Preplanned Studies

Cost-effectiveness Assessment of A Smart Health Education Pillbox for Canine Echinococcosis Control During A Cluster-Randomized Trial — Western China, 2023–2024

Shijie Yang[1]; Chenqing Sun[1]; Ning Xiao[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]; Yuhua Li[8]; Yuancheng Yang[8]; Kaisaier Tuerxunjiang[2]; Zonglin Shen[8]; Xiao-nong Zhou[1,#]

Summary

What is already known about this topic?

Echinococcosis remains a significant zoonotic threat in western China, with canines serving as the primary reservoir for *Echinococcus* transmission. Despite monthly praziquantel (PZQ) deworming programs, challenges in compliance persist in remote pastoral regions due to logistical constraints.

What is added by this report?

The smart health education pillbox (SHEP) demonstrated a 22.62% reduction in the overall cost of dog deworming, an increase of 52.59% in the proportion of dogs receiving the recommended annual deworming frequency of 9–12 times, a 35.45% decrease in the risk of *Echinococcus* infection, and a 1.55-fold higher protective efficacy against canine echinococcosis transmission compared to conventional manual deworming (CMD) approaches.

What are the implications for public health practice?

These results indicate that SHEP reduces labor costs and mitigates echinococcosis transmission risk, highlighting its potential as a valuable tool for disease control.

ABSTRACT

Introduction: Echinococcosis is a zoonotic parasitic disease that necessitates regular deworming of canines. The efficacy of the conventional manual deworming (CMD) is impeded by geography, the workforce, and severe weather conditions. This study evaluated the effectiveness and cost-effectiveness of the smart health education pillbox (SHEP) compared to CMD in canine echinococcosis control.

Methods: A 12-month cluster randomized trial was conducted across nine endemic Chinese counties, where townships were randomly assigned to either the SHEP or CMD group. The primary outcomes included *Echinococcus* antigen positivity rates in dog feces, deworming frequency, and cost components. Data analysis was conducted using SPSS 27.0, employing Generalized Estimating Equations (GEE), odds ratios (*OR*), relative risk (*RR*), relative risk reduction (*RRR*), and protective efficacy (1/*RR*).

Results: SHEP implementation significantly reduced *Echinococcus* infection risk by 35.45% and demonstrated 1.55-fold higher protective efficacy than CMD. The total deworming costs decreased by 22.62%, with substantial savings in personnel (53.15%), transportation (79.48%), and operational time requirements (30.13%). The proportion of dogs that achieved the target annual deworming frequency (9–12 times) increased from 51.89% to 91.38%, representing a relative improvement of 52.59%.

Conclusion: SHEP, which integrates automated reminders of praziquantel (PZQ) tablet delivery, is a promising tool for diminishing resource utilization and mitigating *Echinococcus* transmission in endemic areas.

Echinococcosis, a zoonotic parasitic disease designated by the World Health Organization as a neglected tropical disease, manifests predominantly in cystic (CE) and alveolar (AE) forms, caused by *Echinococcus granulosus sensu lato* and *E. multilocularis*, respectively. Both forms impose substantial public health burdens, with dogs serving as the definitive hosts for transmission. Despite the nationwide monthly praziquantel (PZQ) deworming initiative for dogs implemented in China in 2006, which led to a decrease in canine fecal antigen prevalence from 4.25% to 0.50% (*1*–*2*), persistent operational obstacles such as veterinary workforce shortages, logistical barriers, and

financial constraints in remote regions persistently impede consistent deworming coverage and frequency. Surveys have revealed suboptimal deworming frequency (ranging from 21.7%–68.9%) (*3*–*6*) as a key factor contributing to sustained high rates of canine infection (ranging from 0.15%–1.60%) (*2*). These fluctuations in infection rates contribute to ongoing environmental transmission risks. Therefore, there is a need to explore novel approaches to enhance adherence to canine deworming regimens and mitigate environmental contamination.

