The effectiveness of E-learning in continuing medical education for Tuberculosis health workers: a quasi-experiment from China

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Abstract

Objective

To evaluate the effectiveness of E-learning in continuing medical education (CME) programs for Tuberculosis (TB) health workers in terms of knowledge improvement and behaviour change, and provide policy recommendations based on the evidence from programs implemented in China.

Methods

TB health professionals survey and in-depth interviews were conducted at provincial, prefectural, county, and primary care levels in the three project provinces. Difference-in-difference (DID) and multivariate linear regression models were employed to capture the effectiveness of knowledge improvement. Behaviour change was analysed using both qualitative and quantitative data.

Results

For clinicians, pre-post data showed no significant difference in knowledge increases between pilot and non-pilot areas (pilot areas: +17 points vs. non-pilot areas: +18 points, $p = 0.066$). However, clinicians who attended the synchronous E-learning had an average score 7.3 points higher ($p = 0.026$) and an average knowledge score increase of 0.3 points ($p = 0.028$) for each event attended. Asynchronous E-learning did not have a significant impact among clinical doctors. For public health physicians, E-learning intervention had no significant effect on their knowledge score (DID model: pilot: +4 points vs. non-pilot: +9 points, $p = 0.389$, multivariate linear regression model: $p = 0.161$). For primary care workers, pre-post data showed a significantly higher score increase in the pilot areas (+10 points) than the non-pilot areas (+4 points, $p = 0.005$). Primary care workers who attended the E-learning activities had an average score 10.9 points higher ($p < 0.001$) and an average increase of 1.8 points per training module attended ($p = 0.002$). More than half of participants (56.0% - 57.3%) agreed that they could apply what they learned to their practice, especially among well-educated health personnel from provincial level institutions. Traditional face-to-face training has no significant impact on all types of medical staff.

Conclusions

E-learning interventions for TB clinical and primary care health workers were associated with higher TB knowledge level, and some participants have already started applying what they learned in their practice. However, public health physicians didn't get much benefits from E-learning activities, probably due to the mismatch of training supply of & demand for training and environmental factors.

Introduction

Continuing medical education (CME) is an "established method that can facilitate lifelong learning, focuses on maintaining or developing knowledge, skills, and relationships to ensure competent practice" (D. Davis et al., 1999). Given the context of rapid technological advancement in medicine, it has been proposed that CME may play an important role in updating the physicians' knowledge and skills as well as improving health care outcomes. Since the 1980s, considerable resources have been invested in developing various CME programs in China and globally (C. Brown, Belfield, & Field, 2002; Meng, 2009). However, existing studies showed uncertain effectiveness of CME interventions (D. A. Davis, Thomson, Oxman, & Haynes, 1995; Fonarow et al., 2008; Forsetlund et al., 2009; Nissen, 2015; Rutschmann, Janssens, Vermeulen, & Sarasin, 2004). Two reasons have been posited for this phenomenon: First, traditional didactic sessions have little or no impact, while interactive or mixed workshops were more likely to be associated with some positive effects, as revealed by two systematic reviews (D. Davis et al., 1999; Forsetlund et al., 2009). Second, the clinicians are usually too busy in their daily practices to attend training. Lack of high-quality learning resources, unattractive and irrelevant training contents

were also key barriers to their learning (Committee on Planning a Continuing Health Professional Education Institute, 2010). Therefore, in order to improve the performance of physicians and the health system, it's important to find an appropriate CME training format that could increase access to high-quality training resources, considering health workers' needs in terms of content, timing and location of CME training.

