02, 0.07)	<0.001	33.33 (14.29, 50.00)	<0.001
	Never dewormed (incorrect)	3.70 (100/2,700)	0.49 (5/1,021)	2.58 (24/930)	2.09 (1.10, 3.08)	<0.001	81.01 (42.64, 119.38)	<0.001	0.19 (0.07, 0.50)	<0.001	5.26 (2.00, 14.29)	<0.001
5. Do you properly dispose of your dog's waste after deworming?	Yes (correct; deep burial)	51.04 (1, 378/2,700)	54.65 (558/1,021)	51.73 (433/837)	2.92 (−1.34, 7.18)	0.180	6.06 (−2.78, 14.91)	0.180				
	Occasionally (partly)	21.81 (589/2,700)	25.17 (257/1,021)	21.39 (179/837)	−3.78 (−7.80, 0.24)	0.052	−17.67 (−36.46, 1.12)	0.052	1.18 (1.00, 1.39)	0.052	0.85 (0.72, 1.00)	0.052
	Untreated (incorrect)	27.15 (733/2,700)	20.18 (206/1,021)	26.88 (225/837)	6.70 (2.51, 10.89)	<0.001	24.93 (9.34, 40.52)	<0.001	0.75 (0.64, 0.88)	<0.001	1.33 (1.14, 1.56)	<0.001

Continued

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	CHEG [% (*n*/*N*)]	ARR 95% *CI*	ARR *P*	RRR 95% *CI*	RRR *P*	RR 95% *CI*	RR *P*	1/RR 95% *CI*	1/RR *P*
6. Do you often slaughter cattle and sheep at home?	No (correct)	18.17 (343/1, 888)*	19.00 (164/863)*	17.72 (151/852)*	1.28 (−2.97, 5.53)	0.480	7.22 (−16.76, 31.21)	0.480				
	Yes (incorrect)	81.83 (1, 545/1, 888)*	81.00 (699/863)*	82.28 (701/852)*	1.28 (−2.97, 5.53)	0.480	1.56 (−3.61, 6.72)	0.480	0.98 (0.94, 1.03)	0.480	1.02 (0.97, 1.06)	0.480
7. Do you feed the internal organs of the cattle and sheep to dogs?	Never (correct)	61.04 (943/1, 545)*	67.81 (474/699)*	60.95 (476/781)*	6.86 (2.06, 11.66)	0.006	17.62 (5.29, 29.95)	0.006				
	Occasionally (partly)	25.18 (389/1, 545)*	22.03 (154/699)*	25.74 (201/781)*	3.71 (−0.70, 8.12)	0.100	14.41 (−2.72, 31.54)	0.100	0.86 (0.71, 1.03)	0.100	1.17 (0.97, 1.41)	0.100
	Frequently (incorrect)	13.79 (213/1, 545)*	10.16 (71/699)*	13.32 (104/781)*	3.16 (−0.63, 6.95)	0.064	23.72 (−4.73, 52.18)	0.064	0.76 (0.58, 1.01)	0.058	1.32 (0.99, 1.72)	0.058
8. Are your lambs vaccinated regularly?	Regularly (correct)	55.02 (724/1, 316)*	55.21 (318/576)*	54.79 (349/637)*	0.42 (−4.86, 5.70)	0.890	0.93 (−10.71, 12.57)	0.890				
	Irregularly (partly)	25.23 (332/1, 316)*	27.60 (159/576)*	26.06 (166/637)*	−1.54 (−6.66, 3.58)	0.560	−5.91 (−25.56, 13.74)	0.560	1.06 (0.88, 1.27)	0.560	0.94 (0.79, 1.14)	0.560
	No (incorrect)	19.76 (260/1, 316)*	17.19 (99/576)*	19.15 (122/637)*	1.96 (−2.38, 6.30)	0.37	10.24 (−12.43, 32.91)	0.37	0.90 (0.71, 1.14)	0.37	1.11 (0.88, 1.41)	0.37
9. Do you regularly participate in echinococcosis screening?	Regularly (correct)	73.30 (1, 979/2,700)	86.68 (885/1,021)	74.30 (691/930)	12.38 (9.16, 15.60)	<0.001	48.15 (35.67, 60.63)	<0.001				
	Irregularly (partly)	24.04 (649/2,700)	12.83 (131/1,021)	24.84 (231/930)	12.01 (8.81, 15.21)	<0.001	48.35 (35.47, 61.23)	<0.001	0.52 (0.43, 0.62)	<0.001	1.92 (1.61, 2.33)	<0.001
	No (incorrect)	2.67 (72/2,700)	0.49 (5/1,021)	0.86 (8/930)	0.37 (−0.37, 1.11)	0.32	43.02 (−43.02, 129.07)	0.320	0.57 (0.19, 1.71)	0.320	1.75 (0.59, 5.26)	0.320
Total (Q1-9)	Correct	46.12 (9, 397/20, 373)	52.90 (4, 372/8, 264)	45.40 (3, 517/7, 746)	7.50 (5.96, 9.04)	<0.001	13.74 (10.91, 16.56)	<0.001				
	Partly correct+incorrect	53.88 (10, 976/20, 373)	47.10 (3, 892/8, 264)	54.60 (4, 229/7, 746)	7.50 (5.96, 9.04)	<0.001	13.74 (10.91, 16.56)	<0.001	0.86 (0.84, 0.89)	<0.001	1.16 (1.14, 1.19)	<0.001

Note: Chi-square tests were applied for all comparisons; however, Fisher's exact test was employed when the expected frequency of any cell fell below 5. Blank cells indicate "not calculated (with no need for calculation)".

Abbreviation: *ARR*=absolute risk reduction; *RRR*=relative risk reduction; *RR*=relative risk; 1/*RR*=protective efficacy; *CI*=confidence interval; SHEPG=smart health education pillbox group; RHEG=routine health education group.

* *N*=2,700 at Baseline. At the one-year follow-up, SHEPG (*N*=1,021) and RHEG (*N*=930). Valid response counts for Q2 in RHEG totaled 919; for Q3 in Baseline, 2, 124; for Q5 in RHEG, 837. For Q6, among households raising livestock, counts across the three groups were 1, 888, 863, and 852, respectively; for Q7, among households raising livestock, counts were 1, 545, 699, and 781, respectively; for Q8, among households raising sheep, counts across the three groups were 1, 316, 576, and 637, respectively.

decline in positive attitudes (*ARR*=−1.51; 95% *CI*: −2.31 to −0.71; *P*=0.0002) with increased *RR* of 1.15 (95% *CI*: 1.07–1.24; *P*<0.0001) (Supplementary Table S4, available at https://weekly.chinacdc.cn/). SHEP acceptability among dog owners was high at 89.72% (916/1,021) (Q9, Table 2). Detailed attitude data for questions 1–8 are presented in Table 2 and Supplementary Tables S3–S4.

The questionnaire evaluated dog owners' adoption of recommended echinococcosis control practices. Correct practice rates remained low across all groups (SHEPG: 52.90%; RHEG: 45.40%; Baseline: 46.12%). SHEP intervention achieved significant improvements, with absolute increases of 7.50% over RHEG (*ARR*=7.50%, 95% *CI*: 5.96–9.04; *P*<0.001) and 6.78% over Baseline (*ARR*=6.78%, 95% *CI*: 5.35–8.21; *P*<0.001). These corresponded to relative reductions in incomplete compliance of 13.74% versus RHEG (*RRR*=13.74%, 95% *CI*: 10.91–16.56; *P*<0.001) and 12.58% versus Baseline (*RRR*=12.58%, 95% *CI*: 9.92–15.24; *P*<0.001). *RR* of "partly correct+incorrect" practices was significantly lower in SHEPG versus RHEG (*RR*=0.86, 95% *CI*: 0.84–0.89; *P*<0.001) and Baseline (*RR*=0.87, 95% *CI*: 0.85–0.90; *P*<0.001). SHEP participants were 1.16 times more likely to adopt correct practices than RHEG (1/*RR*=1.16, 95% *CI*: 1.14–1.19; *P*<0.001) and 1.15 times more likely than Baseline (1/*RR*=1.15, 95% *CI*: 1.11–1.18; *P*<0.001) (Table 3; Supplementary Table S5, available at https://weekly.chinacdc.cn/). RHEG showed no significant changes versus Baseline (*ARR*=−0.72%, 95% *CI*: −1.70 to 0.26; *P*=0.150; *RR*=1.01, 95% *CI*: 0.99–1.04; *P*=0.180). Detailed responses are in Table 3 and Supplementary Table S5–6 (available at https://weekly.chinacdc.cn/).

To quantitatively elucidate the knowledge-to-practice conversion mechanism, we developed a path model positing that knowledge (K) influences attitude (A), which shapes practices (P). Three parameters were defined: α (knowledge-to-attitude coefficient), representing attitude generated per unit knowledge (α=A/K); β (attitude-to-practice coefficient), representing practice generated per unit attitude (β=P/A); and η (conversion efficiency index), representing overall knowledge-to-practice efficiency (η=P / K=$\alpha \times \beta$). The derived formulae are: A=$\alpha \times$ K, P=$\beta \times$ A=$\beta \times \alpha \times$ K. Results demonstrated superior attitude-to-practice conversion in SHEPG, with β=0.5765 (95% *CI*: 0.5642–0.5888) significantly exceeding RHEG (0.5132, 95% *CI*: 0.4999–0.5265) and Baseline (0.5126, 95% *CI*: 0.5046–0.5206). The β differences were substantial: $\Delta\beta$=0.0633 for SHEPG versus RHEG and $\Delta\beta$=0.0639 for SHEPG versus Baseline (all *P*<0.0001). SHEPG achieved relative increases in conversion efficiency of 7.88% (0.0423/0.5368) versus RHEG and 6.55% (0.0356/0.5435) versus Baseline, demonstrating greater overall efficiency in translating knowledge into practice (all *P*<0.0001) (Table 4–5). Conversely, RHEG showed only a 1.23% (0.0067/0.5435) increase in conversion efficiency versus Baseline, which was not statistically significant (*Z*=0.799, *P*=0.424) (Table 4–5).

DISCUSSION

The SHEP represents an innovative integration of artificial intelligence and Internet of Things technologies for echinococcosis control, transitioning from RHE to precision-targeted interventions. Its core functionalities include: 1) Systematic Knowledge Delivery: Prerecorded messages broadcast at predetermined intervals (at least three times daily, exceeding 1,095 times annually) strengthen policy comprehension and promote sustained behavioral change. 2) Automated Deworming Reminders: Audio and visual alerts prompt dog owners on scheduled deworming days, enhancing compliance and reducing missed treatments. 3) Precision Targeting: Distribution specifically to dog owners — the primary target population — enables efficient, focused educational outreach and practice promotion. 4) Cultural Adaptability: Multilingual modules (Standard Chinese, Tibetan, Uyghur, Kazakh, and others) ensure accessibility across diverse endemic regions, overcoming literacy barriers through audio-based communication. 5) Technical Reliability: With six-month battery life, compact design, and portability, the platform supports continuous education during pastoral migrations and in remote pasturages, addressing "last-mile" challenges in disease control programs. 6) Dedicated Bait Storage: A secure compartment protects anthelmintic baits, resolving storage challenges.

The 12-month SHEP implementation resulted in substantial improvements in echinococcosis-related knowledge. The SHEPG demonstrated significantly higher overall correct response rates compared to both RHEG and Baseline (Table 1 and Supplementary Table S1). These enhancements were particularly notable across key knowledge domains, validating SHEP's effectiveness as a persistent, interactive tool that reinforces essential health messages and surpasses the less engaging, one-time RHE. The intervention effectively dispelled misconceptions and reduced uncertainty (Table 1 and Supplementary Table S1). Additionally, SHEP demonstrated significant protective value by countering the observed decline in correct response rates on several crucial questions (e.g., Q7, Q8, Q9) within the RHEG, preventing knowledge deterioration and emergence of new misconceptions over time (Table 1 and Supplementary Table S1). Comparison of RHEG to Baseline revealed minimal knowledge improvement; the overall knowledge rate showed no statistically significant change (Table 1 and Supplementary Table S2). These findings suggest that routine, one-time health education is inadequate for consolidating and retaining complex knowledge over time and may prove ineffective against knowledge erosion or misinformation spread without sustained, reinforced messaging.

