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## Community-based tuberculosis active case-finding with mobile x-ray units in Lima, Peru: a RE-AIM evaluation

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## Community-based tuberculosis active case-finding with mobile x-ray units in Lima, Peru: a RE-AIM evaluation

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## ABSTRACT

**Objectives:** Identify barriers and facilitators to integrating community tuberculosis screening with mobile x-ray units into a health system.

**Methods:** RE-AIM (Reach, Effectiveness, Adoption, Implementation, Maintenance) evaluation.

**Setting:** A 3-district region of Lima, Peru.

**Participants:** 63,899 people attended the mobile units during February 7, 2019–February 6, 2020.

**Interventions:** Participants were screened by chest radiography, which was scored for abnormality by computer-aided detection. People with abnormal x-rays were evaluated clinically and by GeneXpert MTB/RIF (Xpert) sputum testing. People diagnosed with tuberculosis at the mobile unit were accompanied to health facilities for treatment initiation.

**Primary and secondary outcome measures:** Reach was defined as the percentage of the population of the 3-district region that attended the mobile units. Effectiveness was defined as the change in tuberculosis case notifications over a historic baseline. Key implementation fidelity indicators were the percentages of people who had chest radiography performed, were evaluated clinically, had sputum samples collected, had valid Xpert results, and initiated treatment.

**Results:** The intervention reached 6% of the target population. In the three districts, average quarterly tuberculosis case notifications were 4–17% higher than expected based on trends from the previous four years. Implementation indicators for screening, sputum collection, and Xpert testing procedures all exceeded 85%. Only 82% of people diagnosed with tuberculosis at the mobile units received treatment; people with negative or trace Xpert results were less likely to receive treatment. Suboptimal treatment initiation was driven by health facility doctors' lack of familiarity with Xpert and lack of confidence in diagnoses made at the mobile unit.

**Conclusion:** Mobile x-ray units were a feasible and effective strategy to extend tuberculosis diagnostic services into communities and improve early case detection. Effective deployment however requires advance coordination among stakeholders and targeted provider training to ensure that people diagnosed with tuberculosis by new modalities receive prompt treatment.

## SUMMARY

### Strengths and limitations of the study

- We evaluated a large program that used mobile x-ray units that screened over 60,000 people in a middle-income country with a high tuberculosis burden during its first year of implementation.
- The structured implementation science evaluation allowed us to not only report the performance of the program but draw conclusions about how to incorporate mobile x-ray units for tuberculosis screening into existing health systems in similar settings.
- However, it should be noted that our study only reflects the first year of implementation and therefore cannot speak to impact or maintenance over a longer term.

## INTRODUCTION

Globally, tuberculosis (TB) kills more people each year than any other infectious disease, and up to 30% of people who develop TB each year are not diagnosed and treated.[1] While better diagnostic technologies and treatments are urgently needed, underutilization of strategies with demonstrated effectiveness also contributes to the slow pace of decline in global TB incidence.[2] One such strategy is targeted active case-finding, where health systems seek out people at high risk for TB through screening of high-risk groups.[3] Since effective treatment renders TB noninfectious,[4] active case-finding can reduce TB transmission by diagnosing more people, diagnosing them earlier, and linking them to prompt treatment.

There are many possible approaches to active case-finding, one of which is using mobile units equipped with x-ray equipment. This strategy can help close the gap in missed diagnoses both by making it convenient for people to get screened in their own communities, and by using a sensitive screening method (chest radiography) that can detect TB before they perceive symptoms.[5] In the 1930-1960s mobile x-ray units were an integral part of TB programs in industrialized countries.[6, 7] In the past decade, some middle-income countries in Asia have incorporated mobile x-ray units for active case-finding into their TB programs,[8-10] and others have used mobile x-ray units in prevalence surveys and pilot projects. However, this strategy is not yet used widely in countries with high TB burdens.

As with the introduction of any new technology, integration of mobile x-ray units into TB programs that have never used them comes with implementation challenges. Implementation research, which systematically and rigorously assesses the implementation of evidence-based interventions in real-world settings, can help to guide the introduction of new practices at a programmatic scale.[11] However, as is the case for many TB interventions,[12] there is a

dearth of implementation research around the use of mobile x-ray units in communities with high TB burdens. To address this gap, in Lima, Peru, we used an implementation science framework to evaluate an active case-finding program that introduced mobile x-ray units with computer-aided detection in a setting where routine TB diagnostic services used a different approach. We sought to assess the impact of the intervention and to identify barriers and facilitators to integrating the intervention approach into the local health system.

## METHODS

We conducted a RE-AIM evaluation [13] of the first year of implementation of TB Móvil, a program that uses x-ray vans for TB active case-finding in community settings. TB Móvil is an ongoing program that is part of the Zero TB Initiative,[14] an alliance of implementers committed to creating islands of TB elimination through the deployment of a comprehensive strategy that includes searching actively for cases using sensitive diagnostics, treating active cases as quickly as possible with the correct medications, and preventing disease through the treatment of TB infection and infection control in congregate settings.[2] During the evaluation period, it was implemented by an intervention team from the non-governmental organization Socios En Salud in collaboration with the Ministry of Health, municipal governments, and community organizations.

### Study population and setting

The intervention area comprised three districts with a combined population of 1.1 million,[15] and annual TB case notification rates of 120-130 per 100,000. TB Móvil started implementation in February 2019 in northern Lima. During the first year, the intervention



operated for 12 months in Carabayllo district (district A), 9 months in Comas district (district B), and 3 months in Independencia district (district C).

In the intervention area, TB services are concentrated in 51 public health facilities operated by the DIRIS Lima Norte (the regional authority of the Ministry of Health). The intervention area also contains a regional referral hospital operated by the Ministry of Health, as well as a regional hospital and four primary care centers operated by EsSalud, a government insurance program for people employed in or retired from the formal economy. There is no private-sector TB treatment in Peru.[16] During the evaluation period, the routine approach to TB detection was a two-step process of screening for respiratory symptoms among people seeking care at health facilities and then using sputum smear microscopy to diagnose TB; this approach is known to have limited sensitivity.[17] Although radiography has higher sensitivity for TB detection, only hospitals and large health facilities had x-ray capacity.