E-learning provides a unique opportunity so address the challenges in CME. Due to the COVID-19 pandemic, we saw an unprecedented explosion of online and remote training in 2020 (Bacher-Hicks, Goodman, & Mulhern, 2020; Hamilton et al., 2020). But "Rome wasn't built in a day", with the great progress of information technology, the E-learning market has been growing rapidly around the world since the 1990s (Education Management Information Centre, Engineering Research Centre of the Ministry of Education for Digital Learning and Education Public Services, & Baidu Education, 2018; Hayashi, Chen, Ryan, & Wu, 2020; Kaur, 2019). Existing evidence indicated that E-learning could reduce the cost (Bettinger, Fox, Loeb, & Taylor, 2017; Deming, Goldin, Katz, & Yuchtman, 2015), improve the access to education (Goodman, Melkers, & Pallais, 2016) as well as provide more flexibilities for students who have work and family commitments (Johnson & Mejia, 2014; Xu & Xu, 2019). However, whether E-learning can improve student outcomes remains controversial (Hadadgar et al., 2016; Ruiz, Mintzer, & Leipzig, 2006; Xu & Xu, 2019). In addition, most of the available evidence comes from higher education-based studies (Bernard et al., 2004; Joyce, Crockett, Jaeger, Altindag, & O'Connell, 2015; Means, Toyama, Murphy, Bakia, & Jones, 2009). Little E-learning research was conducted in CME settings (Bernard et al., 2004; Cook et al., 2010; Vaona et al., 2018), especially in low- and middle-income countries (Barteit et al., 2020; Eslaminejad, Masood, & Ngah, 2010; Gagnon et al., 2007).

Since 2017, China-Gates Foundation TB Control Program (phase three) introduced and expanded a new comprehensive model of TB control in China. E-learning including distance training and online training for TB health workers was an integral part of the program. This study aims to evaluate whether E-learning can improve TB health personnel's knowledge and behaviour, in order to provide policy recommendations for improving the utilization of E-learning in CME.

Method

Intervention design

E-learning as part of capacity building project was implemented from May 2016 to June 2019 among three project provinces (Zhejiang represents the most developed eastern area in China, while Jilin is from the less developed central area and Ningxia represents the least developed western area). In each province, the China-Gates program selected two cities as pilot areas for E-learning project according to their level of socioeconomic development and TB health service capacity (number of TB health workers, Gross Domestic Product (GDP) per capita, information technology development).

Two key interventions were designed in the E-learning project of the China-Gates Foundation TB Control Program Phase 3. First, the "National TB Telemedicine Consultation and Training Platform" is a live, synchronous training platform was developed by Clinical Centre on Tuberculosis (hereinafter referred to as "synchronous training"). This platform focused on the training of complex clinical conditions for TB clinical staff at the county level and above. The platform also provides multiple formats of training sessions, including lectures, case studies, and online meetings. Second, China TB prevention Online Training Website, an asynchronous training and qualification system (hereinafter referred to as "asynchronous training") were developed for all TB health workers, including clinical doctors, public health physicians, and primary care medical staff. The online system focused on basic theory and routine treatment according to the latest version of national TB treatment and control guideline. In addition, the website sessions are provided by recorded videos, which created more flexibilities of time and space for health personnel. Both synchronous and asynchronous training sessions were delivered by national level TB experts (China-Gates TB Control Project Office of Clinical Centre for Tuberculosis Prevention, 2017),

Evaluation design

This evaluation study was mixed method research. With the conventional “Input-Process-Output” framework, we selected representative study sites from multiple levels (provincial, city, county, township and village-level). Before the intervention, for both intervention groups and control groups, we selected one city in each province as study sites according to their level of socioeconomic development (for example, GDP per capita, types of TB health service delivery model, etc.). Based on similar criteria, two counties from each city and three towns from each county (including at least one remote or mountainous town) were also selected. We also conducted the baseline survey before the intervention to capture the baseline knowledge level of TB health workforces. During the intervention, we monitored the process of training by routine reports from the IT system (quantitative data) and the interviews of organizers, lecturers and participators (qualitative data). These data would help us to open the black box of mechanism of the E-learning. After the intervention, we re-examined the knowledge level of TB health workforces and employed the difference in difference (DID) method to capture the effectiveness of E-learning interventions. (Fig. 1).