The SHEP intervention notably influenced dog owners' attitudes, as evidenced in Table 2 and Supplementary Table S3. The 3.30% increase in ARR confirmed SHEP's effectiveness in disseminating information and positively shaping behavioral intentions. The 28.57% reduction in risk of negative attitudes demonstrated that the intervention strengthened positive intentions while mitigating resistance and hesitancy (P<0.001). Significant improvements were observed in key practice-related attitudes, including proper burial of dog waste (Q4), support for centralized slaughter (Q5), and avoidance of feeding raw viscera to dogs (Q7). All changes were statistically significant (P<0.001) and critical for interrupting the parasite's transmission cycle (Table 2). Furthermore, 89.72% of SHEPG participants expressed willingness to use the smart pillbox (Q9), indicating high acceptability of this innovative technology and promising potential for large-scale implementation.

The ultimate measure of an intervention's effectiveness lies in its capacity to transform knowledge and attitudes into meaningful behavioral change. Our analysis of conversion efficiency quantified the SHEP's impact across the knowledge-attitude-practice pathway (Table 4). This study revealed a persistent disconnect between high knowledge levels (Table 1) and positive attitudes (SHEPG, 91.76%; RHEG, 88.46%; Baseline, 89.97%; Table 2), contrasted with substantially lower adoption of recommended practices (SHEPG, 52.90%; RHEG, 45.40%; Baseline, 46.12%; Table 3). This pattern underscores the challenge of bridging the *knowledge-attitude-practice gap* in health education interventions. The SHEP intervention successfully addressed this challenge, markedly enhancing participants' ability to translate positive attitudes into concrete actions. The device functioned as a behavioral facilitator, narrowing the *knowledge-attitude-practice gap* by delivering timely cues and reminders while simplifying execution of desired practices, such as adherence to deworming schedules.

This study has limitations warranting consideration. The 1-year follow-up period is brief for evaluating

TABLE 4. The K, A, P, α, β, and η across SHEPG, RHEG, and Baseline after the 12-month follow-up, 2023–2024.

Group	*K*	*A*	*P*	α (95% *CI*)	β (95% *CI*)	η (95% *CI*)
SHEPG	0.9135	0.9176	0.5290	1.0045 (0.9954, 1.0136)	0.5765 (0.5642, 0.5888)	0.5791(0.5668, 0.5914)
RHEG	0.8457	0.8846	0.4540	1.046 (1.0328, 1.0592)	0.5132 (0.4999, 0.5265)	0.5368 (0.5228, 0.5508)
Baseline	0.8485	0.8997	0.4612	1.0603 (1.0526, 1.0680)	0.5126 (0.5046, 0.5206)	0.5435 (0.5349, 0.5521)

Abbreviation: K=knowledge; A=attitude; P=practice; α=knowledge-to-attitude coefficient; β=attitude-to-practice coefficient; η=conversion efficiency index; *CI*=confidence interval; SHEPG=smart health education pillbox group; RHEG=routine health education group.

TABLE 5. The Δα, Δβ, and Δη across SHEPG, RHEG, and Baseline after the 12-month follow-up, 2023–2024.

Group	Δα	Z (*P*)	Δβ	Z (*P*)	Δη	Z (*P*)
SHEPG *vs*. RHEG	−0.0415	−5.08 (<0.001)	0.0633	6.85 (*P*<0.001)	0.0423	5.32 (<0.001)
SHEPG *vs*. Baseline	−0.0558	−9.21 (<0.001)	0.0639	8.53 (<0.001)	0.0356	4.87 (<0.001)
RHEG *vs*. Baseline	0.0143	1.835 (0.067)	−0.0006	−0.0758 (0.940)	0.0067	0.799 (0.424)

Note: To maintain consistency across all comparisons, data in this table are retained to four decimal places because Δβ in RHEG versus Baseline equals −0.0006.

Abbreviation: Δα=difference in knowledge-to-attitude conversion coefficients between groups; Δβ=difference in attitude-to-practice conversion coefficients between groups; Δη=difference in conversion efficiency index between groups; Z=Z-test statistic; SHEPG=smart health education pillbox group; RHEG=routine health education group.

long-term sustainability of behavioral changes. The outcomes relied on self-reported data, susceptible to social desirability bias, recall bias, and cultural influences. Additionally, SHEP effectiveness may be constrained by inadequate internet connectivity in remote pastoral areas. Future research should prioritize scaling up the SHEP intervention and integrating it with complementary veterinary and public health measures to achieve synergistic effects in echinococcosis control.

In conclusion, the SHEP's demonstrated efficacy and high acceptability among dog owners support its integration into national public health strategies for sustainable control of echinococcosis and other zoonotic diseases.

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SUPPLEMENTARY MATERIALS

SUPPLEMENTARY TABLE S1. Knowledge rates, *ARR*, *RRR*, *RR*, and 1/*RR* comparing SHEPG with Baseline after 12-month follow-up, 2023-2024.

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
				95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
Q1. Have you heard of echinococcosis?	Yes (correct)	93.89 (2,535/2,700)	96.87 (989/1,021)	2.98 (1.33, 4.63)	<0.001	49.02 (21.87, 76.16)	<0.001				
	No	3.96 (107/2,700)	0.59 (6/1,021)	3.37 (2.40, 4.34)	<0.001	85.10 (73.89, 96.31)	<0.001	0.15 (0.07, 0.33)	<0.001	6.76 (3.03, 15.09)	<0.001
	Not sure	2.15 (58/2,700)	2.55 (26/1,021)	−0.40 (−1.48, 0.68)	0.466	−18.60 (−68.84, 31.63)	0.466	1.19 (0.74, 1.89)	0.481	0.84 (0.53, 1.35)	0.481
Q2. How do people get echinococcosis?	Get infected if they accidentally ingest worm eggs excreted by dogs or foxes (correct)	66.33 (1,791/2,700)	71.69 (732/1,021)	5.36 (2.29, 8.43)	<0.001	15.94 (6.81, 25.07)	<0.001				
	By eating unclean internal organs of cattle or sheep	29.67 (801/2,700)	27.23 (278/1,021)	2.44 (0.60, 5.48)	0.116	8.22 (2.02, 18.43)	0.116	0.92 (0.82, 1.03)	0.144	0.92 (0.82, 1.03)	0.144
	Human-to-human	4.00 (108/2,700)	1.08 (11/1,021)	2.92 (1.93, 3.91)	<0.001	73.00 (48.25, 97.75)	<0.001	0.27 (0.15, 0.50)	<0.001	3.70 (2.00, 6.67)	<0.001
Q3. How do dogs get infected with echinococcus?	By consuming the diseased internal organs of cattle or sheep (correct)	93.03 (1976/2,124)**	98.53 (1006/1,021)	5.50 (3.87, 7.13)	<0.001	78.57 (55.29, 101.86)	<0.001				
	Dog-to-dog	6.50 (138/2,124)**	0.98 (10/1,021)	5.52 (4.41, 6.63)	<0.001	84.92 (67.92, 101.92)	<0.001	0.15 (0.08, 0.29)	<0.001	6.67 (3.45, 12.82)	<0.001
	Human-to-dog	0.47 (10/2,124)**	0.49 (5/1,021)	−0.02 (−0.69, 0.65)	0.951	−4.26 (−138.30, 146.81)	0.951	1.04 (0.36, 3.03)	0.943	0.96 (0.33, 2.78)	0.943
Q4. Are you aware of the national policies for echinococcosis patients?	Fully aware (correct)	43.85 (1,184/2,700)	73.16 (747/1,021)	29.31 (25.87-32.75,)	<0.001	52.20 (46.11-58.30,)	<0.001				
	Partially aware	46.33 (1,251/2,700)	25.86 (264/1,021)	20.47 (16.93, 24.01)	<0.001	44.18 (36.54, 51.82)	<0.001	0.56 (0.50, 0.62)	<0.001	1.79 (1.61, 1.99)	<0.001
	Not aware	9.81 (265/2,700)	0.98 (10/1,021)	8.83 (7.28, 10.38)	<0.001	90.01 (84.13, 95.89)	<0.001	0.10 (0.05, 0.19)	<0.001	10.01 (5.26, 19.05)	<0.001
Q5. Is deworming dogs a preventive measure for echinococcosis?	Yes (correct)	96.96 (2,618/2,700)	99.80 (1,019/1,021)	2.84 (1.73, 3.95)	<0.001	91.18 (55.91, 126.45)	<0.001				
	No	1.56 (42/2,700)	0.00 (0/1,021)	1.56 (0.79, 2.33)	<0.001	100.00 (58.04, 100.00)*	<0.001	0.05 (0.00, 0.79)*	0.033	19.61 (1.27, ∞)*	0.033
	Not sure	1.48 (40/2,700)	0.20 (2/1,021)	1.28 (0.68, 1.88)	*P*<0.001	86.49 (45.95, 100.00)	<0.001	0.13 (0.03, 0.54)	0.005	7.69 (1.85, 33.33)	0.005

Continued

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
				95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
Q6. Is the safe disposal (deep burial) of dog feces a preventive measure for echinococcosis?	Yes (correct)	90.70 (2, 449/2,700)	93.83 (958/1,021)	3.13 (1.29, 4.97)	<0.001	33.69 (13.89, 53.49)	<0.001				
	No	5.15 (139/2,700)	4.80 (49/1,021)	0.35 (−1.02, 1.72)	0.616	6.80 (−46.61, 33.01)	0.616	0.93 (0.68, 1.28)	0.674	1.08 (0.78, 1.48)	0.674
	Not sure	4.15 (112/2,700)	1.37 (14/1,021)	2.78 (1.83, 3.73)	<0.001	66.99 (44.10, 89.88)	<0.001	0.33 (0.19, 0.57)	<0.001	3.03 (1.75, 5.26)	<0.001
Q7. Is not feeding raw livestock internal organs to dogs a preventive measure for echinococcosis?	Yes (correct)	90.74 (2, 450/2,700)	92.26 (942/1,021)	1.52 (−0.47, 3.51)	0.134	16.36 (−5.06, 37.78)	0.134				
	No	6.26 (169/2,700)	6.95 (71/1,021)	−0.69 (−2.48, 1.10)	0.450	−11.02 (−17.58, 39.62)	0.450	1.11 (0.85, 1.45)	0.442	0.90 (0.69, 1.18)	0.442
	Not sure	3.00 (81/2,700)	0.78 (8/1,021)	2.22 (1.37, 3.07)	<0.001	74.00 (45.67, 100.00)	<0.001	0.26 (0.13, 0.52)	<0.001	3.85 (1.92, 7.69)	<0.001
Q8. Is not playing with dogs a preventive measure for echinococcosis?	Yes (correct)	93.30 (2, 519/2,700)	96.57 (986/1,021)	3.27 (1.79-4.75, *P*)	<0.001	48.96 (26.79-71.13, *P*)	<0.001				
	No	4.04 (109/2,700)	2.84 (29/1,021)	1.20 (0.08, 2.32)	0.036	29.70 (1.98, 57.42)	0.036	0.70 (0.47, 1.05)	0.084	1.42 (0.95, 2.13)	0.084
	Not sure	2.67 (72/2,700)	0.59 (6/1,021)	2.08 (1.29, 2.87)	<0.001	77.90 (48.31, 100.00)	<0.001	0.22 (0.10, 0.49)	<0.001	4.55 (2.04, 10.00)	<0.001
Q9. Is washing hands before meals a preventive measure for echinococcosis?	Yes (correct)	96.56 (2, 607/2,700)	99.41 (1, 015/1,021)	2.85 (1.73, 3.97)	<0.001	81.82 (49.72, 113.92)	<0.001				
	No	1.22 (33/2,700)	0.49 (5/1,021)	0.73 (0.08, 1.38)	0.028	59.84 (6.56, 100.00)	0.028	0.40 (0.16, 1.02)	0.055	2.50 (0.98, 6.25)	0.055
	Not sure	2.22 (60/2,700)	0.10 (1/1,021)	2.12 (1.48, 2.76)	<0.001	95.50 (66.67, 100.00)	<0.001	0.04 (0.01, 0.29)	<0.001	25.00 (3.45, 100.00)*	<0.001
Total (Q1-9)	Yes (correct)	84.85 (20, 129/23, 724)	91.35 (8, 394/9, 189)	6.50 (5.71, 7.29)	<0.001	42.97 (39.38, 46.56)	<0.001				
	Other responses (incorrect)	15.15 (3, 595/23, 724)	8.65 (795/9, 189)	6.50 (5.71, 7.29)	<0.001	42.97 (39.38, 46.56)	<0.001	0.57 (0.53, 0.61)	<0.001	1.75 (1.64, 1.88)	<0.001

Note: Chi-square tests were applied for all comparisons; however, Fisher's exact test was substituted when the expected frequency in any cell fell below 5. Blank cells denote "not calculated (unnecessary)".