From 2023 to 2024, a 12-month cluster randomized trial was conducted across nine endemic counties: Xiji County, Ningxia Hui Autonomous Region, Yushu City, Qinghai Province; Emin County, Hejing County, Artux City, Qapqal Xibe Autonomous County, Xinjiang Uygur Autonomous Region; Shangri-La City, Yunnan Province; Tianzhu Xizang Autonomous County, Gansu Province; and Fourth Division, Xinjiang Production and Construction Corps. Within each county, two townships were randomly assigned to interventions: one to the smart health education pillbox (SHEP) group and the other to the conventional manual deworming (CMD) group, with 150 eligible households with dogs randomly selected as study participants in each group. The SHEP group received an automated SHEP reminder and dog owner deworming scheme, where each targeted household received a pre-programmed SHEP and a deworming schedule (e.g., monthly deworming on the 5th day of each month, totaling 12 times annually). On designated deworming days, the SHEP delivered five sequential one-minute reminders combining auditory prompts ("Owner, please administer deworming PZQ chewable tablet to your dog") and visual cues (flashing red indicator light). Successful completion of all five steps — 1) opening the SHEP lid, 2) removing the PZQ chewable tablets, 3) administering them to the dog, 4) returning unused tablets to the compartment, and 5) closing the lid — is necessary to activate the green light and receive an auditory acknowledgment ("Congratulations! The deworming work has been successfully completed"). Failure to execute all five steps within the scheduled day (e.g., due to dog owner absence) would activate persistent reminders for three consecutive days. In the CMD group, conventional manual deworming procedures were followed in which health workers (veterinarians) from the township or village visited households on scheduled deworming dates to administer door-to-door PZQ chewable tablets. Additionally, stratified training, including canine fecal testing and questionnaire administration, was conducted for all participants across both the SHEP and CMD cohorts.

The primary indicators included the *Echinococcus* antigen-positive rate in dog feces, deworming frequency, and cost components. Data analysis was conducted using SPSS (version 27.0, IBM Corp., NY, USA), employing Generalized Estimating Equations (GEE), odds ratios (*OR*), relative risk (*RR*), relative risk reduction (*RRR*), and protective efficacy (1/*RR*). The distribution of deworming frequencies between groups was assessed using the Cochran-Armitage test, employing two-tailed testing, with statistical significance set at $P<0.05$.

Dog fecal samples were collected twice from each enrolled dog in both groups: at baseline in 2023 and at a 12-month follow-up in 2024. Copro-ELISA was performed at 9 county CDC locations. Baseline fecal testing of 2,643 samples (SHEP group: 1,310; CMD group: 1,333) revealed no significant intergroup variance in *Echinococcus* antigen positivity (*OR*=0.86, [95% confidence interval (*CI*): 0.30, 2.48, *P*=0.78]. At the 12-month follow-up (2,270 samples: SHEP group, 1,169; CMD group: 1,101), no significant efficacy difference was observed between the two groups (*OR*=0.74, 95% *CI*: 0.18, 3.04, *P*=0.68). Both groups demonstrated significant risk reduction compared to the baseline (SHEP group: *OR*=0.273, 95% *CI*: 0.04, 0.96, *P*=0.048; CMD group: *OR*=0.30, 95% *CI*: 0.11, 0.80, *P*=0.016). GEE accounting for repeated measures and cluster effects (9 counties) indicated that the SHEP group yielded a 35.45% greater risk reduction than the CMD group (*RRR*=35.45%, 95% *CI*: –63.78%, –15.21%), with a protective efficacy ratio (1/*RR*) of 1.55-fold (95% *CI*: 0.75, 0.97, *P*=0.046) (Table 1).

At the 12-month follow-up, the deworming frequency in the SHEP group was assessed by enumerating residual PZQ chewable tablets in the SHEP compartments, while in the CMD group, cross-verification of township/village health worker (veterinarian) deworming logs against dog owner interview records was performed. Furthermore, SHEP functionality was monitored, and the annual 12 PZQ tablets were replenished in the SHEP group (each SHEP had a three-year service period). Statistical analysis using the Cochran–Armitage test revealed a significantly higher deworming frequency in the SHEP group than in the CMD group (Z=16.78, $P<0.001$). All frequency bands showed significant differences

TABLE 1. *OR* for *Echinococcus* antigen in fecal samples between SHEP and CMD groups at baseline and 12-month follow-up in nine endemic counties, 2023–2024.