We conducted three waves of field trips (baseline, process, and the final evaluation) in 2017, 2018, and 2019, respectively. Two different types of data were collected for analysis. Firstly, we performed two waves of staff surveys in TB health workers from three provinces during the baseline (2017) and final evaluation (2019), which provided quantitative data about demographic information, training needs, participants' reactions to the training program, and a 10-question TB quiz. Questions in the TB quiz were prepared by national experts from the National Clinical Centre on Tuberculosis, Chinese Centre for Disease Control and Prevention (CDC). Three different types of quiz are used for clinical, public health physicians, and primary care workers. We also asked several questions on behaviour change in the questionnaires, the participants could choose whether they can put what they have learned into daily practices. All TB health workers on duty on the day of fieldwork were invited to fill in the questionnaire. In total, 555 TB-related health workers completed the baseline questionnaire survey and 757 completed the final questionnaire survey (Table 1). With the help of coordinators, participants were also recruited for key informant interviews and focused group discussions (FGDs) at each level with a purposive sampling method.

Table 1
Sample size and general information of TB health worker survey

		Baseline survey			Final survey		
		Clinical physicians	Public health physicians	Primary care workers	Clinical physicians	Public health physicians	Primary care workers
Total		143	79	274	190	92	476
Province	Zhejiang	52	31	54	58	45	132
	Jilin	63	24	129	86	24	164
	Ningxia	28	24	91	46	23	180
Level of institutions	Provincial	15	24	—	54	25	—
	Prefecture	36	30	—	75	33	—
	County	92	25	—	61	34	—
Areas	Non-pilot areas	79	37	165	84	50	160
	Pilot areas	64	42	109	106	42	316
Training participation	Never participated	—	—	—	26	40	337
	Participated in asynchronous activities	—	—	—	134	48	139
	Participated in synchronous activities	—	—	—	143	—	—
Gender	Female	81	46	98	115	61	171
	Male	61	33	176	75	31	301
Age group	< 30	10	8	30	29	16	43
	30–50	113	62	190	145	60	316
	> 50	20	9	50	16	16	117
Education level	Technical school or below	21	4	90	4	6	177
	College (3 years)	30	20	149	31	18	249
	University or above (≥ 5 years)	92	55	33	155	68	46
Professional title	None or primary	37	23	228	76	29	445
	Middle	64	20	37	55	30	23
	Senior	42	26	5	59	32	4
Data source: TB health worker survey. CDCs: Centres for Disease Control and Prevention.							

Qualitative data were collected to explore the effectiveness on behaviour change. Key informant interviews were conducted with program officers at national and provincial levels, trainers and trainees of E-learning activities. In each

designated hospital and CDC, focus group discussions (FGDs) were convened with 6–8 TB-related doctors, 2–3 public health physicians, or 1–3 primary care workers. The topic guides included issues on the subjective effects of E-learning, the feedback in the online and remote training from the trainers and trainees, especially compared with the traditional face to face training. The interviews and FGDs were conducted in a quiet meeting room or office room without any other irrelevant person. A senior researcher conducted the interviews and FGDs as the interviewer or facilitator, with a junior researcher as observer and notetaker. The talks were recorded after participants signed the consent forms. In total, we conducted 30 key informant interviews and 44 FGDs.