Abbreviation: *ARR*=absolute risk reduction; *RR*=relative risk; *RRR*=relative risk reduction; 1/*RR*=protective efficacy; *CI*=confidence interval; SHEPG=smart health education pillbox group; RHEG=routine health education group.

*For cells containing zero counts (Q5-No, Q9-Not sure), the Haldane-Anscombe correction was implemented by adding 0.5 to each cell. The *RRR* for Q5-No is designated as 100% when intervention group risk equals zero; the *CI* was computed using this correction.

**All responses were valid except for 576 logical errors identified in Q3 at Baseline.

SUPPLEMENTARY TABLE S2. Knowledge rates, *ARR*, *RRR*, *RR*, and 1/*RR* comparing RHEG with Baseline after 12-month follow-up, 2023-2024.

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
				95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
Q1. Have you heard of echinococcosis?	Yes (correct)	93.89 (2, 535/2,700)	90.97 (846/930)	−2.92 (−4.67, -1.17)	0.001	−47.33 (−75.66, -18.99)	0.001				
	No	3.96 (107/2,700)	4.95 (46/930)	−0.99 (−2.40, 0.42)	0.169	−25.00 (−88.10, 38.10)	0.169	1.25 (0.89, 1.75)	0.201	0.80 (0.57, 1.12)	0.201
	Not sure	2.15 (58/2,700)	4.09 (38/930)	−1.94 (−3.23, -0.65)	0.003	−90.23 (−150.70, -29.77)	0.003	1.90 (1.28, 2.83)	0.001	0.53 (0.35, 0.78)	0.001
Q2. How do people get echinococcosis?	Get infected if they accidentally ingest worm eggs excreted by dogs or foxes (correct)	66.33 (1, 791/2,700)	66.92 (615/919)*	0.59 (−2.76, 3.94)	0.730	1.75 (−8.20, 11.70)	0.730				
	By eating unclean internal organs of cattle or sheep	29.67 (801/2,700)	30.47 (280/919)*	−0.80 (−3.75, 2.15)	0.595	−2.70 (−12.64, 7.24)	0.595	1.03 (0.91, 1.16)	0.642	0.97 (0.86, 1.10)	0.642
	Human-to-human	4.00 (108/2,700)	2.61 (24/919)*	1.39 (0.17, 2.61)	0.026	34.75 (4.25, 65.25)	0.026	0.65 (0.42, 1.01)	0.055	1.54 (0.99, 2.38)	0.055
Q3. How do dogs get infected with echinococcus?	By consuming the diseased internal organs of cattle or sheep (correct)	93.03 (1, 976/2, 124)*	96.34 (896/930)	3.31 (1.86, 4.76)	<0.001	47.29 (26.57, 68.00)	<0.001				
	Dog-to-dog	6.50 (138/2, 124)*	2.15 (20/930)	4.35 (3.00, 5.70)	<0.001	66.92 (46.15, 87.69)	<0.001	0.33 (0.21, 0.52)	<0.001	3.03 (1.92, 4.76)	<0.001
	Human-to-dog	0.47 (10/2, 124)*	1.51 (14/930)	−1.04 (−1.79, -0.29)	0.007	−221.28 (−380.85, -61.70)	0.007	3.21 (1.45, 7.12)	0.004	0.31 (0.14, 0.69)	0.004
Q4. Are you aware of the national policies for echinococcosis patients?	Fully aware (correct)	43.85 (1, 184/2,700)	49.13 (450/916)*	5.28 (2.29, 8.27)	<0.001	9.41 (4.08, 14.74)	<0.001				
	Partially aware	46.33 (1, 251/2,700)	41.48 (380/916)*	4.85 (1.32, 8.38)	0.007	10.46 (2.85, 18.08)	0.007	0.90 (0.82, 0.98)	0.012	1.12 (1.02, 1.22)	0.012
	Not aware	9.81 (265/2,700)	9.39 (86/916)*	0.42 (−1.68, 2.52)	0.696	4.28 (−34.15, 25.58)	0.696	0.96 (0.76, 1.21)	0.714	1.04 (0.83, 1.32)	0.714

Continued

Question	Response	Baseline [% (n/N)]	SHEPG [% (n/N)]	ARR		RRR		RR		1/RR	
				95% CI	P	95% CI	P	95% CI	P	95% CI	P
Q5. Is deworming dogs a preventive measure for echinococcosis?	Yes (correct)	96.96 (2, 618/2,700)	95.46 (799/837)*	−1.50 (−2.72, -0.28)	0.016	−48.39 (−87.10, -9.68)	0.016				
	No	1.56 (42/2,700)	2.03 (17/837)*	−0.47 (−1.52, 0.58)	0.379	−30.13 (−97.26, 37.00)	0.379	1.30 (0.74, 2.29)	0.361	0.77 (0.44, 1.35)	0.361
	Not sure	1.48 (40/2,700)	2.51 (21/837)*	−1.03 (−1.96, -0.10)	0.030	−69.59 (−132.43, -6.76)	0.030	1.70 (1.01, 2.85)	0.045	0.59 (0.35, 1.00)	0.045
Q6. Is the safe disposal (deep burial) of dog feces a preventive measure for echinococcosis?	Yes (correct)	90.70 (2449/2,700)	89.35 (831/930)	−1.35 (−3.29, 0.59)	0.173	−14.88 (−36.27, 6.52)	0.173				
	No	5.15 (139/2,700)	4.19 (39/930)	0.96 (−0.46, 2.38)	0.185	18.64 (−8.94, 46.22)	0.185	0.81 (0.58, 1.14)	0.230	1.23 (0.88, 1.72)	0.230
	Not sure	4.15 (112/2,700)	6.45 (60/930)	−2.30 (−3.85, -0.75)	0.004	−55.42 (−92.77, -18.07)	0.004	1.55 (1.16, 2.08)	0.003	0.64 (0.48, 0.86)	0.003
Q7. Is not feeding raw livestock internal organs to dogs a preventive measure for echinococcosis?	Yes (correct)	90.74 (2, 450/2,700)	86.56 (805/930)	−4.18 (−6.68, -1.68)	0.001	−45.11 (−72.07, -18.15)	0.001				
	No	6.26 (169/2,700)	6.02 (56/930)	0.24 (−1.41, 1.89)	0.775	3.83 (−37.86, 30.19)	0.775	0.96 (0.72, 1.28)	0.778	1.04 (0.78, 1.39)	0.778
	Not sure	3.00 (81/2,700)	7.42 (69/930)	−4.42 (−5.98, -2.86)	<0.001	−147.33 (−199.33, -95.33)	<0.001	2.47 (1.84, 3.32)	<0.001	0.40 (0.30, 0.54)	<0.001
Q8. Is not playing with dogs a preventive measure for echinococcosis?	Yes (correct)	93.30 (2519/2,700)	90.32 (840/930)	−2.98 (−4.83, -1.13)	0.002	−44.48 (−72.09, -16.87)	0.002				
	No	4.04 (109/2,700)	4.84 (45/930)	−0.80 (−2.22, 0.62)	0.270	−19.80 (−73.27, 33.66)	0.270	1.20 (0.86, 1.67)	0.289	0.83 (0.60, 1.16)	0.289
	Not sure	2.67 (72/2,700)	4.84 (45/930)	−2.17 (−3.53, -0.81)	0.002	−81.27 (−132.21, -30.34)	0.002	1.81 (1.27, 2.58)	0.001	0.55 (0.39, 0.79)	0.001
Q9. Is washing hands before meals a preventive measure for echinococcosis?	Yes (correct)	96.56 (2, 607/2,700)	90.65 (843/930)	−5.91 (−7.72, -4.10)	<0.001	−168.86 (−220.00, -117.71)	<0.001				
	No	1.22 (33/2,700)	5.16 (48/930)	−3.94 (−5.32, -2.56)	<0.001	−322.95 (−436.07, -209.84)	<0.001	4.23 (2.76, 6.48)	<0.001	0.24 (0.15, 0.36)	<0.001
	Not sure	2.22 (60/2,700)	4.19 (39/930)	−1.97 (−3.32, -0.62)	0.004	−88.74 (−149.55, -27.93)	0.004	1.89 (1.28, 2.78)	0.001	0.53 (0.36, 0.78)	0.001
Total (Q1-9)	Yes (correct)	84.85 (20, 129/23, 724)	84.57 (6, 925/8, 187)	−1.85 (−8.32, 4.62)	0.575	−1.84 (−10.89, 7.21)	0.691				
	Other responses (incorrect)	15.15 (3, 595/23, 724)	15.43 (1, 263/8187)	−0.28 (−1.26, 0.70)	0.575	−1.85 (−8.32, 4.62)	0.575	1.02 (0.96, 1.08)	0.569	0.98 (0.93, 1.04)	0.569

Note: Chi-square tests were employed for all comparisons; however, Fisher's exact test was applied when the expected frequency of any cell fell below 5. Blank cells denote “not calculated (with no need for)”.

Abbreviation: *ARR*=absolute risk reduction; *RR*=relative risk; *RRR*=relative risk reduction; 1/*RR*=protective efficacy; *CI*=confidence interval; SHEPG=smart health education pillbox group; RHEG =routine health education group.

* All responses were valid except for 576, 11, 14, and 93 logical errors identified in Q3 at Baseline and Q2, Q4, and Q5 in RHEG, respectively.

SUPPLEMENTARY TABLE S3. Attitude rates, *ARR*, *RRR*, *RR*, and 1/*RR* comparing SHEPG with Baseline after the 12-month follow-up, 2023-2024.