### **Intervention**

We operated two mobile screening units for 8 hours per day for 28 days a month, spending the number of months described above in each district. X-ray vans were equipped with Cad4TB v6 (Delft, 's-Hertogenbosch, Netherlands) automated detection software to efficiently triage attendees such that only those with abnormal radiographs consistent with TB underwent further evaluation procedures. We worked with local community leaders to choose screening locations with high foot traffic such as parks, community centers, and markets. We partnered with health facility decision-makers to operate screening sites immediately outside the facility to screen both health facility attendees and health care workers. We also partnered with transportation companies to operate screening sites at the terminals of major bus lines with the

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2  
3 goal of making screening accessible to working adults as they commute. Finally, we partnered  
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5 with companies and institutions to screen staff and residents. A structured community  
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7 engagement strategy was used to inform and educate local residents about the program and  
8  
9 encourage attendance.[18]

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12 People  $\geq 4$  years old were eligible for screening provided they were not receiving TB  
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14 treatment (Figure 1). Children  $< 4$  years old were eligible for screening only if they were close  
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16 contacts of TB patients; this is because the Cad4TB v6 software was validated only for children  
17  
18  $\geq 4$  years old. After registering for screening, attendees waited for chest radiography; during the  
19  
20 wait time, which ranged from 5-50 minutes depending on attendance, attendees received  
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22 education about TB symptoms, transmission, and diagnosis. Chest radiography was performed  
23  
24 in the x-ray van by a radiography technician and scored automatically by Cad4TB. People with  
25  
26 abnormal radiographs were referred to a physician at the screening unit for clinical evaluation  
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28 and were asked for a sputum sample for testing by GeneXpert MTB/RIF (Cepheid, Sunnyvale,  
29  
30 CA, USA; referred to as “Xpert”). Field staff used their discretion in requesting sputum from  
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32 young children given children’s general inability to produce sputum.[19] Xpert testing was  
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34 performed at the Socios En Salud laboratory initially using standard cartridges and switching to  
35  
36 “Ultra” cartridges after 6 months. People could be diagnosed with TB based on a positive Xpert  
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38 result or by the physician at the screening unit based on clinical and radiographic evidence. All  
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40 people diagnosed with TB were accompanied by community health workers (community  
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42 members with basic training in health issues) to public health facilities for treatment initiation.  
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44 All procedures were free of cost. Data on all procedures were directly entered into an electronic  
45  
46 data collection system; data on treatment initiation reflects results obtained by 13 March 2020.  
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## RE-AIM evaluation

We used the RE-AIM framework [13] to evaluate how the intervention's approach to TB active case-finding performed within the Peruvian health system. Several components of the intervention approach differed from routine practice within the local TB services: (1) screening and evaluation services were provided within community settings, (2) people without symptoms or risk factors could be screened, (3) chest radiography was used for screening and to aid diagnosis, and (4) Xpert was used for bacteriologic testing. Evaluation focused on understanding how well the health system was able to incorporate these new approaches and their impact on TB diagnosis.

To assess **reach**, we divided the number of people who registered for screening and who reported living in each of the three districts by the number of residents in these districts. We further stratified analysis by age and sex. We specifically assessed reach among males and people 15-44 years old (referred to as "working-age adults"), as these demographic groups comprise the majority of TB cases diagnosed in Peru.[16] We used a Wilcoxon rank-sum test to compare the proportion of attendees who were male and the proportion who were working-age adults among different types of screening sites, using an exact test for categories with  $\leq 5$  sites, and considering  $p < 0.05$  as significant.

To assess **effectiveness**, we considered two main objectives of active case-finding: to diagnose additional cases and to diagnose cases earlier. To assess additionality, we obtained quarterly case notifications from each of the three districts during 2015-2019. We coded each quarter as pre-intervention or intervention and calculated the average difference between actual case notifications during intervention quarters and expected notifications assuming a linear trend

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2  
3 based on the pre-intervention quarters. We included in this analysis only health facilities that  
4 notified TB cases during both the pre-intervention and intervention periods to eliminate bias  
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6 from changing catchment populations. To assess whether cases were diagnosed early, we  
7  
8 assessed the percentage of cases that had a positive sputum smear microscopy result. Smear  
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10 positivity is associated with increased sputum bacillary load,[20] which is a marker for more  
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12 advanced disease.[21]  
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17 To assess **adoption** of the intervention approach by the health system, we used both  
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19 quantitative and qualitative approaches. As a quantitative measure of adoption, we calculated  
20  
21 the percentage of health facilities that accepted having the mobile unit stationed outside to screen  
22  
23 their staff and clients. We also analyzed the time between screening and treatment initiation for  
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25 people diagnosed with TB by the intervention; this is because we considered the promptness of  
26  
27 treatment initiation to be an indicator of the health system's ability to incorporate the  
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29 intervention approach into existing services. For a qualitative measure of adoption, we examined  
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31 descriptions of interactions with stakeholders in the health system regarding implementation of  
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33 the intervention, as recorded in meeting minutes from monthly coordination calls and quarterly  
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35 reports to intervention funders.  
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40 To assess **implementation**, we quantified performance indicators using a framework for  
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42 evaluation of TB active case-finding.[22, 23] We focused on five key indicators that reflect  
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44 implementation fidelity: percentage of people registered who were screened by chest  
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46 radiography, percentage of people with abnormal chest radiographs who were evaluated  
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48 clinically, percentage of people with abnormal chest radiographs who had sputum samples  
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50 collected for Xpert testing, percentage of sputum samples with valid Xpert results, and  
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percentage of people diagnosed with TB who initiated treatment. Where any of these fell below 85%, we probed operational data to identify reasons for suboptimal fidelity.

Our **maintenance** assessment focused on institutional factors that would promote or inhibit the continued use of the intervention approach within the public health system. Given that the intervention was grant-funded for this first year, we reviewed call minutes and program reports from the evaluation period for evidence of investment by the health system in maintaining or expanding the intervention.

### **Patient and public involvement**

Patients and the public were involved in multiple aspects of program implementation and research. Patient and community preferences were taken into account when developing the implementation plan for the intervention. During program implementation, our community engagement strategy involved meeting with community leaders prior to the arrival of the screening program in a community to gain community buy-in and disseminate information. In addition, recruitment of people to the screening program was mostly done by community members, including community health workers, TB survivors, and community-based artists. Results of the intervention have been progressively disseminated to the community via social media. As with all studies implemented by Socios En Salud, the research plan was presented to a community advisory board for approval.