Data analysis

For both quantitative and qualitative data, analyses were conducted around two dimensions. First, the impact of E-learning on physicians' knowledge about TB. Comparison of knowledge scores was made before and after the training activities among TB health workers. Besides, we used two different identification strategies to capture the association between knowledge improvement and E-learning interventions. We employed the following DID model to control for the unobserved time-invariant fixed effects and common time-varying trends (formula 1):

$$(1) Y = \beta_0 + \beta_1 t + \beta_2 \text{Training} * t + \beta_3 X + \alpha_i + \varepsilon$$

The subscript i indicates the medical institutions (for clinical and public health physicians) or township (for primary care workers). The dependent variables Y represents TB knowledge score among TB health workers. α_i is a series of institutional-level fixed effects (for clinical and public health physicians) or township-level fixed effects (for primary care workers) that controls for the unobserved time-invariant heterogeneity across institutions or towns. ε refers to the error term. X is a set of covariates including the health workers' gender, age, permanent post, professional titles, education level, medical discipline, length of service, and monthly income. The key variable of interest is a dummy variable - *Training*. It equals 1 for physicians in pilot areas after the implementation training program and equals 0 for other situations. The coefficient of *Training* (β_2) captures the average treatment effects of the E-learning intervention on the knowledge scores.

Multivariate linear regression was also conducted to capture which training format is the most effective in terms of knowledge improvement (formula 2), and to quantify the dose–response relationship between training participation and the accumulation of TB knowledge (formula 3). The subscript f , s , and a indicate three different formats of training: face-to-face training, synchronous E-learning, and asynchronous E-learning. There are two variables of interest: *Training* here is a dummy variable; it equals 1 if the physician has participated in a specific type of training. *T_times* is a continuous variable that stands for the number of sessions related to this specific type of training. In other words, if there β_2 , β_3 , or β_4 statistically significant in the following model, we can conjecture that the training intervention may have a positive or negative impact on physicians' knowledge.

$$(2) Y = \beta_0 + \beta_1 t + \beta_2 \text{Training}_f + \beta_3 \text{Training}_s + \beta_4 \text{Training}_a + \beta_5 X + \alpha_i + \varepsilon$$

$$(3) Y = \beta_0 + \beta_1 t + \beta_2 T_times_f + \beta_3 T_section_s + \beta_4 T_times_a + \beta_5 X + \alpha_i + \varepsilon$$

The second dimension was the effectiveness of E-learning on physicians' TB control practice, which is mostly based on qualitative data with quantitative supplementary data. We transcript and analysed the interviews using a thematic framework approach. The analytical framework was developed based on the topic guides and emerging issues from the

interviews and FGDs. The quantitative data were analysed using Stata 14.0 (StataCorp, College Station, TX, USA) and the qualitative data were analysed in MAXQDA 2018 (VERBI GmbH, Berlin, German).

Results

1. Effectiveness of E-learning on TB health workers' knowledge

After the E-learning training, the knowledge level of TB health workers has been significantly improved. The average score of clinical quiz rose from 65 to 82 points ($P < 0.001$), the average score of public health quiz rose from 65 points before the intervention to 71 points ($P = 0.009$), and the average score of primary care quiz rose from 79 points before the intervention to 85 points after the intervention ($P < 0.001$).

However, the further univariate analysis suggested that the change score among the clinical physicians in the pilot area (+ 17 points) was not statistically different from the physicians in the non-pilot area (+ 18 points, $P = 0.714$). Similar results were observed in public health physicians (pilot area: +4 points, non-pilot area: +9 points, $P = 0.772$). Despite the null effect among health workers from the county-level and above, the change score of primary care personnel in pilot areas (10 points) was statistically higher than that in non-pilot areas (4 points, $P < 0.001$, Table 2).

Table 2

Descriptive statistics of TB knowledge change of pre-and post-training for TB health workers (Mean $\pm$ standard deviation, full marks = 100)