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
				95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
Q1. Would you like to wash your hands before meals?	Yes	97.30 (2, 627/2,700)	98.33 (1, 004/1,021)	1.03 (0.04, 2.02)	0.042	38.10 (1.48, 74.72)	0.042				
	No	2.70 (73/2,700)	1.67 (17/1,021)	1.03 (0.04, 2.02)	0.042	38.15 (1.48, 74.81)	0.042	0.62 (0.37, 1.04)	0.072	1.62 (0.96, 2.72)	0.072
Q2. Would you agree to tether all your dogs?	Yes	95.63 (2, 582/2,700)	97.16 (992/1,021)	1.53 (0.25, 2.81)	0.019	35.11 (5.73, 64.49)	0.019				
	No	4.37 (118/2,700)	2.84 (29/1,021)	1.53 (0.25, 2.81)	0.019	35.01 (5.72, 64.30)	0.019	0.65 (0.44, 0.97)	0.035	1.54 (1.03, 2.29)	0.035
Q3. Would you agree to free regular dog deworming?	Yes	97.22 (2, 625/2,700)	98.82 (1, 009/1,021)	1.60 (0.64, 2.56)	<0.001	57.14 (22.92, 91.36)	<0.001				
	No	2.78 (75/2,700)	1.18 (12/1,021)	1.60 (0.64, 2.56)	<0.001	57.55 (23.02, 92.08)	<0.001	0.42 (0.24, 0.75)	0.003	2.36 (1.33, 4.20)	0.003
Q4. Would you agree to bury dog waste deeply after deworming?	Yes	92.70 (2, 503/2,700)	96.38 (984/1,021)	3.68 (1.92, 5.44)	<0.001	50.00 (26.09, 73.91)	<0.001				
	No	7.30 (197/2,700)	3.62 (37/1,021)	3.68 (1.92, 5.44)	<0.001	50.41 (26.30, 74.52)	<0.001	0.50 (0.35, 0.69)	<0.001	2.02 (1.44, 2.82)	<0.001
Q5. Would you support centralized slaughter?	Yes	49.74 (939/1,888)*	61.76 (533/863)*	12.02 (7.68, 16.36)	<0.001	23.94 (15.29, 32.59)	<0.001				
	No	50.26 (949/1,888)*	38.24 (330/863)*	12.02 (7.68, 16.36)	<0.001	23.92 (15.28, 32.56)	<0.001	0.76 (0.69, 0.84)	<0.001	1.31 (1.19, 1.45)	<0.001
Q6. Would you agree to free lamb vaccination?	Yes	87.16 (1, 147/1, 316)*	88.02 (507/576)*	0.86 (−3.14, 4.86)	0.700	6.73 (−24.61, 38.07)	0.700				
	No	12.84 (169/1, 316)*	11.98 (69/576)*	0.86 (−3.14, 4.86)	0.70	6.70 (−24.45, 37.85)	0.70	0.93 (0.72, 1.21)	0.60	1.07 (0.83, 1.39)	0.60
Q7. Would you avoid feeding dogs raw livestock organs?	Yes	86.86 (1, 342/1,545)*	90.70 (634/699)*	3.84 (1.27, 6.41)	0.003	29.20 (9.66, 48.74)	0.003				
	No	13.14 (203/1,545)*	9.30 (65/699)*	3.84 (1.27, 6.41)	0.003	29.22 (9.66, 48.78)	0.003	0.71 (0.54, 0.92)	0.010	1.41 (1.08, 1.84)	0.010
Q8. Would you agree to free regular check-ups (screening)?	Yes	98.26 (2, 653/2,700)	98.33 (1, 004/1,021)	0.07 (−0.85, 0.99)	0.94	4.00 (−48.00, 56.00)	0.94				
	No	1.74 (47/2,700)	1.67 (17/1,021)	0.07 (−0.85, 0.99)	0.94	4.02 (−48.28, 56.32)	0.94	0.96 (0.55, 1.68)	0.88	1.04 (0.60, 1.82)	0.88
Q9. Would you use our Smart Health Education Pillbox?	Yes	N/A	89.72 (916/1,021)†	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	No	N/A	10.28 (105/1,021)†	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total (Q1-8)	Yes	89.97 (16, 418/18, 249)	91.76 (7, 583/8, 264)	1.79 (0.95, 2.63)	<0.001	17.86 (9.49, 26.23)	<0.001				
	No	10.03 (1, 831/18, 249)	8.24 (681/8, 264)	1.79 (0.95, 2.63)	<0.001	17.85 (9.48, 26.22)	<0.001	0.82 (0.76, 0.89)	<0.001	1.22 (1.12, 1.32)	<0.001

Note: Chi-square tests were employed for all comparisons; however, Fisher's exact test was applied when the expected frequency of any cell fell below 5. Blank cells denote “not calculated (with no need for)”.

Abbreviation: *ARR*=absolute risk reduction; *RR*=relative risk; *RRR*=relative risk reduction; 1/*RR*=protective efficacy; *CI*=confidence interval; SHEPG=smart health education pillbox group; RHEG=routine health education group; N/A=not applicable.

*At baseline (*N*=2,700) and one-year follow-up in the SHEPG (*N*=1,021), the numbers of valid responses to Q5 among households raising livestock were 1,888 and 863, respectively; for Q6 among households raising sheep, 1, 316 and 576, respectively; and for Q7 among households raising livestock, 1,545 and 699, respectively†The attitude survey regarding SHEP usage was conducted exclusively in the SHEPG.

SUPPLEMENTARY TABLE S4. Attitude rates, *ARR*, *RRR*, *RR*, and 1/*RR* comparing RHEG with Baseline after the 12-month follow-up, 2023-2024.

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
				95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
Q1. Would you like to wash your hands before meals?	Yes	97.30 (2, 627/2,700)	97.74 (909/930)	0.44 (−0.73, 1.61)	0.450	16.30 (−27.04, 59.63)	0.450				
	No	2.70 (73/2,700)	2.26 (21/930)	0.44 (−0.73, 1.61)	0.450	16.30 (−27.04, 59.63)	0.450	0.84 (0.52, 1.35)	0.470	1.19 (0.74, 1.91)	0.470
Q2. Would you agree to tether all your dogs?	Yes	95.63 (2, 582/2,700)	95.94 (803/837)*	0.31 (−1.54, 2.16)	0.740	7.14 (−35.38, 49.66)	0.740				
	No	4.37 (118/2,700)	4.06 (34/837)*	0.31 (−1.54, 2.16)	0.740	7.09 (−35.24, 49.43)	0.740	0.93 (0.64, 1.35)	0.700	1.08 (0.74, 1.56)	0.700
Q3. Would you agree to free regular dog deworming?	Yes	97.22 (2, 625/2,700)	98.17 (913/930)	0.95 (−0.02, 1.92)	0.055	34.48 (−0.72, 69.68)	0.055				
	No	2.78 (75/2,700)	1.83 (17/930)	0.95 (−0.02, 1.92)	0.055	34.17 (−0.72, 69.06)	0.055	0.66 (0.39, 1.11)	0.120	1.52 (0.90, 2.57)	0.120
Q4. Would you agree to bury dog waste deeply after deworming?	Yes	92.70 (2, 503/2,700)	92.95 (778/837)*	0.25 (−1.45, 1.95)	0.770	3.45 (−19.83, 26.72)	0.770				
	No	7.30 (197/2,700)	7.05 (59/837)*	0.25 (−1.45, 1.95)	0.770	3.42 (−19.86, 26.71)	0.770	0.97 (0.73, 1.28)	0.820	1.03 (0.78, 1.37)	0.820
Q5. Would you support centralized slaughter?	Yes	49.74 (939/1,888)*	50.36 (419/852)*	0.62 (−3.58, 4.82)	0.770	1.23 (−7.08, 9.54)	0.770				
	No	50.26 (949/1,888)*	49.64 (433/852)*	0.62 (−3.58, 4.82)	0.770	1.23 (−7.12, 9.58)	0.770	0.99 (0.90, 1.09)	0.810	1.01 (0.92- 1.11,)	0.810
Q6. Would you agree to free lamb vaccination?	Yes	87.16 (1, 147/1, 316)*	86.81 (553/637)*	−0.35 (−4.31, 3.61)	0.860	−2.73 (−33.59, 28.13)	0.860				
	No	12.84 (169/1, 316)*	13.19 (84/637)*	−0.35 (−4.31, 3.61)	0.860	−2.73 (−33.56, 28.10)	0.860	1.03 (0.80, 1.32)	0.830	0.97 (0.76, 1.25)	0.83
Q7. Would you avoid feeding dogs raw livestock organs?	Yes	86.86 (1, 342/1,545)*	85.53 (668/781)*	−1.33 (−4.74, 2.08)	0.440	−10.14 (−36.15, 15.87)	0.440				
	No	13.14 (203/1,545)*	14.47 (113/781)*	−1.33 (−4.74, 2.08)	0.440	−10.12 (−36.07, 15.82)	0.440	1.10 (0.89, 1.36)	0.380	0.91 (0.74, 1.12)	0.380
Q8. Would you agree to free regular check-ups (screening)?	Yes	98.26 (2, 653/2,700)	98.28 (914/930)	0.02 (−0.85, 0.89)	0.97	1.15 (−48.98, 51.28)	0.970				
	No	1.74 (47/2,700)	1.72 (16/930)	0.02 (−0.89, 0.85)	0.970	1.15 (−51.28, 48.98)	0.970	0.99 (0.56, 1.74)	0.970	1.01 (0.57, 1.78)	0.970
Total (Q1-8)	Yes	89.97 (16, 418/18, 249)	88.46 (5, 957/6, 734)	−1.51 (−2.31, - 0.71)	<0.001	−15.00 (−22.96, - 7.04)	<0.001				
	No	10.03 (1, 831/18, 249)	11.54 (777/6, 734)	−1.51 (−2.31, - 0.71)	<0.001	−15.06 (−23.04, - 7.08)	<0.001	1.15 (1.07, 1.24)	<0.001	0.87 (0.81, 0.93	<0.001

Note: Chi-square tests were employed for all statistical comparisons; however, Fisher's exact test was applied when the expected frequency of any cell fell below 5. Blank cells indicate values that were not calculated (and not required).

Abbreviation: *ARR*=absolute risk reduction; *RR*=relative risk; *RRR*=relative risk reduction; 1/*RR*=protective efficacy; *CI*=confidence interval; SHEPG=smart health education pillbox group; RHEG=routine health education group.

*At Baseline (*N*=2,700) and at the one-year follow-up in the RHEG (*N*=1,021), the distribution of valid responses varied by question. For questions 2 and 4 in the RHEG, 837 valid responses were recorded. For question 5, which was restricted to households raising livestock, valid responses totaled 1,888 at Baseline and 852 in the RHEG. For question 6, limited to households raising sheep, valid responses numbered 1, 316 at Baseline and 637 in the RHEG. For question 7, again restricted to households raising livestock, valid responses were 1,545 at Baseline and 781 in the RHEG.

SUPPLEMENTARY TABLE S5. Practice rates, *ARR, RRR, RR, 1/RR* between SHEPG and Baseline after the 12-month follow-up, 2023-2024.