### **Ethical considerations**

The intervention and evaluation were approved by the Ethics Committee of the Universidad Peruana Cayetano Heredia. A waiver of informed consent for screening procedures and data collection was granted on the basis that procedures posed minimal risk to participants

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3 and that informed consent could not feasibly be administered in the context of a high-volume  
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5 community screening program. The Harvard Medical School IRB determined that its  
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7 involvement did not constitute human subjects research.  
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## 11 RESULTS

### 14 Reach

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17 In one year, the two mobile units registered 63,899 attendees at 215 screening locations  
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19 in north Lima. Of these, 58,962 (92%) reported residing in the intervention area. We estimate  
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21 that the mobile unit screening reached 6% of residents in the intervention area, including 9% of  
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23 district A residents, 4% of district B residents, and 3% of district C residents. Coverage was  
24  
25 higher for females versus males in all districts (A: 11% vs 7%; B: 5% vs 3%; C: 3% vs 2%; p  
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27 <0.001 for all comparisons). Coverage was higher among older adults compared to younger  
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29 adults (Figure S1).  
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33 Sites where screening was open to the public included general community locations,  
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35 health facilities, markets, transport terminals, and a shopping mall (Table 1). At general  
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37 community screening sites, a median of 39% (interquartile range [IQR]: 36–42%) of attendees  
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39 were male, and a median of 41% (IQR 36–44%) of attendees were working-age adults. In  
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41 comparison, transport terminal sites had significantly higher percentages of both male attendees  
42  
43 and working-age attendees. In addition, the mobile units were stationed at five sites where  
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45 screening was restricted to staff and residents of specific institutions known to have  
46  
47 predominantly young and male populations, including an army barrack, a police complex, two  
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49 companies, and a technical college. These sites also had significantly higher percentages of male  
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51 and working-age attendees.  
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**Table 1:** Percent male and working-age attendees, by type of screening site

Type of site	Number of sites	Percent male attendees			Percent working-age attendees (age 15-44)		
		Median	IQR	p-value	Median	IQR	p-value
General community	156	39	36-42	ref	41	36-44	ref
Health facilities	32	34	31-39	<0.001	39	36-43	0.508
Markets	12	40	37-41	0.528	40	36-44	0.837
Transport terminals	9	65	62-69	<0.001	46	44-51	<0.001
Company or institution	5	61	56-64	<0.001	89	80-90	<0.001
Shopping mall	1	38	N/A	0.854	61	N/A	0.013

IQR = interquartile range. N/A = not applicable. P-value from Wilcoxon rank sum test.

## Effectiveness

During the evaluation period, the intervention diagnosed TB in 393 people, of whom 343 (87%) reported living in the intervention area. Average case notifications were 13% higher than expected during 4 intervention quarters in district A, 4% higher than expected during three intervention quarters in district B, and 17% higher than expected during 1 intervention quarter in district C (Table S1). Of people diagnosed with TB, 388 (99%) had a valid Xpert result, of whom 315 (81%) had a positive result (including trace positive results). All 388 also had smear microscopy performed, with only 99 (26%) having a positive result.

## Adoption

During the evaluation period, the intervention team approached 32 health facilities in the three districts to ask if the mobile unit could be stationed outside the health facility to screen clients and staff. All (100%) accepted. These facilities included both hospitals, 29 of the 51 (57%) public health facilities overseen by the DIRIS Lima Norte, and one of the four (25%) EsSalud primary care facilities. A report noted that the intervention team received requests for additional screening locations than it could not accommodate (Table 2).



**Table 2:** Observations relating to adoption and maintenance recorded in meeting minutes and reports

RE-AIM construct: theme	Quotation from meeting minutes
Adoption: requests for intervention services by health system	“We have received numerous requests to bring the van to screen in different areas of Lima; although we have not been able to accommodate these requests, they demonstrate the demand for such services.” (Q1 2019 report)
Adoption: challenges to having TB diagnoses accepted by health system	“While the screening program operated successfully, we have encountered challenges with delayed treatment initiation for people diagnosed with TB. This has happened because the doctors are requesting more procedures (such as CT) before deciding to initiate treatment, and many of them have limited knowledge of GeneXpert.” (Q4 2019 report)
	“Some people with positive GeneXpert results have to wait to see a pulmonologist, delaying treatment initiation.” (November 2019 meeting minutes)
Adoption: facilitators to having TB diagnoses accepted	“We held some meetings with [an infectious disease doctor from the United States] in which he talked about GeneXpert Ultra and its use. This helped the doctors in the primary care facilities of Carabayllo understand better the response to these cases.” (September 2019 meeting minutes)
Maintenance: expansion of intervention to other areas with Ministry of Health support	“The TB Movil intervention is being offered to the Ministry of Health in the municipality of La Victoria.” (January 2020 meeting minutes)
	“There is a possibility that the Ministry of Health will give us access to 8 cases of Xpert cartridges that are currently in [another city]. The objective is to use them in north Lima and also other screenings that the Ministry of Health coordinates. We are discussing whether to do the Xpert testing in the Socios En Salud laboratory or a Ministry of Health laboratory.” (January 2020 meeting minutes)
Maintenance: integration of intervention approach into policy	“We have had meetings with the Ministry of Health and the National TB Program in which they expressed interest in developing a directive for TB active case-finding. We presented the approach of TB Móvil. The meeting was with [Dr. X], with whom we have another meeting scheduled for next week to discuss the coordination of the activities of TB Móvil and the Ministry of Health.” (November 2019 meeting minutes)

Among patients with Xpert-positive rifampicin-susceptible TB who initiated treatment, the median time from screening to treatment initiation was 6 days (IQR 3–11 days). Time to treatment initiation was not significantly different for those with rifampicin-resistant TB (median 7, IQR 3–18 days;  $p=0.607$ ). However, time to treatment initiation was longer for those without a positive Xpert result (median 9, IQR 4–23 days;  $p=0.026$ ) and those with trace positive Xpert results (median 11, IQR 4–28 days,  $p=0.003$ ).