		Baseline knowledge score			Final knowledge score		
		Clinical physicians	Public health physicians	Primary care workers	Clinical physicians	Public health physicians	Primary care workers
Total		65 $\pm$ 21	65 $\pm$ 16	79 $\pm$ 19	82 $\pm$ 19***	71 $\pm$ 14***	85 $\pm$ 16***
Intervention	Non-pilot areas	66 $\pm$ 22	63 $\pm$ 19	82 $\pm$ 18	84 $\pm$ 17***	72 $\pm$ 14*	86 $\pm$ 14
	Pilot areas	63 $\pm$ 20	66 $\pm$ 13	74 $\pm$ 19	80 $\pm$ 20***	70 $\pm$ 15*	84 $\pm$ 17***
Training participation	Never participated	—	—	—	81 $\pm$ 20	68 $\pm$ 18	83 $\pm$ 17
	Participated in asynchronous activities	—	—	—	83 $\pm$ 19	73 $\pm$ 11	90 $\pm$ 13
	Participated in synchronous activities	—	—	—	83 $\pm$ 18	—	—
Data source: TB health worker survey. CDCs: Centres for Disease Control and Prevention.							
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ for pre-post difference.							

The DID model showed that after controlling for institutional fixed effects, personal characteristics and other control variables, the knowledge level of clinicians from the county level and above institutions were statistically significant improvement after the E-learning intervention of the China-Gates Project ($P < 0.001$). Nevertheless, the improvement of the knowledge level of pilot areas is slightly lower than that of non-pilot areas for both clinical physicians and public health physicians, and the difference is not significant. However, the results of primary care workers shown a different pattern:

the improvement of knowledge level among primary care workers in the pilot areas was significantly higher than that in the non-pilot areas, with an average improvement of 8.0 points ($P < 0.001$). But the knowledge level of primary care workers in all sample areas did not change significantly before and after the intervention (Table 3).

Table 3
Effect of China-Gates TB training program on health workers' knowledge: Difference-in-Difference model

Independent variables	Dependent variables: knowledge score		
	($\bar{x}$) Clinical physicians	($\bar{x}$) Public health physicians	($\bar{x}$) Primary care workers
Time (Final = 1; Baseline = 0)	17.26*** (3.09)	8.88** (4.34)	1.75 (1.41)
Time $\times$ Area (pilot area = 1, non-pilot area = 0)	-2.16 (3.82)	-4.09 (6.00)	7.97*** (2.22)
Controls for institution fixed effect and individual characteristics	Yes	Yes	Yes
Sample size	334	168	721
Adjusted R^2	0.364	0.558	0.365
Data source: TB health worker survey. Standard deviation in parentheses. Control variables including dummy variables (township-level or institutional fixed effect, gender, permanent post, academic major, professional titles, and job positions) and continuous variables (age, monthly income, years of medical education, and length of service).			
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.			

The results of multivariate linear regression showed that for the clinical physicians who actually participated in the training of the China-Gates E-learning Program, their clinical knowledge improved more than their colleagues who did not participate. After controlling for institutional fixed effects and personal characteristics, with “whether to participate in remote training” and “number of participants” as the measurement of participation, the TB knowledge level of clinical physicians who have participated in synchronous learning activities increased by 7.3 points on average ($P = 0.023$). For each time they participate in a synchronous session, their clinical TB quiz score could increase by 0.3 points on average ($P = 0.034$). Asynchronous learning activities have no significant impact on the knowledge level of clinical and public health physicians, but a significant positive effect was seen among primary care staff. Compared with those who did not participate, the knowledge level increased by an average of 10.9 points for trained primary care workers ($P < 0.001$). For each module they participated in, their knowledge scores could increase by an average of 1.8 points ($P < 0.001$). Moreover, after they obtain a certificate, the average score of the participants could increase by 11.2 points ($P < 0.001$). Traditional face-to-face training has no significant impact on the improvement of the knowledge for public health and primary care staff, and even has a negative impact on clinical physicians. We didn't find any statistically significant improvement for the public health physicians in terms of their TB knowledge level, no matter what format of training they have taken (Table 4).