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
				95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
1. Do you wash your hands before meals?	Three times a day or more (correct)	53.89 (1, 455/2,700)	59.94 (612/1,021)	6.05 (3.15, 8.95)	<0.001	13.12 (6.83, 19.41)	<0.001				
	1-2 times a day (partly)	23.96 (647/2,700)	27.13 (277/1,021)	−3.17 (−7.35, 1.01)	0.041	−13.23 (−30.68, 4.22)	0.041	1.13 (1.00, 1.28)	0.041	0.88 (0.78, 1.00)	0.041
	Occasionally (incorrect)	22.15 (598/2,700)	12.93 (132/1,021)	9.22 (6.18, 12.26)	<0.001	41.63 (27.90, 55.36)	<0.001	0.58 (0.49, 0.69)	<0.001	1.71 (1.45, 2.04)	<0.001
2. How is your dog typically restrained?	Always tethered (correct)	27.89 (753/2,700)	31.73 (324/1,021)	3.84 (0.77, 6.91)	0.015	5.32 (1.07, 9.58)	0.015				
	Tethered during the day, free at night (partly)	14.96 (404/2,700)	13.22 (135/1,021)	1.74 (−0.81, 4.29)	0.18	11.63 (−5.41, 28.67)	0.18	0.88 (0.74, 1.06)	0.18	1.14 (0.94, 1.35)	0.18
	Tethered in settlements, free during migration (partly)	47.78 (1, 290/2,700)	48.09 (491/1,021)	−0.31 (−3.95, 3.33)	0.87	−0.65 (−8.27, 6.97)	0.87	1.01 (0.93, 1.09)	0.87	0.99 (0.92, 1.08)	0.87
	Never tethered (incorrect)	9.37 (253/2,700)	6.95 (71/1,021)	2.42 (0.42, 4.42)	0.019	25.83 (4.48, 47.18)	0.019	0.74 (0.58, 0.95)	0.019	1.35 (1.05, 1.72)	0.019
3. Do you often pet or hug your dog?	Never (correct)	8.24 (175/2, 124)*	10.19 (104/1,021)	1.95 (−0.11, 4.01)	0.063	2.13 (−0.12, 4.37)	0.063				
	Occasionally (partly)	53.95 (1, 146/2, 124)*	52.69 (538/1,021)	1.26 (−2.54, 5.06)	0.500	2.34 (−4.71, 9.38)	0.500	0.98 (0.91, 1.05)	0.500	1.02 (0.95, 1.10)	0.500
	Often (incorrect)	37.81 (803/2, 124)*	37.12 (379/1,021)	0.69 (−3.24, 4.62)	0.730	1.82 (−8.57, 12.21)	0.730	0.98 (0.88, 1.09)	0.730	1.02 (0.92, 1.14)	0.730
4. Do you deworm your dog regularly?	Yes (correct; 9-12 times/yr)	61.00 (1, 647/2,700)	91.38 (933/1,021)	30.38 (27.06, 33.70)	<0.001	77.90 (69.38, 86.41)	<0.001				
	Frequently (4-8 times/yr) (partly)	18.11 (489/2,700)	7.44 (76/1,021)	10.67 (7.90, 13.44)	<0.001	58.92 (43.62, 74.22)	<0.001	0.41 (0.33, 0.52)	<0.001	2.44 (1.92, 3.03)	<0.001
	Occasionally (1-3 times/yr) (partly)	17.19 (464/2,700)	0.69 (7/1,021)	16.50 (14.60, 18.40)	<0.001	95.99 (84.93, 107.05)	<0.001	0.04 (0.02, 0.08)	<0.001	25.00 (12.50, 50.00)	<0.001
	Never dewormed (incorrect)	3.70 (100/2,700)	0.49 (5/1,021)	3.21 (2.22, 4.20)	<0.001	86.76 (60.00, 113.51)	<0.001	0.13 (0.05, 0.32)	<0.001	7.69 (3.13, 20.00)	<0.001
5. Do you properly dispose of your dog's waste after deworming?	Yes (correct; deep burial)	51.04 (1, 378/2,700)	54.65 (558/1,021)	3.61 (0.19, 7.03)	0.039	7.37 (0.39, 14.35)	0.039				
	Occasionally (partly)	21.81 (589/2,700)	25.17 (257/1,021)	−3.36 (−7.38, 0.66)	0.031	−15.41 (−33.84, 3.02)	0.031	1.15 (1.01, 1.31)	0.031	0.87 (0.76, 0.99)	0.031
	Untreated (incorrect)	27.15 (733/2,700)	20.18 (206/1,021)	6.97 (3.82, 10.12)	<0.001	25.67 (14.07, 7.27)	<0.001	0.74 (0.65, 0.85)	<0.001	1.35 (1.18, 1.54)	<0.001

Continued

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
				95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
6. Do you often slaughter cattle and sheep at yard?	No (correct)	18.17 (343/1,888)*	19.00 (164/863)*	0.83 (−3.41, 5.07)	0.600	1.02 (−4.17, 6.20)	0.600				
	Yes (incorrect)	81.83 (1,545/1,888)*	81.00 (699/863)*	0.83 (−3.41, 5.07)	0.600	1.01 (−4.17, 6.20)	0.600	0.99 (0.95, 1.03)	0.600	1.01 (0.97, 1.05)	0.600
7. Do you feed the internal organs of the cattle and sheep to dogs?	Never (correct)	61.04 (943/1,545)*	67.81 (474/699)*	6.77 (2.17, 11.37)	0.003	17.38 (5.57, 29.19)	0.003				
	Occasionally (partly)	25.18 (389/1,545)*	22.03 (154/699)*	3.15 (−0.95, 7.25)	0.130	12.51 (−3.77, 28.79)	0.130	0.88 (0.74, 1.04)	0.130	1.14 (0.96, 1.35)	0.130
	Frequently (incorrect)	13.79 (213/1,545)*	10.16 (71/699)*	3.63 (0.63, 6.63)	0.021	26.33 (4.57, 48.09)	0.021	0.74 (0.57, 0.95)	0.021	1.35 (1.05, 1.75)	0.021
8. Are your lambs vaccinated regularly?	Regularly (correct)	55.02 (724/1, 316)*	55.21 (318/576)*	0.19 (−4.85, 5.23)	0.940	0.42 (−10.79, 11.63)	0.940				
	Irregularly (partly)	25.23 (332/1, 316)*	27.60 (159/576)*	−2.37 (−7.37, 2.63)	0.300	−9.39 (−29.21, 10.43)	0.300	1.09 (0.93, 1.29)	0.300	0.92 (0.78, 1.08)	0.300
	No (incorrect)	19.76 (260/1, 316)*	17.19 (99/576)*	2.57 (−1.58, 6.72)	0.200	13.01 (−8.00, 34.01)	0.200	0.87 (0.70, 1.08)	0.200	1.15 (0.93, 1.43)	0.200
9. Do you regularly participate in echinococcosis screening?	Regularly (correct)	73.30 (1979/2,700)	86.68 (885/1,021)	13.38 (10.16, 16.60)	<0.001	50.11 (38.05, 62.17)	<0.001				
	Irregularly (partly)	24.04 (649/2,700)	12.83 (131/1,021)	11.21 (8.01, 14.41)	<0.001	46.63 (33.32, 59.94)	<0.001	0.53 (0.45, 0.63)	<0.001	1.89 (1.59, 2.22)	<0.001
	No (incorrect)	2.67 (72/2,700)	0.49 (5/1,021)	2.18 (1.20, 3.16)	<0.001	81.65 (44.94, 118.36)	<0.001	0.18 (0.07, 0.45)	<0.001	5.56 (2.22, 14.29)	<0.001
Total (Q1-9)	Correct	46.12 (9, 397/20, 373)	52.90 (4, 372/8, 264)	6.78 (5.35, 8.21)	<0.001	12.58 (9.92, 15.24)	<0.001				
	Correct partly+incorrect	53.88 (10, 976/20, 373)	47.10 (3, 892/8, 264)	6.78 (5.35, 8.21)	<0.001	12.58 (9.92, 15.24)	<0.001	0.87 (0.85, 0.90)	<0.001	1.15 (1.11, 1.18)	<0.001

Note: The chi-square test was used for all comparisons, but if the expected frequency of any cell was less than 5, Fisher's exact test was used. The blank cells indicate “not calculated (with no need for)”.

Abbreviation: *ARR*=absolute risk reduction; *RR*=relative risk reduction; *RR*= relative risk; 1/*RR*=protective efficacy; *CI*=confidence interval; SHEPG=smart health education pillbox group; RHEG=routine health education group.

*At Baseline (N=2,700), and one-year follow-up in the SHEPG (N=1,021). The numbers of valid responses to Q3 in Baseline were 2, 124; the numbers of valid responses to Q6 based on households raising livestock were 1,888 and 863, respectively; the numbers of valid responses to Q7 based on households raising livestock were 1,545 and 699, respectively; the numbers of valid responses to Q8 based on households raising sheep were 1, 316 and 576, respectively.

SUPPLEMENTARY TABLE S6. Practice rates, ARR, RRR, RR, 1/RR between RHEG and Baseline after the 12-month follow-up, 2023-2024.

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
				95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
1. Do you wash your hands before meals?	Three times a day or more (correct)	53.89 (1, 455/2,700)	54.73 (509/930)	0.84 (−2.91, 4.59)	0.660	1.83 (−6.38, 10.04)	0.660				
	1-2 times a day (partly)	23.96 (6, 47/2,700)	24.95 (232/930)	0.99 (−4.51, 2.53)	0.580	−4.13 (−18.83, 10.57)	0.580	1.04 (0.91, 1.19)	0.580	0.96 (0.84, 1.10)	0.580
	Occasionally (incorrect)	22.15 (598/2,700)	20.32 (189/930)	1.83 (−1.30, 4.96)	0.250	8.26 (−5.94, 22.46)	0.250	0.92 (0.79, 1.06)	0.250	1.09 (0.94, 1.27)	0.250
2. How is your dog typically restrained?	Always tethered (correct)	27.89 (753/2,700)	28.84 (265/919)*	0.95 (−2.58, 4.48)	0.590	−3.41 (−15.88, 9.06)	0.590				
	Tethered during the day, free at night (partly)	14.96 (404/2,700)	14.79 (136/919)*	0.17 (−2.99, 3.33)	0.880	1.14 (−19.93, 2.21)	0.880	0.99 (0.83, 1.18)	0.880	1.01 (0.85, 1.20)	0.880
	Tethered in settlements, free during migration (partly)	47.78 (1, 290/2,700)	48.42 (445/919)*	−0.64 (−4.15, 2.87)	0.720	−1.34 (−9.33, 6.65)	0.720	1.01 (0.94, 1.09)	0.720	0.99 (0.92, 1.07)	0.720
	Never tethered (incorrect)	9.37 (253/2,700)	7.94 (73/919)*	1.43 (−0.77, 3.63)	0.200	15.26 (−7.13, 37.65)	0.170	0.85 (0.67, 1.07)	0.170	1.18 (0.93, 1.49)	0.170
3. Do you often pet or hug your dog?	Never (correct)	8.24 (175/2, 124)*	9.25 (86/930)	1.01 (−1.07, 3.09)	0.340	12.26 (−42.96, 18.44)	0.340				
	Occasionally (partly)	53.95 (1, 146/2, 124)*	53.01 (493/930)	0.94 (−2.72, 4.60)	0.610	1.74 (−6.10, 9.58)	0.610	0.98 (0.91, 1.06)	0.610	1.02 (0.94, 1.10)	0.610
	Often (incorrect)	37.81 (803/2, 124)*	37.74 (351/930)	0.07 (−3.69, 3.83)	0.980	0.19 (−10.98, 11.36)	0.980	1.00 (0.90, 1.11)	0.980	1.00 (0.90, 1.11)	0.980
4. Do you deworm your dog regularly?	Yes (correct; 9-12 times/yr)	61.00 (1, 647/2,700)	59.89 (557/930)	−1.11 (−4.60, 2.38)	0.530	−2.85 (−11.80, 6.10)	0.530				
	Frequently (4-8 times/yr) (partly)	18.11 (489/2,700)	16.88 (1, 57/930)	1.23 (−1.66, 4.12)	0.400	6.79 (−9.17, 22.75)	0.400	0.93 (0.79, 1.10)	0.400	1.08 (0.91, 1.27)	0.400
	Occasionally (1-3 times/yr) (partly)	17.19 (464/2,700)	20.65 (192/930)	−3.46 (−6.31, -0.61)	0.019	−20.13 (−36.71, -3.55)	0.019	1.20 (1.03, 1.40)	0.019	0.83 (0.71, 0.97)	0.019
	Never dewormed (incorrect)	3.70 (100/2,700)	2.58 (24/930)	1.12 (−0.26, 2.50)	0.110	30.27 (−7.03, 67.57)	0.110	0.70 (0.45, 1.08)	0.110	1.43 (0.93, 2.22)	0.110
5. Do you properly dispose of your dog's waste after deworming?	Yes (correct; deep burial)	51.04 (1, 378/2,700)	51.73 (433/837)*	0.69 (−3.36, 4.74)	0.740	−1.41 (−10.29, 7.47)	0.740				
	Occasionally (partly)	21.81 (589/2,700)	21.39 (179/837)*	0.42 (−3.09, 3.93)	0.820	1.93 (−14.17, 18.03)	0.820	0.98 (0.84, 1.14)	0.820	1.02 (0.88, 1.19)	0.820
	Untreated (incorrect)	27.15 (733/2,700)	26.88 (225/837)*	0.27 (−3.38, 3.92)	0.880	1.00 (−12.45, 14.45)	0.880	0.99 (0.87, 1.13)	0.880	1.01 (0.88, 1.15)	0.880
6. Do you often slaughter cattle and sheep at yard?	No (correct)	18.17 (343/1,888)*	17.72 (151/852)*	−0.45 (−3.96, 3.06)	0.800	2.48 (−21.77, 26.73)	0.800				
	Yes (incorrect)	81.83 (1,545/1,888) *	82.28 (701/852)*	−0.45 (−3.96, 3.06)	0.800	−0.55 (−4.84, 3.74)	0.800	1.01 (0.97, 1.04)	0.800	0.99 (0.96, 1.03)	0.800