Challenges in having diagnoses from the intervention accepted by the health system were documented in meeting minutes and reports (Table 2). One reason for delay was that people

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3 diagnosed with TB were referred for re-evaluation by pulmonologists at the government  
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5 hospitals, even if they had positive Xpert results, underlining a lack of knowledge about this  
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7 diagnostic test and its significantly higher sensitivity as compared to sputum smear microscopy.  
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10 The utility of education for providers in reducing treatment delays was also documented.  
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12 Meetings in which health facility physicians were trained with regards to the role of radiography  
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14 and Xpert in TB diagnosis were noted to have improved the acceptability of diagnoses coming  
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16 from the intervention and reduced treatment initiation delays.  
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## 22 Implementation

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24 Of the 63,899 attendees registered over 1 year, 58,268 (91%) had chest radiography  
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26 performed (Table 3). One new TB diagnosis was made per 148 people screened by chest  
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28 radiography, and one Xpert-positive diagnosis per 44 people tested by Xpert. We were able to  
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30 confirm treatment initiation for 323 (82%) of the 393 people diagnosed with TB.  
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34 **Table 3:** Implementation indicators for TB Móvil screening program

37 Step	38 Number completing	39 % and denominator
40 Registered for screening	63,899	
41 Chest radiograph performed*	58,178	91% of those registered
42 Chest radiograph abnormal	16,689	29% of radiographs performed
43 Clinical evaluation performed at the screening site*	14,389	86% of those with abnormal radiographs
44 Sputum sample received at laboratory*	13,860	83% of those with abnormal radiographs
45 Valid Xpert result*	13,832	>99% of sputum samples received
46 Xpert-positive	315	2% of Xpert tests
47 Rifampicin resistance detected	71	23% of positive Xpert results
48 New TB cases diagnosed (both Xpert-positive and clinical diagnoses)	393	2% of those with abnormal radiographs
49 TB treatment initiated*	323	82% of those diagnosed with TB

50 \*Key implementation fidelity indicators assessed

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52 The two key implementation fidelity indicators that fell below 85% were the percent of  
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54 people with abnormal chest radiographs for whom sputum samples were submitted and the  
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3 percent of people diagnosed with TB who initiated treatment. When we analyzed sputum  
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5 submission by age, we found that 88% of people age  $\geq 10$  years old submitted a sputum sample,  
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7 compared to 17% of children  $< 10$  years old, suggesting that the suboptimal value of this  
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9 indicator was driven by young children's inability to produce sputum.  
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12 We found that the percentage of people initiating TB treatment varied depending on the  
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14 basis of the TB diagnosis (Figure 2). Treatment initiation was documented for 95% of people  
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16 with Xpert-positive rifampicin-susceptible TB. The percentage of people who initiated treatment  
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18 was significantly lower for all other types of diagnoses (86% for rifampicin-resistant TB,  
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20  $p=0.019$ ; 64% for those with trace positive Xpert results,  $p<0.001$ ; 53% for those without a  
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22 positive Xpert result, who were diagnosed based on clinical and/or radiographic criteria,  
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24  $p<0.001$ ). Rejection of the intervention's TB diagnosis by a health facility physician was  
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26 documented for 9% of those with trace positive Xpert results and 26% of those without positive  
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28 Xpert results.  
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### 35 **Maintenance**

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37 Meeting minutes noted that the Ministry of Health had agreed to let the intervention team  
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39 use its Xpert machines and cartridges to expand the screening program beyond the intervention  
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41 districts (Table 2). A meeting with the National TB Program was also reported which examined  
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43 the possibility of incorporating the x-ray van strategy into a new active case-finding policy. As  
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45 of January 2021, the program has expanded to multiple districts within and outside Lima, with  
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47 the Ministry of Health providing Xpert testing and clinical staff.  
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## DISCUSSION

We found that an intervention using community-based mobile x-ray screening units was effective for increasing TB diagnoses and diagnosing TB that was negative by smear microscopy. In its first year, the intervention reached 6% of the population of a region of around 1 million inhabitants and increased quarterly case notifications by 4–17% across the three districts. Although decision-makers at many health facilities were eager to collaborate with the intervention, we encountered challenges with individual physicians at local clinics not accepting TB diagnoses based on x-ray and Xpert. Our experience illustrates the complexities involved in health-system adoption of a new standard of care that differs substantially from routinized practice.

The high implementation fidelity we observed for procedures that took place at the screening site suggest both demand for free TB diagnostic services and acceptability of mobile x-ray screening units as a way to deliver these services. Despite long wait times, attendees generally completed the screening and evaluation procedures. Moreover, high attendance resulted in a large number of people screened. Our implementation strategy compared favorably to interventions using mobile x-ray units in community settings elsewhere.[8, 9, 24] However, men and working-age adults were underrepresented among attendees, resulting in uneven reach of the intervention. While offering screening at transport terminals and places of work increased attendance for both of these demographic groups, feedback from the implementation team suggested larger structural barriers at play. In Peru, people working in the informal economic sector have no protection from loss of income or employment should they be diagnosed with TB, thus disincentivizing uptake of TB screening. This observation underscores the importance of

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3 legal and social protection programs, in addition to expanded case-finding interventions, for  
4 increasing detection of stigmatized diseases like TB.[25]  
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8 The major implementation barriers we encountered occurred at local health facilities  
9 when people diagnosed with TB by the mobile units went to initiate treatment. Many TB  
10 diagnoses based on trace positive Xpert results or clinical/radiographic criteria were rejected by  
11 the local physicians, and patients experienced delays in treatment initiation. Similar challenges  
12 were observed in other countries when Xpert was first introduced as a replacement for smear  
13 microscopy. In India, the willingness of providers to make clinical diagnoses decreased once  
14 Xpert was introduced, in part because Xpert was viewed as a “gold standard” with perfect  
15 sensitivity.[26] Moreover, variable knowledge about Xpert among providers led to  
16 disagreements over the use of Xpert testing for TB diagnosis.[27] In other countries, treatment  
17 initiation delays for patients with positive Xpert results were observed because of confusion over  
18 guidelines for reporting Xpert-positive patients.[28] While Xpert had been used at a small scale  
19 in Peru’s public health system prior to the present intervention, a lack of knowledge about Xpert  
20 at the primary care level contributed to some reluctance in accepting Xpert diagnoses, especially  
21 when trace positive results were obtained. Together, these challenges emphasize the importance  
22 of clear practice guidelines and regular training for primary-level clinicians when new diagnostic  
23 practices are introduced.  
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44 The primary limitations of this initial evaluation reflect time and resource constraints. We  
45 did not perform qualitative research through interviews or focus groups to better explain the  
46 barriers to adoption of the intervention approach by the health system. For example, we do not  
47 know whether clinical diagnoses of TB in patients with clinical and radiographic findings but a  
48 negative Xpert were rejected because doctors perceived Xpert as having perfect sensitivity or  
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3 because of low inter-rater reliability for chest radiographs, both of which have been observed in  
4 other settings.[26, 29] In addition, we did not collect data about the specific health care  
5 providers or health care facilities managing each patient, which could have allowed us to  
6 determine whether treatment initiation challenges were associated with certain provider or  
7 facility characteristics. Finally, the timeframe of the evaluation limited our ability to quantify  
8 durability of this intervention over time. Thus, while providing useful knowledge for integrating  
9 mobile x-ray units into TB programs in settings with high TB burdens, our study also highlights  
10 areas in which further implementation research is needed.