Table 4
Effect of China-Gates TB training program on health workers' knowledge: multivariate linear regression model

Independent variables	Dependent variables: knowledge score					
	($\bar{x}$)	($\bar{x}$)	($\bar{x}$)	($\bar{x}$)	($\bar{x}$)	($\bar{x}$)
	Clinical physicians	Public health physicians	Primary care workers	Clinical physicians	Public health physicians	Primary care workers
Time (Final = 1; Baseline = 0)	12.38***	6.12*	0.64	12.57***	7.57**	1.75
	(3.38)	(3.96)	(1.35)	(2.99)	(3.79)	(1.41)
Participated in the face-to-face training (Yes = 1, No = 0)	1.63	2.94	0.40	—	—	—
	(2.97)	(5.08)	(2.20)	—	—	—
Participated in the synchronous learning activities (Yes = 1, No = 0)	7.28**	—	—	—	—	—
	(3.19)	—	—	—	—	—
Participated in the asynchronous learning activities (Yes = 1, No = 0)	1.63	2.94	10.94***	—	—	—
	(2.97)	(5.08)	(1.92)	—	—	—
Count of face-to-face sessions	—	—	—	-0.45**	-0.13	0.0004
	—	—	—	(0.20)	(0.68)	(0.18)
Count of synchronous activities	—	—	—	0.34**	—	—
	—	—	—	(0.16)	—	—
Count of asynchronous activities	—	—	—	0.40	-0.15	1.84***
	—	—	—	(0.41)	(1.13)	(0.31)
Obtained the certificate (Yes = 1, No = 0)	—	—	—	0.75	0.51	11.24***
	—	—	—	(3.55)	(7.92)	(2.08)
Controls for institution fixed effect and individual characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Sample size	333	169	721	332	169	719
Adjusted R ²	0.357	0.546	0.382	0.376	0.539	0.392
Data source: TB health worker survey. Standard deviation in parentheses. Control variables including dummy variables (township-level or institutional fixed effect, gender, permanent post, academic major, professional titles, job positions) and continuous variables (age, monthly income, years of medical education, length of service).						
*** p < 0.01, ** p < 0.05, * p < 0.1.						

We conducted three different types of sensitivity analyses. For the multivariate linear regression model, the dependent variable was replaced from the original score to the Z-score, and found that the results did not change significantly. For the DID model, two placebo tests were conducted (test 1: rerandomization; test 2: re-allocation according to the quality control subproject – another China-Gates TB control subproject). After re-grouping, the interaction coefficients between the pilot area and the time variable were no longer significant, indicating that the intervention effects we observed were not due to a random factor or the effects of other pilot projects. In the leave-one-out analysis, we run the DID model again with excluding one of 13 counties each time. Although the interaction terms were only significant at the $\alpha = 0.1$ level after

excluding the samples of Tongxin or Nong'an counties, they were still are significantly positive at the $\alpha = 0.05$ level after excluding the other 11 counties one by one, indicating that the improvement in the level of knowledge of the medical staff was significant and robust (Appendix 1).

2. Effectiveness of E-learning on healthcare worker's behaviour

The E-learning project not only improved the knowledge of tuberculosis among medical staff, but also enabled some medical staff to apply the knowledge they learned in their daily practice, which improved their quality of care. We measured their perceptions of the impact that E-learning would have on their practice as a proxy indicator of behaviour. Overall, there was high heterogeneity in the impact on the medical staff's behaviour. The behaviour change varied among medical staff in different regions and at different levels of institutions.

According to the results of the questionnaire survey, 56.0% (93/166) of the 166 synchronous E-learning session participants agreed that "the training knowledge can be applied to my work". The univariate analysis suggested that medical staff at the provincial level ($P < 0.001$), undergraduate degree or above ($P < 0.001$), and pilot areas ($P = 0.039$) were more likely to agree with this argument. For asynchronous E-learning training, among the 309 participants, 57.3% (177/309) agreed that the knowledge and skills they learned through the program can be applied to their work. Compared with the results of synchronous E-learning, the proportion of county-level and low-educated personnel agreed on that argument in asynchronous E-learning training was higher (Table 5).