Continued

Question	Response	Baseline [% (*n*/*N*)]	SHEPG [% (*n*/*N*)]	ARR		RRR		RR		1/RR	
				95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*	95% *CI*	*P*
7. Do you feed the internal organs of the cattle and sheep to dogs?	Never (correct)	61.04 (943/1,545)*	60.95 (476/781)*	−0.09 (−4.51, 4.33)	0.980	−0.23 (−11.59, 11.13)	0.980				
	Occasionally (partly)	25.18 (389/1,545)*	25.74 (201/781)*	−0.56 (−4.51, 3.39)	0.770	−2.22 (−17.92, 13.48)	0.770	1.02 (0.88, 1.19)	0.770	0.98 (0.84, 1.14)	0.770
	Frequently (incorrect)	13.79 (213/1,545)*	13.32 (104/781)*	0.47 (−2.97, 3.91)	0.770	3.41 (−21.53, 28.35)	0.770	0.97 (0.77, 1.21)	0.770	1.03 (0.83, 1.30)	0.770
8. Are your lambs vaccinated regularly?	Regularly (correct)	55.02 (724/1, 316)*	54.79 (349/637)*	−0.23 (−5.18, 4.72)	0.930	−0.51 (−11.52, 10.50)	0.930				
	Irregularly (partly)	25.23 (332/1, 316)*	26.06 (166/637)*	−0.83 (−4.78, 3.12)	0.680	−3.29 (−18.95, 12.37)	0.680	1.03 (0.88, 1.22)	0.680	0.97 (0.82, 1.14)	0.680
	No (incorrect)	19.76 (260/1, 316)*	19.15 (122/637)*	0.61 (−3.12, 4.34)	0.750	3.09 (−15.78, 21.96)	0.750	0.97 (0.79, 1.19)	0.750	1.03 (0.84, 1.27)	0.750
9. Do you regularly participate in echinococcosis screening?	Regularly (correct)	73.30 (1,979/2,700)	74.30 (691/930)	1.00 (−2.15, 4.15)	0.530	−3.75 (−15.93, 8.43)	0.530				
	Irregularly (partly)	24.04 (649/2,700)	24.84 (231/930)	−0.80 (−4.23, 2.63)	0.650	−3.33 (−17.59, 10.93)	0.650	1.03 (0.91, 1.17)	0.650	0.97 (0.85, 1.10)	0.650
	No (incorrect)	2.67 (72/2,700)	0.86 (8/930)	1.81 (0.67, 2.95)	0.002	67.79 (34.92, 100.66)	0.002	0.32 (0.16, 0.65)	0.002	3.13 (1.54, 6.25)	0.002
Total (Q1-9)	Correct	46.12 (9, 397/20, 373)	45.40 (3, 517/7, 746)	−0.72 (−1.70, 0.26)	0.150	−1.34 (−3.16, 0.48)	0.150				
	Partly correct+incorrect	53.88 (10, 976/20, 373)	54.60 (4, 229/7, 746)	−0.72 (−1.70, 0.26)	0.150	−1.34 (−3.16, 0.48)	0.150	1.01 (0.99, 1.04)	0.180	0.99 (0.96, 1.01)	0.180

Note: The chi-square test was used for all comparisons, but if the expected frequency of any cell was less than 5, Fisher's exact test was used. The blank cells indicate “not calculated (with no need for)”.

Abbreviation: *ARR*=absolute risk reduction; *RR*=relative risk reduction; *RR*=relative risk; 1/*RR*=protective efficacy; *CI*=confidence interval; SHEPG=smart health education pillbox group; RHEG=routine health education group.

*At Baseline (N=2,700), and one-year follow-up in the RHEG (N=930). The numbers of valid responses to Q 2 in RHEG were 919; the numbers of valid responses to Q3 in Baseline were 2, 124; the numbers of valid responses to Q5 in RHEG were 837; the numbers of valid responses to Q6 based on households raising livestock in both group were 1,888 and 852, respectively; the numbers of valid responses to Q7 based on households raising livestock in both group were 1,545 and 781, respectively; the numbers of valid responses to Q8 based on households raising sheep in both group were 1, 316 and 637, respectively.

Preplanned Studies

Attitudes as a Critical Mediator Between Schistosomiasis Knowledge and Practices Among Students, with Implications for Behavior Change Interventions — Pemba Island, Zanzibar, Tanzania, 2024

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Summary

What is already known about this topic?

Despite mass drug administration (MDA) programs in Zanzibar, schistosomiasis transmission persists due to behavioral gaps, and prior studies in sub-Saharan Africa consistently reveal significant knowledge-practice disparities where improved knowledge alone fails to translate into preventive behaviors.

What is added by this report?

We quantified that attitudes are a pivotal mediator, accounting for 68.35% of knowledge's effect on schistosomiasis prevention practices among Zanzibari students. This finding, from a 2024 cross-sectional study on Pemba Island, shifts the focus from knowledge dissemination alone to attitude transformation as the central strategy for effective behavior change interventions.

What are the implications for public health practice?

Public health interventions must prioritize attitude transformation (mediated 68.35% of knowledge's effect on practices) through education (e.g., peer role-playing) while concurrently improving WASH infrastructure, as attitudes are the critical pathway to behavior change in endemic communities.

ABSTRACT

Introduction: Despite mass drug administration (MDA) in Zanzibar, schistosomiasis persists because of behavioral gaps. This study quantified the mediating role of attitudes in bridging knowledge and preventive practices among schoolchildren, addressing the critical evidence gap in behavioral change (BC) interventions.

Methods: A school-based cross-sectional study (N=390) was conducted on Pemba Island (2024), using cluster sampling. Knowledge, attitudes, and practices (KAP) surveys were combined with urinary egg detection for parasitological confirmation. Statistical analyses included regression to identify influencing factors (P<0.05) and mediation analysis to quantify the role of attitude in the knowledge-practice pathway.

Results: The infection rate was 12.05%. Mean scores were 6.89±1.50 (out of 10) for knowledge, 41.40±9.77 (out of 55) for attitudes, and 19.28±2.78 (out of 30) for practices. Regression analysis identified sex, grade level, access to tap water, and opportunities for water contact as influencing factors (P<0.05). Critically, attitudes mediated 68.35% of the total effect of knowledge on practices, confirming their pivotal role.

Conclusion: These findings highlight the importance of accurate knowledge and positive attitudes towards promoting preventive practices among students. This study thus proposes a community health volunteer (CHV)-led intervention that integrates attitude-focused education (e.g., peer role-playing) with WASH infrastructure improvements.

Schistosomiasis remains highly endemic in tropical and subtropical regions, affecting about 240 million people globally, with 779 million at risk (*1–2*). In Africa, 91.30% of cases require preventive chemotherapy (PC) (*3*). The World Health Organization's (WHO) *2021–2030 Neglected Tropical Diseases (NTD) roadmap* targets interruption of transmission and elimination as a public health problem (*4–5*), posing major challenges for endemic regions like Zanzibar. Pemba Island, about 30 km off mainland Tanzania (*6*), harbors abundant *Bulinus* snails, the main intermediate hosts for *Schistosoma haematobium*. Among students in Africa, schistosomiasis causes significant morbidity, with symptoms such as fever, abdominal pain, diarrhea, and hematuria (*7*), leading to discomfort, impaired well-being, and frequent school absenteeism.

The WHO 2021–2022 guidelines prioritize interrupting schistosomiasis transmission through expanded PC for all age groups, together with the implementation of integrated multisectoral approaches. Although the guidelines target the entire population, school-aged children remain at the highest risk of infection and are the most accessible for intervention in resource-limited settings, such as Zanzibar. Their frequent contact with water makes them more vulnerable to infection, and they also serve as important bridges for disseminating health knowledge within their households, thereby influencing protective behaviors at the family level. Therefore, behavior-centered interventions targeting this group are particularly critical for the effective implementation of the guidelines. A comprehensive review by Trippler et al. highlighted the importance and impact of health education interventions (*8*). However, in Zanzibar, health education programs have been implemented only sporadically and with insufficient resources, reflecting persistent implementation challenges in resource-constrained settings. Against this background, this study focused on school-aged children in Zanzibar, aiming to identify key risk factors affecting the adoption of protective behaviors against schistosomiasis and to provide evidence for the development of targeted behavioral intervention strategies.

The study was conducted from January to March 2024 at Chambani Primary School on Pemba Island. A face-to-face questionnaire survey and urine schistosome egg detection were conducted via cluster sampling of fifth- and sixth-grade students in primary schools, carried out by trained community health volunteers (CHVs). Participants Inclusion Criteria: 1) Students in the fifth and sixth grades, and 2) The students' parents/guardians provided written informed consent; 3) The students were healthy and willing to provide urine samples. Urine samples were collected from participating students at the survey school. The teachers monitored the process and ensured that all the students followed the instructions carefully. The collected urine samples were sent to the China-aided Zanzibar Pathogen Biology Laboratory located on Pemba Island, Zanzibar, Tanzania. Filtration technology with nylon, paper, or polycarbonate membranes was used to filter urine. The material left on the filter membrane was then examined under a microscope. If eggs were present, the number of eggs on the entire filter membrane was recorded, and the result was considered positive (*9*). All participants received MDA with praziquantel at identical frequencies and timings before the survey, ensuring that the observed KAP variations were not confounded by differential chemotherapy exposure.

A structured questionnaire was developed in English and translated into Swahili (Supplementary Material, available at https://weekly.chinacdc.cn/). A pilot survey was conducted with a small group of students, and revisions were made. The questionnaire comprised four parts. Part A collected the basic demographic information. Part B consisted of 10 multiple-choice questions to assess basic knowledge of schistosomiasis (*10–12*). Each correct answer was given a score of 1 point, for a total of 10 points. Part C contained 11 attitude questions rated on a five-point Likert scale (1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree) (*10–11*), with a total possible score of 55. Part D comprised 10 practice-related questions . The first three questions were scored 1–3 for "always," "sometimes," and "never," respectively, and the remaining seven questions were reverse-scored, with a total possible score of 30. Exploratory factor analysis confirmed the construct validity of the questionnaire's attitude (Section C) and behavior (Section D) scales, with satisfactory reliability indices: a Cronbach's alpha of 0.76, a KMO value of 0.79, and a significant Bartlett's test of sphericity value of 2818.72 (P<0.001).

Data were analyzed using SPSS (version 26.0.0.0, IBM Corp., Armonk, NY, USA). Differences were evaluated using independent sample t-tests and analysis of variance (ANOVA). The relationships were assessed using Pearson's correlation analysis. Multiple linear regression models were used to analyze these factors. The significance level was set at α =0.05 (two-tailed).

Among the 390 students surveyed, 176 (45.13%) were male, and 214 (54.87%) were female. The average age of the participants was 13±1.47 years. In total, 212 (54.36%) and 178 (45.64%) students were in the fifth and sixth grades, respectively. The average number of people per household was 8, ranging from 2 to 16 individuals. More than two-thirds of the students' parents were engaged in farming or fishing; specifically, 72.56% of fathers and 74.36% of mothers worked in these fields. Most students had access to tap water (84.10%) and toilets (92.05%) near their homes. Additionally, 76.92% of the participants lived near natural water sources (Table 1). The prevalence of urinary schistosomiasis was 12.05%, with 47 positive cases in 30 boys (63.83%), and 17 girls (36.17%).

The study showed that only 3.80% of the students correctly identified schistosomiasis types, and 24.60% understood that contact with infected urine could transmit *Schistosoma haematobium*. Positive attitudes emerged: 65.10% recognized the disease's health

TABLE 1. Results of the analysis of influencing factors on knowledge, attitudes, and practices regarding schistosomiasis.