11  
12 Local coalitions seeking to rapidly drive down TB will have to introduce new strategies  
13 to transform routine services and systems. While new innovations in diagnostic technologies are  
14 needed, increasing and improving the implementation of evidence-based approaches in settings  
15 with high TB burdens is also important. We found that deploying mobile x-ray units with  
16 automated detection software across a high-risk zone constituted a feasible and effective strategy  
17 to extend TB diagnostic services into communities and improve early case detection. Effective  
18 deployment however requires advance coordination among stakeholders and targeted provider  
19 training to ensure that people diagnosed with TB by new modalities receive prompt treatment.  
20 These implementation lessons can be applied by other TB elimination coalitions around the  
21 world, as part of the mutual aid and exchange of resources among coalitions.

## ACKNOWLEDGEMENTS

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## AUTHOR CONTRIBUTIONS

CMY, SK, and MCB conceptualized the study. CMY, DP, JTG, LL, and MCB led the implementation of the intervention. AKM, CT, RIC, MBB, JJ, CC, and TN supported implementation. CMY and DP planned and supervised data collection. CT and TCN helped to collect and clean data. CMY performed the analysis and wrote the first draft of the manuscript, and all authors revised critically.

## COMPETING INTERESTS

The authors declare no competing interests.

## DATA SHARING

Data are available upon reasonable request. Contact the corresponding author for a data request form.

## FIGURE LEGENDS

**Figure 1.** Screening algorithm used at mobile screening units

**Figure 2.** Treatment initiation among people diagnosed with TB by the intervention, by Xpert result (N=393)

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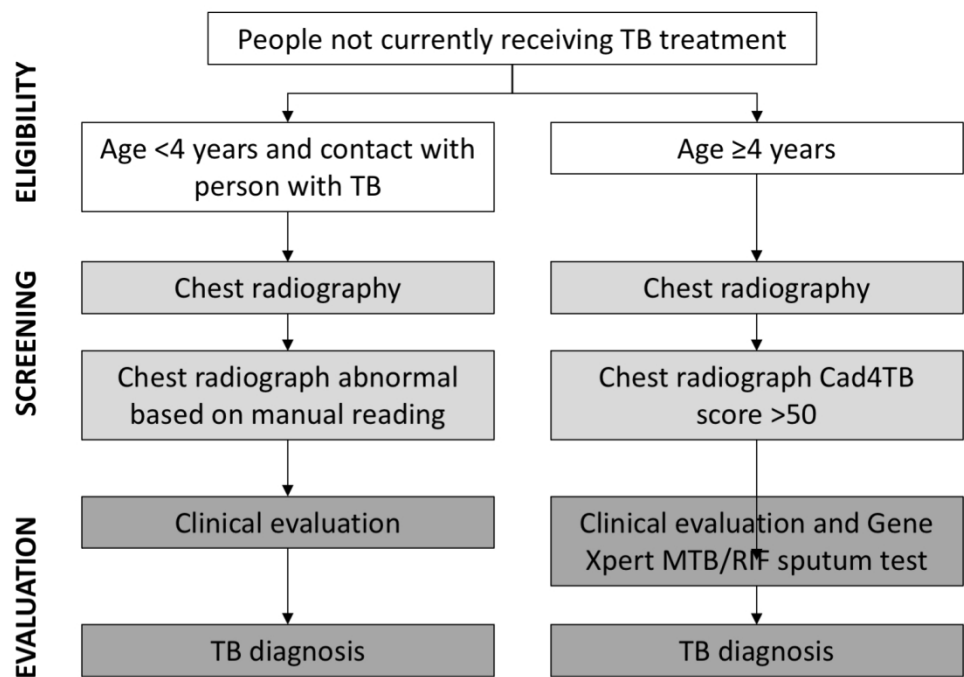
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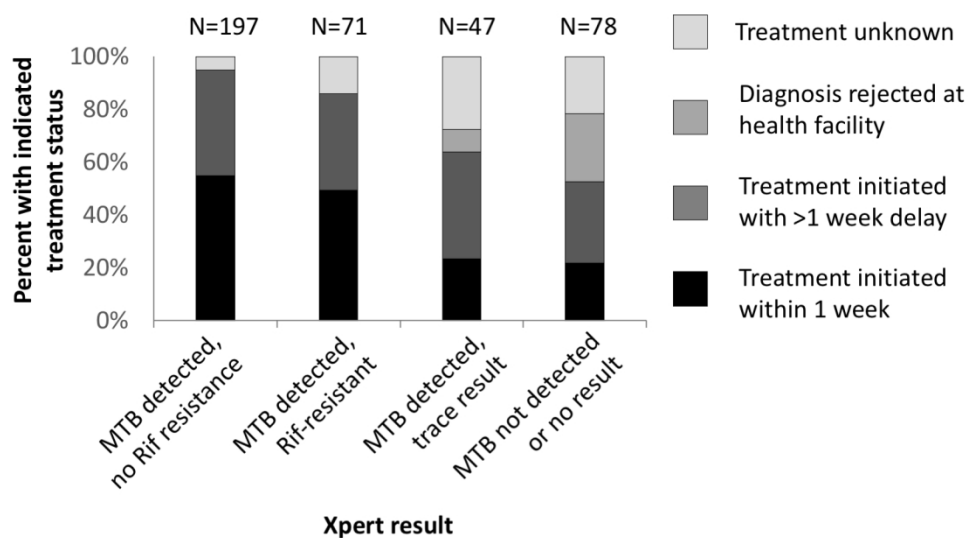
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Supplementary material for “Community-based tuberculosis active case-finding with mobile x-ray units in Lima, Peru: a RE-AIM evaluation”