Table 5

% of TB health workers felt the knowledge and skills they learned through E-learning program can be applied in their daily practices

		Clinical and Public health physicians		Primary care workers (N = 136)
		Synchronous E-learning activities (N = 166)	Asynchronous E-learning activities (N = 173)	
Total		56.0	57.2	57.4
Province	Zhejiang	67.4	61.9	84.2
	Jilin	54.8	56.0	53.3**
	Ningxia	45.5	51.4	50.0**
Level of institutions	Provincial	76.7	72.9	—
	Prefecture	50.8***	59.7***	—
	County	34.9***	41.4***	—
Areas	Non-pilot areas	44.2	49.3*	56.5
	Pilot areas	61.4	63.0	57.8
Education level†	Technical school or below	28.0	44.1	48.2
	College (3 years)	61.1***	61.1	61.0
	University or above (≥ 5 years)	60.7***	58.1	70.0
Data source: TB health worker survey. CDCs: Centres for Disease Control and Prevention.				
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ for Chi-Squared Test.				

In the interview, medical staff who believed the training could change their practice behaviour mentioned that the knowledge they learned in the China-Gates E-learning helped them in three ways: First, doctors at the city and county level or junior doctors learned what they did not know before, such as the knowledge about standardized TB diagnosis and treatment, or they got a more clear and deeper understanding about the knowledge that used to be vague. When they encounter the same situation mentioned in the training in their clinic, they can adopt the more standardized medical practice. The second is for doctors at the provincial and municipal levels, they have a chance to see more intractable cases through training, and learn cutting-edge progress of TB diagnosis and treatment from the national experts. All of them were helpful to cultivate their clinical thinking and they were better prepared for complex clinical problems. The third is that the training itself created a good learning environment in the department, and imperceptibly promotes the learning habit of doctors.

Just like when I first time, I went to listen to some sessions about immunization, about molecular biology, about genes, I was also blinded, but after listened several times, I slowly know that they are talking about. I guess it is just gradual progress, we are cultivating a learning habit during training, and then we can make progress in our clinical (practice). (Provincial TB health professional FGD in Jilin)

During the interview, three main reasons were also put forward for the medical staff who thought they could not apply the knowledge into their practices. First of all, some physicians complained that they have not remembered the new knowledge, or they just reviewed some topics that they have already mastered, either condition would offer any help to their practices. The second reason is due to the hardware equipment. Some county-level medical personnel mentioned that even if they improve their knowledge through training, the equipment, drug list, and laboratory capabilities of their medical institutions cannot be compared with national-level hospitals – they couldn't do the same lab test and treatment as national hospitals usually do. The third reason is that the knowledge learned was not relevant to their daily work. Many public health personnel in the interviews reported that the training content they received did not cover the topics in their daily work and was not helpful.

The problems in daily work are not reflected in the training. I don't understand the problems in the statistical report, but the training has no content on this. (County TB public health physician's interview in Ningxia)

Discussion

To our knowledge, this is the first research with a focus on the implementation and effectiveness of E-learning CME activities in the low- and middle-income countries. Under the dual background of the lack of high-quality educational resources for grassroots doctors, and the great challenges that traditional continuing medical education facing due to the COVID-19 pandemic, E-learning CME has important policy significance in low- and middle-income countries. Our research results have demonstrated that E-learning can significantly improve the knowledge level of participating clinical TB physicians. Moreover, it has a greater effect on primary care workers, and plays an important role in "equalization for basic theory, knowledge, and essential skills" among different level of institutions. However, we didn't see the obvious benefits for public health physicians.