Variable/Category	Knowledge score		Attitude score		Practice score	
	Mean±SD	*P*	Mean±SD	*P*	Mean±SD	*P*
Gender						
Male	7.09±1.53	0.02	42.33±9.87	0.13	19.09±2.95	0.21
Female	6.73±1.46		40.71±9.67		19.44±2.63	
Grade						
Fifth grade	6.31±1.63	<0.001	37.31±9.04	<0.001	18.86±2.92	0.00
Sixth grade	7.58±0.94		46.26±8.27		19.79±2.53	
Household size						
1–10 people	6.94±1.53	0.16	41.22±9.73	0.46	19.32±2.80	0.79
11–20 people	6.67±1.38		42.16±9.98		19.21±2.70	
Father's occupation						
Farmer/fisherman	6.85±1.58	0.02	40.97±9.46	0.15	19.40±2.83	0.20
Worker	6.82±1.37		41.70±12.17		19.59±3.09	
Self-employed worker/businessman	7.13±1.28		44.97 ±9.42		18.61±2.40	
Teacher	7.00±1.18		43.73±7.77		18.55±2.54	
Government staff	7.27±1.01		43.91 ±8.73		17.55±0.93	
Medical staff	–		–		–	
Unemployed	6.40±1.14		36.40±8.82		18.80±2.28	
Others	7.80±0.45		35.20 ±8.64		20.20±1.48	
Mother's occupation						
Farmer/fisherman	7.00±1.49	0.01	41.55±9.02	0.42	19.43±2.84	0.24
Worker	6.60±1.67		42.00±12.30		18.74±2.59	
Self-employed Worker/businessman	6.67±1.39		40.11 ±9.58		18.33±2.32	
Teacher	6.53±1.38		39.53±12.31		18.76±2.43	
Government staff	8.00±1.00		42.67±11.50		18.00±1.73	
Medical staff	6.00±0.00		55.00±0.00		20.50±0.71	
Unemployed	5.86±1.17		38.50±14.47		19.71±3.29	
Others	9.00±1.41		47.00 ±1.41		22.00±1.41	
Whether they have access to tap water near their residence						
Yes	6.88±1.50	0.81	41.90±9.92	0.02	19.29±2.81	0.97
No	6.94±1.50		38.74±8.52		19.27±2.66	
Whether they have access to toilets near their residence						
Yes	6.90±1.48	0.65	41.63±9.59	0.11	19.29±2.81	0.90
No	6.77±1.73		38.71±11.48		19.23±2.50	
Whether they have access to water sources near their residence						
Yes	7.01±1.49	0.00	42.16±8.76	0.02	19.31±2.74	0.76
No	6.49±1.46		38.87±12.29		19.21±2.94	

Note: "–" means data not applicable.
Abbreviations: SD=standard deviation.

threat, 80.40% were willing to seek medical help for symptoms, 77.70% took protective measures, such as wearing gloves and rubber shoes during water activities, and 84.10% desired health education. The study identified misconceptions, with 30.50% falsely linking untreated drinking water to infection and 17% doubting the effectiveness of snail control. In practice, 55%–60% engaged in water-related activities in schistosomiasis-endemic environments, 68.20% never used protective measures, 80.30% never played with classmates known to have schistosomiasis, and 62.10% did not assist or correct the behaviors of classmates with schistosomiasis. Alarmingly, 73.80% delayed seeking treatment, and 65.40% avoided medication post-diagnosis.

Independent-sample t-tests and ANOVA revealed significant differences in the scores across the following categories: While age was recorded (mean: 13±1.47 years), subsequent analysis did not identify it as a significant factor influencing knowledge scores in this cohort. The most significant variations in knowledge were associated with grade level, parental occupation, and proximity to water sources. Attitude scores varied according to grade level, availability of tap water in the vicinity, and proximity to water sources. Practice scores differed only by grade ($P<0.05$) (Table 1).

Multiple linear regression analysis revealed that grade level, availability of tap water in the vicinity, and proximity to water sources were the influencing factors for attitudes, while gender and grade level were the influencing factors for practices ($P<0.05$) (Table 2).

Correlation analysis revealed that knowledge was significantly correlated with attitudes ($r=0.32$, $P<0.001$) and prevention practices ($r=0.12$, $P<0.05$). A one-SD increase in knowledge levels predicted a 32.40% improvement in attitude scores. Notably, the attitude-practice correlation ($r=0.14$, $P<0.01$) was weaker than the knowledge-attitude relationship (Supplementary Table S1, available at https://weekly.chinacdc.cn/).

The structural equation model demonstrated full mediation; schistosomiasis-related knowledge influenced preventive practices through attitude. Knowledge demonstrated a substantial positive effect on attitudes ($\beta=2.11$, $P<0.01$), while attitudes subsequently predicted practices ($\beta=0.03$, $P<0.05$). Notably, the direct effect of knowledge on practices became non-significant after accounting for attitudes ($\beta=0.15$, $P>0.05$). Bootstrap analysis confirmed that attitudes mediated 31.70% of knowledge's total effect on practices [indirect effect=0.07, 95% confidence interval (*CI*): 0.01, 0.14], with a significant total effect (effect size=0.22, 95% *CI:* 0.03, 0.40), but a non-significant direct effect (95% *CI*: 0.04, 0.34) (Supplementary Table S2, Supplementary Figure S1, available at https://weekly.chinacdc.cn/).

DISCUSSION

A 12.05% schistosomiasis prevalence among the students suggests moderate endemicity per WHO guidelines (≥10%), requiring control measures (*5*). Moreover, this analysis revealed notable variations among students in their knowledge of schistosomiasis, attitudes towards prevention, and behavioral changes (BC). Only 50% demonstrated correct knowledge about urogenital schistosomiasis; however, 80.30% practiced social distancing (avoiding contact/helping infected individuals), revealing disease misconceptions

TABLE 2. Results of the Multivariate Analysis on knowledge, attitudes, and practices Regarding Schistosomiasis.

Variable		Standardization coefficients		*P*	95% *CI*
		β	*t*		
Knowledge score	Constant		11.44	<0.001***	[5.76, 8.15]
	Grade	0.32	7.17	<0.001***	[0.71, 1.24]
Attitude score	Constant		9.06	<0.001***	[29.12, 45.26]
	Grade	0.45	9.58	<0.001***	[6.97, 10.58]
	Whether they have access to tap water near their residence	−0.10	−2.16	0.03*	[−5.09, −0.24]
	Whether there is a water source near their residence	−0.10	−2.28	0.02*	[−4.51, −0.33]
Practice score	Constant		14.62	<0.001***	[16.55, 21.69]
	Gender	0.14	2.53	0.01*	[0.17, 1.35]
	Grade	0.16	3.12	0**	[0.34, 1.49]

* $P<0.05$; ** $P<0.01$; *** $P<0.001$.
Abbreviation: *CI*=confidence interval.

and stigma. Corroborating studies from other schistosomiasis-endemic areas in sub-Saharan Africa similarly indicate that disease stigma significantly compromises treatment adherence and the effectiveness of community-based interventions. Therefore, future health education must not only disseminate accurate knowledge but also actively address stigma and promote social inclusion.

The study found that 87.20% of students said they would seek medical care for symptoms such as hematuria, yet only 34.60% of the infected patients did so. Similarly, only 26.10% of the patients sought drug treatment post-infection. This discrepancy may stem from barriers, such as distance to healthcare facilities, costs, and limited awareness (*13*). Since students rarely bear medical expenses, these factors alone may not explain their behavior. Other influences — family support, cultural beliefs, and access to reliable health information — should also be considered. Although 77.70% recognized the need for protective measures like gloves and rubber shoes during water activities, adherence remained low at 68.20%. Similarly, 72.30% correctly identified *Bulinus* snails as key hosts for *Schistosoma haematobium*, but many students frequently interacted with water bodies potentially harboring these snails. These survey results align with studies conducted in Mozambique and Côte d'Ivoire (*14*–*15*) and may be influenced by local factors, including inadequate sanitation facilities and sociocultural aspects. For example, male students face higher risks of grass cutting, livestock herding, and fishing. Avoiding contact with contaminated water is critical for preventing infection, particularly — through improved sanitation infrastructure. Interventions should reflect local sociocultural and resource contexts. Bridging the knowledge-practice gap demands targeted education, behavioral programs, enhanced infrastructure and accessible healthcare in high-risk areas.

The finding that attitudes mediate 68.35% of knowledge's total effect on preventive practices underscores attitudes as key drivers of BC. Knowledge alone is insufficient; interventions must actively reshape perceptions and emotional responses to bridge the knowledge-practice gap. Therefore, BC interventions must prioritize attitude transformation through interactive, culturally resonant education (e.g., peer role-playing and case studies) led by trusted CHVs. These efforts should be integrated with tangible WASH infrastructure improvements (e.g., expanding tap water access) to address practical barriers and reinforce positive beliefs. Interventions must also be tailored by grade level: for higher grades, deepening the scientific understanding of etiology and prevention, and for lower grades, focusing on foundational hygiene and fear reduction. By leveraging CHVs to bridge formal education with community implementation and continuously measuring attitude shifts as key outcomes, programs can effectively convert knowledge into sustained protective practices, thus closing the critical knowledge-attitude-practice gap identified in this study.

The study is subject to at least three limitations. First, the small sample size may restrict the statistical power of the analyses and limit the generalizability of the results to broader populations. Second, reliance on self-reported data introduces the potential for response bias, such as social desirability or recall inaccuracies, which may affect the accuracy of behavioral measures. Finally, insufficient consideration of seasonal factors could overlook temporal variations in transmission risk, thereby narrowing the understanding of schistosomiasis dynamics across different times of the year.

This study underscores the critical gaps in schistosomiasis awareness among post-pandemic students on Pemba Island and highlights the strategic value of integrating CHVs into health education frameworks. By leveraging the CHVs' localized expertise and community trust, interventions can bridge knowledge deficits while fostering sustainable BC. These findings align with KAP theory, emphasizing the necessity of dual-focused strategies that simultaneously strengthen disease-specific knowledge and cultivate proactive health attitudes. Future efforts should prioritize adaptable community-driven approaches to optimize prevention practices and effectively mitigate transmission risks.

Ethical Statement: Conducted within the administration of district NTD offices and approved by the Ethics Review Committee of Zanzibar (ZAMREC/002/MAY/014). Informed consent was obtained from all parents or legal guardians.

Conflicts of interest: No conflicts of interest.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Results of the correlation analysis of schistosomiasis KAP among students.

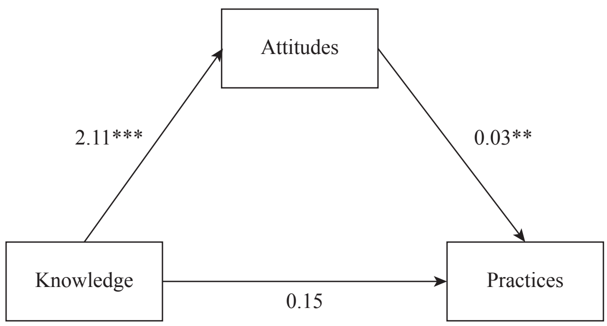
KAP	Knowledge	Attitudes	Practices
Knowledge	1		
Attitudes	0.32***	1	
Practices	0.12*	0.14**	1

Abbreviation: KAP=knowledge, attitudes, and practices;
* *P*<0.05; ** *P*<0.01; *** *P*<0.001.

SUPPLEMENTARY TABLE S2. Estimates of the mediating effects of schistosomiasis-related KAP among primary school students on Pemba Island.

Variable	Effect	BootSE	BootLLCI	BootULCI	Effect size
Total effect	0.22	0.09	0.03	0.40	
Indirect effect	0.15	0.10	−0.04	0.34	68.35%
Direct effect	0.07	0.03	0.01	0.14	31.65%

Abbreviation: KAP=knowledge, attitudes, and practices; BootSE=Bootstrap Standard Error; BootLLCI=Bootstrap Lower Limit for the Confidence Interval; BootULCI=Bootstrap Upper Limit for the Confidence Interval.