Figure S1: Percent of intervention area residents reached, by district and age

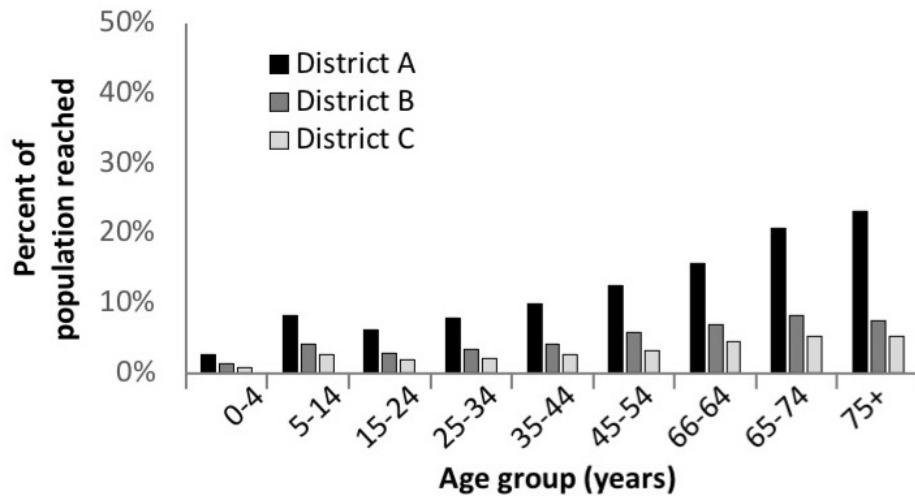


Table S1: Average quarterly TB case notifications during 2015-2019

Time period		Average quarterly TB notifications		
		District A	District B	District C
Pre-intervention period	2015	68	162	74
	2016	69	168	83
	2017	71	168	79
	2018	78	176	84
	2019 non-intervention quarters	N/A	172	78
Expected notifications during intervention quarters based on linear trend from pre-intervention period		78	177	81
Actual notifications during 2019 intervention quarters		88	184	95

# BMJ Open

## Identifying barriers and facilitators to implementation of community-based tuberculosis active case-finding with mobile X-ray units in Lima, Peru: a RE-AIM evaluation

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Secondary Subject Heading:	Health services research, Infectious diseases
Keywords:	Tuberculosis < INFECTIOUS DISEASES, Public health < INFECTIOUS DISEASES, Molecular diagnostics < INFECTIOUS DISEASES





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## Identifying barriers and facilitators to implementation of community-based tuberculosis active case-finding with mobile X-ray units in Lima, Peru: a RE-AIM evaluation

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## ABSTRACT

**Objectives:** Identify barriers and facilitators to integrating community tuberculosis screening with mobile X-ray units into a health system.

**Methods:** RE-AIM (Reach, Effectiveness, Adoption, Implementation, Maintenance) evaluation.

**Setting:** 3-district region of Lima, Peru.

**Participants:** 63,899 people attended the mobile units during February 7, 2019–February 6, 2020.

**Interventions:** Participants were screened by chest radiography, which was scored for abnormality by computer-aided detection. People with abnormal X-rays were evaluated clinically and by GeneXpert MTB/RIF (Xpert) sputum testing. People diagnosed with tuberculosis at the mobile unit were accompanied to health facilities for treatment initiation.

**Primary and secondary outcome measures:** Reach was defined as the percentage of the population of the 3-district region that attended the mobile units. Effectiveness was defined as the change in tuberculosis case notifications over a historic baseline. Key implementation fidelity indicators were the percentages of people who had chest radiography performed, were evaluated clinically, had sputum samples collected, had valid Xpert results, and initiated treatment.

**Results:** The intervention reached 6% of the target population and was associated with an 11% (95%CI 6-16%) increase in quarterly case notifications, adjusting for the increasing trend in notifications over the previous three years. Implementation indicators for screening, sputum collection, and Xpert testing procedures all exceeded 85%. Only 82% of people diagnosed with tuberculosis at the mobile units received treatment; people with negative or trace Xpert results were less likely to receive treatment. Suboptimal treatment initiation was driven by health facility doctors' lack of familiarity with Xpert and lack of confidence in diagnoses made at the mobile unit.

**Conclusion:** Mobile X-ray units were a feasible and effective strategy to extend tuberculosis diagnostic services into communities and improve early case detection. Effective deployment however requires advance coordination among stakeholders and targeted provider training to ensure that people diagnosed with tuberculosis by new modalities receive prompt treatment.

## SUMMARY

### Strengths and limitations of the study

- An implementation science evaluation of a large program that screened over 60,000 people for TB in a middle-income country allowed us to both assess the performance of the program and draw conclusions about how to incorporate mobile X-ray units for tuberculosis screening into existing health systems in similar settings.
- Individual-level programmatic data allowed us not only to assess overall reach and implementation fidelity but also to analyze heterogeneity in these areas.
- The assessment of effectiveness adjusts for temporal trends but is limited by an inability to control for the effects of other program or population changes that might have contributed to increased case notifications.
- The assessment of adoption and maintenance are limited by a reliance on secondary data sources rather than focus groups or interviews.

## INTRODUCTION

Globally, around 10 million people develop tuberculosis (TB) each year, and up to 30% of people who develop TB each year are not diagnosed and treated (1). While better diagnostic technologies and treatments are urgently needed, underutilization of strategies with demonstrated effectiveness also contributes to the slow pace of decline in global TB incidence (2). One such strategy is targeted active case-finding, where health systems seek out people at high risk for TB through screening of high-risk groups (3). Since effective treatment renders TB noninfectious (4), active case-finding has the potential to reduce TB transmission by diagnosing people earlier in their disease course and in larger numbers.