Site of fecal collection	Function of sample	Date of collection	SHEP automated reminder + dog owner deworming		Door-to-door deworming by township/village health workers		*OR*	95% *CI*	*P*
			Number tested	Positive rate, % (positive number)	Number tested	Positive rate, % (positive number)			
The Fourth Division	Baseline	2023-10	138	0	150	0 (0)			
	Follow-up	2024-11	113	0	124	0			
Xiji County	Baseline	2023-10	150	0	150	0			
	Follow-up	2024-12	113	0	110	0			
Hejing County	Baseline	2023-11	150	0	150	0			
	Follow-up	2024-12	150	0.67 (1)	150	0.67 (1)			
Qapqal Xibe Autonomous County	Baseline	2023-11	150	1.33 (2)	150	2.00 (3)			
	Follow-up	2024-12	118	0	111	0.90 (1)			
Emin County	Baseline	2023-11	150	0	150	0			
	Follow-up	2024-12	131	0	85	0			
Artux City	Baseline	2023-11	150	0	138	0			
	Follow-up	2024-12	124	0	84	0			
Shangri-La City	Baseline	2023-11	132	0.76 (1)	150	0			
	Follow-up	2024-12	132	0	150	0			
Yushu City	Baseline	2023-09	140	1.43 (2)	145	1.38 (2)			
	Follow-up	2024-10	140	0	144	0			
Tianzhu Xizang Autonomous County	Baseline	2023-10	150	2.00 (3)	150	1.33 (2)			
	Follow-up	2024-10	148	0	143	0			
Total	Baseline	2023	1,310	0.61(8)	1,333	0.53 (7)	0.86	0.30, 2.48	0.78
	Follow-up	2024	1,169	0.09(1)	1,101	0.18 (2)	0.74	0.18, 3.04	0.68

Abbreviations: *OR*=odds ratio; *CI*=confidence interval; SHEP=Smart Health Education Pillbox; CMD=conventional manual deworming.

TABLE 2. *OR*, *RR*, and *RRR* of deworming frequency distribution between SHEP and CMD groups for PZQ chewable tablet delivery in nine endemic counties, 2023–2024.

Residual PZQ chewable tablets (tab)	Deworming frequency (times/year)	SHEP automated reminder +dog owner deworming (%, *n*)	Door-to-door deworming by township/village health workers (%, *n*)	*OR*	95% *CI*	*P*	*RR*	*RRR* (%)
0−3	9−12	91.38 (933/1,021)	59.89 (557/930)	6.61	5.41, 8.08	<0.001	1.526	−52.59
4−8	4−8	7.44 (76/1,021)	16.88 (157/930)	0.40	0.31, 0.52	<0.001	0.441	55.87
9−12	0−3	1.08 (11/1,021)	23.23 (216/930)	0.04	0.02, 0.07	<0.001	0.046	95.35

Note: Each SHEP contained 12 PZQ chewable tablets, and the compulsory deworming frequency was once a month, 12 times a year.
Abbreviation: OR=odds ratio; RR=relative risk; RRR=relative risk reduction; *CI*=confidence interval; SHEP=smart health education pillbox; CMD=conventional manual deworming; PZQ=praziquantel.

(*P*<0.001), with SHEP achieving a 52.59% increase in high-frequency adherence (9–12 times/year; *OR*=6.61, 95% *CI*: 5.41, 8.08) and a 95.35% reduction in low-frequency risk (≤3 times/year, *OR*=0.036, 95% *CI*: 0.02, 0.07) (Table 2).

Throughout the study, expenses related to materials, personnel, transportation, and time allocation for the delivery of PZQ chewable tablets were meticulously documented. The SHEP yielded a 22.62% reduction in the overall cost of dog deworming, resulting in annual savings of 53.15% in labor costs, 79.48% in transportation costs, 30.13% in time costs and the commuting efficiency increased by 83.33% (Table 3).