SUPPLEMENTARY FIGURE S1. The mediation model for primary school students on Pemba Island regarding schistosomiasis-related KAP.
Note: The number 2.11 represents the effect of knowledge (independent variable) on attitudes (mediator), which is significant; 0.03 is the effect of attitudes (mediator) on practices (dependent variable), controlling for knowledge, and is significant; 0.15 denotes the direct effect of knowledge (independent variable) on practices (dependent variable), controlling for attitudes.
Abbreviation: KAP=knowledge, attitudes, practices;
* *P*<0.05; ** *P*<0.01; *** *P*<0.001.

Outbreak Reports

First Imported Case of Cerebral Schistosomiasis Mansoni — China, May 2025

Weiqi Chen[1]; Yalan Zhang[1]; Xiaohui Ma[1]; Tiantian Jiang[1]; Dongyang Zhao[1]; Yan Deng[1,#]

Summary

What is already known about this topic?

Schistosoma mansoni (*S. mansoni*) is predominantly distributed across Africa, the Middle East, the Caribbean Islands, and South America, infecting approximately 54 million people annually. China is not an endemic region for schistosomiasis mansoni, and no cases of cerebral schistosomiasis mansoni have been previously documented.

What is added by this report?

This report documents the first imported case of cerebral schistosomiasis mansoni in China. We present the epidemiological investigation, distinctive clinical manifestations, diagnostic challenges including misdiagnosis and delayed diagnosis, and the critical role of pathogen detection in case confirmation.

What are the implications for public health practice?

With the continuous emergence of imported S. mansoni cases and the gradual expansion of intermediate host breeding grounds, active monitoring should be conducted for potential risks of local transmission within China. To prevent this disease from becoming endemic, CDCs and medical institutions must strengthen their diagnostic, treatment, and prevention capabilities, as well as their monitoring and early warning capacities for imported schistosomiasis mansoni.

ABSTRACT

Objective: To report the first imported case of cerebral schistosomiasis mansoni in China and highlight the public health risks posed by this disease.

Methods: We conducted an epidemiological investigation, performed laboratory testing of clinical samples, and collected diagnostic and treatment data. The infection source was determined through comprehensive analysis of epidemiological history, clinical manifestations, and laboratory findings.

Results: Before returning to China, the patient had resided for nearly 10 years in schistosomiasis-endemic regions, including Angola and the Democratic Republic of the Congo (DRC), where mountain spring water was used for drinking and daily activities. One month before returning to China, the patient developed central nervous system symptoms, including limb weakness and slowed reactions. Laboratory testing revealed markedly elevated eosinophil (EOS) levels, with both percentage (25.0%) and absolute count (3.30×10^9/L) exceeding normal ranges. High-throughput sequencing (HTS) of blood samples identified *Schistosoma mansoni* DNA sequences, and microscopic stool examination detected *S. mansoni* eggs.

Conclusion: China is not an endemic area for *S. mansoni*. This study reports the first imported case of cerebral schistosomiasis mansoni in China. With the continuous emergence of imported *S. mansoni* cases and the gradual expansion of intermediate host breeding grounds, we should actively monitor the potential risk of local transmission occurring in China. Enhanced protective awareness among outbound tourists and strengthened public health surveillance are essential measures to counter the threat posed by imported cases.

Schistosomiasis mansoni is a parasitic disease caused by adult *Schistosoma mansoni* parasites inhabiting venous vessels, including mesenteric small veins and hemorrhoidal venous plexuses. Primary clinical manifestations include abdominal pain, diarrhea, and hepatosplenomegaly (*1*). The disease predominantly affects populations in Africa, the Eastern Mediterranean region, and Central and South America (*2*), with approximately 54 million people infected worldwide annually (*3*–*4*). China is endemic for *Schistosoma japonicum* infection but not for *S. mansoni* infection (*5*).

In May 2025, the Henan CDC received a report of one suspected case of schistosomiasis mansoni. Based on clinical symptoms, epidemiological findings, pathogen identification, and molecular biology evidence, this case was confirmed as an imported case of cerebral schistosomiasis mansoni.

This case underscores the critical importance of early detection and surveillance of imported schistosomiasis mansoni cases in China and reveals emerging public health challenges associated with increased international travel and global connectivity.

INVESTIGATION AND RESULTS

In May 2025, a hospital in Henan Province, China, reported a 51-year-old male worker as a suspected case of parasitic disease, presenting with central nervous system symptoms and blood eosinophilia. After excluding cerebral infarction, the case was definitively diagnosed as *S. mansoni* infection based on multiple lines of evidence: detection of eggs in stool samples, clinical presentation, epidemiological history, etiological findings, and high-throughput sequencing (HTS) testing of blood samples. Following one month of praziquantel treatment, *S. mansoni* eggs were no longer detectable in the patient's stool.

Notably, the patient did not present with typical schistosomiasis symptoms such as fever, abdominal pain, diarrhea, or hepatosplenomegaly. Instead, central nervous system manifestations emerged in April 2025, including limb weakness, slowed reaction time, memory impairment, and loss of independent ambulation. Magnetic resonance imaging revealed extensive FLAIR hyperintensities throughout the bilateral frontal, parietal, temporal, and occipital lobes, with additional involvement of the brainstem and cerebellum. Hemosiderin deposition was noted in the bilateral frontal, parietal, and occipital lobes and the left cerebellar hemisphere. Hypointensity were also observed in the bilateral globus pallidus, suggesting mineral deposition or calcification (Figure 1). Central nervous system lesions resulting from ectopic egg migration can manifest without the more common hepatointestinal symptoms, potentially complicating clinical suspicion of schistosomiasis.

Routine blood testing demonstrated marked eosinophilia, with both the percentage (25.0%) and absolute count (3.30×10^9/L) exceeding normal reference ranges. HTS analysis of blood samples identified four sequences of *S. mansoni*. Fecal examination employed three methods: automated routine analysis, the egg-hatching method following nylon mesh bag concentration, and the modified Kato-Katz thick smear technique. Automated stool analysis failed to detect any eggs, and the egg-hatching method revealed no miracidia. Using the Kato-Katz technique, examination of three fecal smears yielded no *S. mansoni* eggs; however, continued testing of an additional seven smears (10 total) identified a single egg (Figure 2). These combined findings provided definitive etiological evidence for diagnosis.

Epidemiologically, the patient had worked in schistosomiasis-endemic regions, including Angola from 2013 to 2024, and the Democratic Republic of the Congo (DRC) from December 2024 to April 2025. While in the DRC, the patient had frequent contact with local mountain spring water, which served as the primary source for both drinking and daily household use. Although intermediate host breeding grounds have emerged in southern China, the country remains non-endemic for schistosomiasis mansoni. Consequently, this case represents an *S. mansoni* infection acquired in Africa.

Retrospective investigation revealed that in April 2025, while still abroad, the patient exhibited a markedly elevated eosinophil (EOS) percentage (47%)

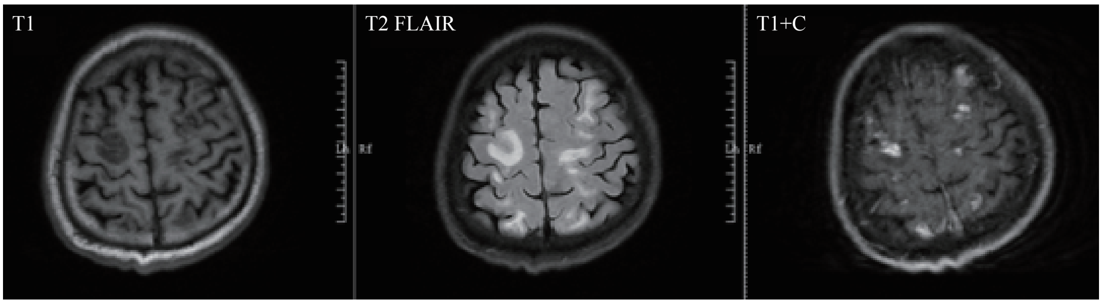


FIGURE 1. MRI findings reveal multiple symmetrical abnormal signals in the bilateral frontal, parietal, temporal, and occipital lobes, as well as the periventricular regions of the bilateral lateral ventricles.
Abbreviation: MRI=magnetic resonance imaging.

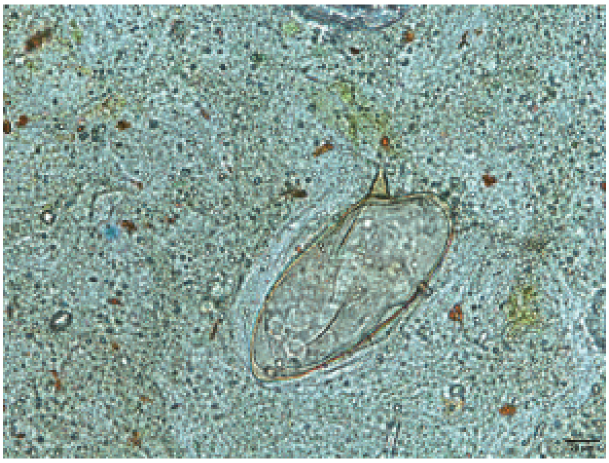


FIGURE 2. Egg detected at Kato-Katz thick-smear preparations, 400×magnification.
Note: The lateral subterminal spine is the character of *S. mansoni* eggs.

accompanied by right-sided limb weakness and sluggish responsiveness. Despite these findings, the patient was diagnosed with cerebral infarction. Symptomatic treatment failed to produce clinical improvement. Upon returning to China, the EOS percentage remained elevated at 30%; however, municipal-level medical institutions where the patient first sought treatment did not consider parasitic infection as a differential diagnosis after excluding cerebral infarction. Provincial medical institutions subsequently employed HTS testing based on routine blood test results to guide the diagnostic workup, which was ultimately confirmed through the detection of parasite eggs in stool samples examined at the Henan CDC.

DISCUSSION

Most *S. mansoni* infections present primarily with gastrointestinal manifestations, including abdominal pain and diarrhea (*1*,*6*–*7*). Severe infections may progress to portal hypertension and esophageal variceal bleeding (*3*). Within the nervous system, schistosomiasis mansoni predominantly affects the spinal cord (*8*). Although a limited number of cerebral schistosomiasis cases have been documented in Brazil and other regions (*9*–*12*), the present case represents the first such report from China. This case provides valuable clinical insights for diagnosing similar presentations in the future.

Definitive diagnosis of *S. mansoni* infection requires detection of *S. mansoni* eggs or miracidia in fecal examinations or tissue biopsies (*13*). The Kato-Katz thick smear technique represents a widely used method for detecting parasite eggs in stool samples and remains suitable for laboratory diagnosis of most intestinal parasitic infections. In this case, direct smear examination and nylon mesh bag concentration failed to detect pathogens, and only a single egg was identified in one Kato-Katz slide among ten slides examined. Given that *S. mansoni* produces only one-fifth to one-tenth the number of eggs compared with *Schistosoma japonicum*, this low egg burden presents significant diagnostic challenges that laboratory personnel must recognize. Furthermore, HTS has demonstrated an invaluable role in guiding clinical diagnosis of rare or atypically presenting parasitic infections (*14*–*15*).

Despite blood test results suggesting possible parasitic infection when neurological symptoms emerged, municipal-level hospitals did not initially pursue parasitic antibody or pathogen screening upon case admission. This observation suggests that enhanced training in recognizing imported parasitic diseases may be needed at the primary care level, particularly for rare and imported infectious diseases.

In conclusion, this study documents the first imported case of cerebral schistosomiasis mansoni in China and underscores the potential threat of local transmission from imported cases. With the continuous emergence of imported *S. mansoni* cases and the gradual expansion of intermediate host breeding grounds, we should actively monitor the potential risk of local transmission occurring in China. Primary medical institutions and CDCs must strengthen their capacity for preventing and controlling imported cases from Africa and other endemic regions, while simultaneously enhancing laboratory testing capabilities. Strengthening the integration of medical and preventive measures, improving the sensitivity of sentinel surveillance at the primary care level, and preventing clinical misdiagnosis and missed diagnosis will effectively reduce the risk of local transmission triggered by imported cases.

Conflicts of interest: No conflicts of interest.

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