There are many possible approaches to active case-finding, one of which is using mobile units equipped with X-ray equipment. This strategy can help close the gap in missed diagnoses both by making it convenient for people to get screened in their own communities, and by using a sensitive screening method (chest radiography) that can detect TB before they perceive symptoms (5). In the 1930-1960s mobile X-ray units were an integral part of TB programs in industrialized countries (6, 7). In the past decade, some middle-income countries in Asia have incorporated mobile X-ray units for active case-finding into their TB programs (8-11), and other countries have used mobile X-ray units in prevalence surveys and pilot projects. However, this strategy is not yet used widely in countries with high TB burdens.

As with the introduction of any new technology, integration of mobile X-ray units into TB programs that have never used them comes with implementation challenges. Implementation research, which systematically and rigorously assesses the implementation of evidence-based interventions in real-world settings, can help to guide the introduction of new practices at a programmatic scale (12). However, as is the case for many TB interventions (13), there is a

dearth of implementation research around the use of mobile X-ray units in communities with high TB burdens. To address this gap, in Lima, Peru, we used an implementation science framework to evaluate an active case-finding program that introduced mobile X-ray units with computer-aided detection in a setting where routine TB diagnostic services used a different approach. We sought to assess the impact of the intervention and to identify barriers and facilitators to integrating the intervention approach into the local health system.

## METHODS

We conducted a RE-AIM evaluation (14) of the first year of implementation of TB Móvil, a program that uses mobile screening units with X-ray vans for TB active case-finding in community settings. TB Móvil is an ongoing program that is part of the Zero TB Initiative (15), an alliance of implementers committed to creating islands of TB elimination through the deployment of a comprehensive strategy that includes searching actively for cases using sensitive diagnostics, treating active cases as quickly as possible with the correct medications, and preventing disease through the treatment of TB infection and infection control in congregate settings (2). During the evaluation period, TB Móvil was implemented by an intervention team from the non-governmental organization Socios En Salud in collaboration with the Ministry of Health, municipal governments, and community organizations.

### Study population and setting

The intervention area comprised three districts with a combined population of 1.1 million (16), and annual TB case notification rates of 120-130 per 100,000. TB Móvil started implementation in February 2019 in northern Lima. During the first year, the intervention

operated for 12 months in Carabayllo district (District A), 9 months in Comas district (District B), and 3 months in Independencia district (District C).

In the intervention area, TB services are concentrated in 51 public health facilities operated by the DIRIS Lima Norte (the regional authority of the Ministry of Health). The intervention area also contains a regional referral hospital operated by the Ministry of Health, as well as a regional hospital and four primary care centers operated by EsSalud, a government insurance program for people employed in or retired from the formal economy. There is no private-sector TB treatment in Peru (17). During the evaluation period, the routine approach to TB detection was a two-step process of screening for respiratory symptoms among people seeking care at health facilities and then using sputum smear microscopy to diagnose TB; this approach is known to have limited sensitivity (18). Although radiography has higher sensitivity for TB detection, only hospitals and large health facilities had X-ray capacity.

### **Intervention**

We operated two mobile screening units for 8 hours per day for 28 days a month, spending the number of months described above in each district. X-ray vans were equipped with CAD4TB v6 (Delft Imaging, 's-Hertogenbosch, Netherlands) automated detection software to efficiently triage attendees such that only those with abnormal radiographs consistent with TB underwent further evaluation procedures. We worked with local community leaders to choose screening locations with high foot traffic such as parks, community centers, and markets. We partnered with health facility decision-makers to operate screening sites immediately outside the facility to screen both health facility attendees and health care workers. We also partnered with transportation companies to operate screening sites at the terminals of major bus lines with the



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3 goal of making screening accessible to working adults as they commute. Finally, we partnered  
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5 with companies and institutions to screen staff and residents. A structured community  
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7 engagement strategy was used to inform and educate local residents about the program and  
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9 encourage attendance (19).

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12 People  $\geq 4$  years old were eligible for screening provided they were not receiving TB  
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14 treatment (Figure S1). Children  $< 4$  years old were eligible for screening only if they were close  
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16 contacts of TB patients; this is because the CAD4TB v6 software was validated only for children  
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18  $\geq 4$  years old. All attendees registered for screening, at which point we collected information on  
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20 their age, sex, and district of residence. After registration, attendees waited for chest  
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22 radiography; during the wait time, which ranged from 5-50 minutes depending on attendance,  
23  
24 attendees received education about TB symptoms, transmission, and diagnosis. Chest  
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26 radiography was performed in the X-ray van by a radiography technician and scored  
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28 automatically by CAD4TB. People with abnormal radiographs were referred to a physician at  
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30 the screening unit for clinical evaluation and were asked for a sputum sample for testing by  
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32 GeneXpert MTB/RIF (Cepheid, Sunnyvale, CA, USA; referred to as “Xpert”). Field staff used  
33  
34 their discretion in requesting sputum from young children given children’s general inability to  
35  
36 produce sputum (20). Xpert testing was performed at the Socios En Salud laboratory initially  
37  
38 using standard cartridges and switching to “Ultra” cartridges after 6 months. People could be  
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40 diagnosed with TB based on a positive Xpert result or by the physician at the screening unit  
41  
42 based on clinical and radiographic evidence. All people diagnosed with TB were accompanied  
43  
44 by community health workers (community members with basic training in health issues) to  
45  
46 public health facilities for treatment initiation, and radiographs and Xpert results were given to  
47  
48 the health facility doctors. All procedures were free of cost. Data on all procedures were directly  
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3 entered into an electronic data collection system; data on treatment initiation reflects results  
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5 obtained by 13 March 2020.  
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## 10 **RE-AIM evaluation**

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12 We used the RE-AIM framework (14) to evaluate how the intervention's approach to TB  
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14 active case-finding performed within the Peruvian health system. We chose the RE-AIM  
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16 framework because it assesses implementation and effectiveness outcomes at individual and  
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18 health system levels, making it well suited for identifying barriers and facilitators to integrating a  
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20 new intervention into a health system. Several components of the intervention approach differed  
21  
22 from routine practice within the local TB services: (1) screening and evaluation services were  
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24 provided within community settings, (2) people without symptoms or risk factors could be  
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26 screened, (3) chest radiography was used for screening and to aid diagnosis, and (4) Xpert was  
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28 used for bacteriologic testing. Evaluation focused on understanding how well the health system  
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30 was able to incorporate these new approaches and their impact on TB diagnosis.  
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## 38 **Reach**

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40 To assess reach, we divided the number of people who registered for screening and who  
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42 reported living in each of the three districts by the number of residents in these districts. We  
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44 further stratified analysis by age and sex. We specifically assessed reach among males and  
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46 people 15-44 years old (referred to as "working-age adults"), as these demographic groups  
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48 comprise the majority of TB cases diagnosed in Peru (17). We used a Wilcoxon rank-sum test to  
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50 compare the proportion of attendees who were male and the proportion who were working-age  
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adults among different types of screening sites, using an exact test for categories with  $\leq 5$  sites, and considering  $p < 0.05$  as significant.