DISCUSSION

The persistence of canine echinococcosis, despite China's nationwide monthly deworming program

TABLE 3. Expenditures on PZQ chewable tablets delivered for SHEP and CMD groups in nine endemic counties, 2023–2024.

Groups	Delivery methods	SHEP (CNY/year)*	PZQ chewable tablets (CNY/year) †	Manpower (CNY/year) §	Transportation (CNY/year) ¶	Total cost (CNY, dog /year) **	Cost per deworming (CNY, time/dog) ††	Total time (hour, dog/year) §§	Time per deworming (hours, dog /time) ††	Total commuting times per year	Saved commuting times per year
SHEP group	SHEP automated reminder + dog owner deworming	38.33	11.4	17.54	10.64	77.91	6.49	1.09	0.09	2	10
CMD group	Door-to-door deworming by township/village health workers	0	11.4	37.44	51.84	100.68	8.39	1.56	0.13	12	0

Abbreviation: CNY=Chinese Yuan; SHEP=smart health education pillbox; CMD=conventional manual deworming; PZQ=praziquantel.

* According to the market price, each SHEP is priced at 115 yuan, with a service life of three years and 12 deworming reminders per year (once a month); the annual depreciation cost is 38.33 yuan.

† According to the market bidding price, each commercially available PZQ chewable tablet costs 0.95 yuan, and each dog requires 12 tablets annually.

§ Based on the 2024 statistical yearbooks of nine counties, the average wages of health and veterinary personnel and residents' incomes were estimated, including the labor cost of township doctors and village deworming personnel, who worked 22 days a month for 8 hours each day.

¶ Estimated according to the average depreciation cost of vehicles and fuel expenses in these nine counties at the end of 2024, including the number of visits to rural areas and households.

** This includes the cost of SHEP and PZQ chewable tablets, manpower, and transportation.

†† Compulsory deworming frequency was once a month, 12 times a year.

§§ The time cost includes the commuting time of township doctors and village deworming personnel.

initiated in 2006, highlights systemic challenges. While the prevalence of antigens in dogs has decreased from 4.25% (*1*) to 0.50% (*2*), achieving the WHO's advocated dog infection rate targets (<0.01%) remains a formidable task (*7*). Conventional manual door-to-door deworming efforts by township/village health workers encounter persistent obstacles, such as geographic isolation, severe weather conditions, and shortages of veterinary professionals in endemic regions such as Xinjiang and Qinghai. Deworming frequency adherence — ranging from 21.7% to 47.5% (*3*,*6*) (12 times per year) — and deworming coverage in individual townships, varying from 24% to 84% in Ningxia (*4*), illustrate the challenges faced. Moreover, cultural customs (e.g., non-harm principles), strong human-dog relationships, and limited health literacy impede compliance, while issues such as overreported deworming records by health workers (veterinarians) lead to data inaccuracies. These factors contribute to sustained environmental egg contamination, with canine infection rates persistently fluctuating between 0.15% and 1.60% across the endemic provincial-level administrative divisions (PLADs) (*2*).

The SHEP addresses these gaps using a multifaceted approach. Its automated reminder system, featuring monthly light and voice alerts that persist for three days if unacknowledged, mitigates forgetfulness and seasonal mobility (e.g., pastoral transhumance). The dedicated compartment prevents PZQ chewable tablet loss, which is a critical failure point in dog-owner-administered programs. Additionally, daily health broadcasts enhance dog owners' awareness and facilitate the transition from mere knowledge of control measures to the adoption of healthy behaviors, countering cultural resistance by emphasizing the link between deworming and the reduction of zoonotic risks. This integrated design aligns with the One Health principle, concurrently targeting behavioral, logistical, and educational obstacles.