Our results are quite different from most previous studies in higher education settings, most of which identified negative effects of online courses on college student education (Alpert, Couch, & Harmon, 2016; Bambara, Harbour, Davies, & Athey, 2009; Banerjee & Duflo, 2014; Bowen, Chingos, Lack, & Nygren, 2013; B. W. Brown & Liedholm, 2002; Chevalier, Dolton, & Luhrmann, 2014; Figlio, Rush, & Yin, 2013; Hart, Friedmann, & Hill, 2018; Hoxby, 2014; Oreopoulos, Petronijevic, Logel, & Beattie, 2018; Perna et al., 2013; Smith, 2017; Streich, 2014; Xu & Jaggars, 2013; Xu & Jaggars, 2014). These differences illustrate that the impact of modern educational technology on education is very complex. It may improve students' access to high-quality resources and therefore have a positive impact on students' learning outcomes, and it may also affect the learning experience and have a negative impact. Most of the existing research focuses on comparing the face-

to-face and online training in which the students can receive the same educational resources. The online training format may prohibit students' active participation in the learning process, resulting in negative learning outcomes. Few studies have been done to explore the effect of E-learning in the context of uneven distribution of educational resources to grassroots doctors, who had no access to national and provincial medical education resources without the E-learning opportunities.

Our results indicate different benefits based on the training format and the target group. First, from the perspective of target group, primary health workers have the greatest benefits, while public health personnel benefited the least. Mismatch of training supply of & demand for training and environmental factors are the main reasons of the differences (Wang, et al, unpublished). In the China-Gates TB control project, the training supply and demand for clinical physicians and primary care personnel are well matched, while the training contents for public health physicians were not consistent with what they demanded. Secondly, in terms of training format, this study found that the two types of E-learning training were both effective in some ways, but the face-to-face training were not significantly effective. This is consistent with the relevant research results in other fields of medical continuing education (Cervero & Gaines, 2015), suggesting that the existing traditional CME model needs to be reformed.

This study has several limitations. Firstly, this study did not collect panel data at the individual level. Due to data availability, we collected two-phase repeated cross-sectional data, which was a representative sample of health workers in the study sites. The regression analysis may have endogenous missing variables. This study employed three different strategies in statistical analysis to enhanced the validity of the results. Secondly, this study did not involve the objective measurement of physicians' health service delivery behaviour to evaluate the effect of training intervention on physicians' behaviour. Instead, we used the self-reported behavioural change after the training. Third, the whole China-Gates TB project is a set of comprehensive and complex interventions. Many project counties have multiple interventions at the same time, such as the development of new information systems, application of electronic medical monitors, and the health insurance payment reform for tuberculosis patients. All these interventions might have an impact on the physician's knowledge level, and it is difficult to distinguish the specific effects of each intervention. However, sensitivity analysis showed no evidence that other interventions have a direct impact on the knowledge level of medical staff.

Conclusion

This study indicates different benefits of E-learning based on the training format and the target group. For TB clinical and primary care health workers, E-learning interventions are associated with higher TB knowledge level. However, public health physicians do not get significant benefits from the E-learning activities. Traditional face-to-face training has no significant impact on all types of medical staff. Future studies on E-learning activities in CME should explore the learning environment within the health systems to further realize the potentials of E learning activities to improve health workers' knowledge and behaviour.

Abbreviations

TB
Tuberculosis
CME
Continuing medical education
DID
Difference-in-difference
COVID-19
Coronavirus disease 2019

GDP
Gross Domestic Product
CDC
Centre for Disease Control and Prevention
FGDs
Focused Group Discussions

Declarations

Ethical approval and consent to participate

The Duke University Institutional Review Board provided ethics approval of the survey (Approval number: 2017-0768). All respondents read a statement that explained the purpose of the study and gave their consent to continue.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors report no competing of interest. The authors alone are responsible for the content and writing of this article.

Authors' Contributions

XL and ST conceived and designed the study. ZW, LZ, and WJ participated the surveys and conducted data analysis. ZW prepared the tables and figures; ZW, LZ, and XL wrote the first draft of the manuscript. ST and YL contributed to and critically revised the manuscript. All authors reviewed and approved the final manuscript. ZW and LZ contributed equally to this work and should be regarded as co-first authors.

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Figures

Figure 1

evaluation design

Figure 1

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