This trial highlights the superior efficacy of SHEP on both fronts. SHEP reduced canine *Echinococcus* antigen positivity to 0.09% (compared to 0.18% in conventional delivery; *OR*=0.273, 95% *CI*: 0.040–0.960), achieving near-elimination levels. This significant reduction in infected dogs was presumed to decrease environmental egg contamination by approximately 2.1 million eggs/dog annually, considering that each infected dog sheds approximately 40,000 eggs daily during peak transmission seasons (*8*–*9*). The resulting decline in soil egg burdens reduced human exposure risk, driving the basic

reproduction number (R_0) below 1.0 when canine prevalence falls below 0.1%. SHEP interrupts sustained transmission cycles and aligns with the WHO elimination objectives through source-level decontamination. From an economic standpoint, SHEP significantly improved the deworming frequency distribution, achieving a high adherence rate of 91.38% (9–12 times/year), compared to 59.89% with door-to-door manual delivery. The 6.6-fold increase in the odds of optimal adherence indicated that automated reminders effectively addressed habitual noncompliance, leading to a 95.35% reduction in low-frequency deworming risks. These improvements were realized alongside an 83.33% increase in commuting efficiency, and notable reductions of 53.15%, 79.48%, and 30.13% in labor, transportation, and time costs, respectively. These advancements are particularly crucial for regions with limited personnel and resources, such as highland pastoral areas. The 22.6% cost savings achieved by SHEP facilitate its scalable deployment in hyper-endemic areas, such as Qinghai and Sichuan. The adherence efficacy of SHEP aligns with the WHO's emphasis on sustaining deworming frequency and effectively supports the control objectives outlined in the "National Implementation Plan for Comprehensive Prevention and Control of Echinococcosis and Other Key Parasitic Diseases (2024–2030)" (*10*).

This study had several limitations. First, the assumed 3-year device lifespan requires field validation. Additionally, corrosion or damage in extreme environments may increase long-term costs. Second, the deworming frequency adherence in the CMD group relied on unverified self-reporting. Finally, factors, such as county variability, dog attrition within the target population, and limited temporal sampling, may have introduced bias into the estimates. Future iterations should focus on product optimization, integration of deworming strategies, and implementation of spatiotemporal covariance structures through stratified models and multiple imputations to address these limitations and enhance canine echinococcosis control measures.

In conclusion, the SHEP effectively addresses the fundamental challenges associated with conventional deworming practices by promoting verifiable and cost-efficient adherence. By targeting the crucial dog-human-animal interface, SHEP directly interrupts the transmission cycle, providing a scalable solution to attain a sub-0.01% canine infection target. This is recommended as the preferred intervention to improve dog deworming adherence. The integration of SHEP into national programs has the potential to optimize resource utilization and expedite efforts towards the elimination of echinococcosis.

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Corresponding author: Xiaonong Zhou, zhouxn1@chinacdc.cn.

[1] National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention (Chinese Center for Tropical Diseases Research), National Key Laboratory of Intelligent Tracking and Forecasting for Infectious Diseases, National Health Commission Key Laboratory on Parasite and Vector Biology, WHO Centre for Tropical Diseases, National Center for International Research on Tropical Diseases, Ministry of Science and Technology, Shanghai, China; [2] Xinjiang Uygur Autonomous Region Center for Disease Control and Prevention, Urumqi City, Xinjiang Uygur Autonomous Region, China; [3] Ningxia Hui Autonomous Region Center for Disease Control and Prevention, Yinchuan City, Ningxia Hui Autonomous Region, China; [4] Qinghai Institute for Endemic Disease Prevention and Control, Xining City, Qinghai Province, China; [5] Department of Parasitic Diseases, Gansu Center for Disease Control and Prevention, Lanzhou City, Gansu Province, China; [6] Yunnan Institute of Parasitic Diseases, Kunming City, Yunnan Province, China; [7] Center for Disease Control and Prevention of Xinjiang Production and Construction Corps, Urumqi City, Xinjiang Uygur Autonomous Region, China; [8] Tianzhu Tibetan Autonomous County Center for Disease Control and Prevention, Wuwei City, Gansu Province, China.

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