## Effectiveness

To assess effectiveness, we considered two main objectives of active case-finding: to diagnose additional cases and to diagnose cases earlier. To assess additionality, we obtained quarterly case notifications from Ministry of Health facilities in each of the three districts during 2015-2019. We coded each quarter as pre-intervention or intervention and calculated the average difference between actual case notifications during intervention quarters and expected notifications assuming a linear trend based on the pre-intervention quarters; the appropriateness of a linear trendline was confirmed by plotting residuals of the linear regression. We included in this analysis only health facilities that notified TB cases during both the pre-intervention and intervention periods to eliminate bias from changing catchment populations. An overall effect estimate of the intervention was generated using a Poisson regression to model quarterly case notifications during 2016-2019 from each of the three intervention districts as a function of time and whether the intervention was being implemented, using the average quarterly case notifications in 2015 as an offset.

To assess whether cases were diagnosed early, we calculated the percentage of cases that had a positive sputum smear microscopy result based on the same sputum sample used for Xpert testing. Smear positivity is associated with increased sputum bacillary load (21), which is a marker for more advanced disease (22), so a low proportion of smear positivity could indicate earlier diagnosis. Given that only a single spot sputum sample was tested, smear microscopy is expected to have lower sensitivity than under ideal conditions; however, a community-based

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3 screening program in the Philippines that used a similar diagnostic algorithm, found nearly half  
4 of people diagnosed with TB to have positive smear results based on the spot sputum specimens  
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6 collected at the screening site (8).  
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## 10 11 12 **Adoption**

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14 We assessed two quantitative measures of adoption. The first measure was the percentage  
15 of health facilities that accepted having the mobile unit stationed outside to screen their staff and  
16 clients. We considered this to be an indicator of the acceptability of the intervention to the health  
17 system, which is an important driver of adoption. The second measure was the time between  
18 screening and treatment initiation for people diagnosed with TB by the intervention. We  
19 considered the promptness of treatment initiation to be an indicator of the health system's ability  
20 to incorporate the intervention approach into existing services.  
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31 To better understand drivers of these two adoption measures, we qualitatively analyzed  
32 meeting minutes from monthly coordination calls (13 documents) and quarterly reports to  
33 intervention funders during 2019 (4 documents) using a Framework Analysis approach (23). We  
34 extracted into matrices all passages related to the intervention coordinators' interactions with  
35 health facilities or other organizations, as well as passages related to treatment initiation. We  
36 then coded these passages according to whether they described acceptance or rejection of the  
37 intervention, or barriers or facilitators to treatment initiation for patients diagnosed by the  
38 intervention.  
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## 51 **Implementation**

To assess implementation, we quantified performance indicators using a framework for evaluation of TB active case-finding (24, 25). We focused on five key indicators that reflect implementation fidelity: percentage of people registered who were screened by chest radiography, percentage of people with abnormal chest radiographs who were evaluated clinically, percentage of people with abnormal chest radiographs who had sputum samples collected for Xpert testing, percentage of sputum samples with valid Xpert results, and percentage of people diagnosed with TB who initiated treatment. Where any of these fell below 85%, we probed operational data to identify reasons for suboptimal fidelity.

## **Maintenance**

Our maintenance assessment focused on the extent to which the intervention was institutionalized into the routine TB services. Given that the intervention was grant-funded and implemented by an NGO for this first year, the maintenance of the intervention was dependent on the Ministry of Health incorporating the approach into its programming. To assess the extent to which this occurred, we reviewed call minutes and program reports from the evaluation period for evidence of investment by the Ministry of Health in maintaining or expanding the intervention beyond the initial year.

## **Patient and public involvement**

Patients and the public were involved in multiple aspects of program implementation and research. Patient and community preferences were taken into account when developing the implementation plan for the intervention. During program implementation, our community engagement strategy involved meeting with community leaders prior to the arrival of the

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3 screening program in a community to gain community buy-in and disseminate information. In  
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5 addition, recruitment of people to the screening program was mostly done by community  
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7 members, including community health workers, TB survivors, and community-based artists.  
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10 Results of the intervention have been progressively disseminated to the community via social  
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12 media. As with all studies implemented by Socios En Salud, the research plan was presented to  
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14 a community advisory board for approval.  
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### 19 **Ethical considerations**

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21 The intervention and evaluation were approved by the Ethics Committee of the  
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23 Universidad Peruana Cayetano Heredia. A waiver of informed consent for screening procedures  
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25 and data collection was granted on the basis that procedures posed minimal risk to participants  
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27 and that informed consent could not feasibly be administered in the context of a high-volume  
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29 community screening program. The Harvard Medical School IRB determined that its  
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31 involvement did not constitute human subjects research.  
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## 38 **RESULTS**

### 39 **Reach**

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41 In one year, the two mobile units registered 63,899 attendees at 215 screening locations  
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43 in north Lima. Of these, 58,962 (92%) reported residing in the intervention area. We estimate  
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45 that the mobile unit screening reached 6% of residents in the intervention area, including 9% of  
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47 District A residents, 4% of District B residents, and 3% of District C residents. The higher  
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49 coverage in District A was due to the longer duration of implementation; on average, the  
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51 program reached 3% of District A residents, 2% of District B residents, and 5% of District C  
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residents per 100 days spent in each respective district. Coverage was higher for females versus males in all districts (A: 11% vs 7%; B: 5% vs 3%; C: 3% vs 2%;  $p < 0.001$  for all comparisons). Coverage was higher among older adults compared to younger adults (Figure S2).

Sites where screening was open to the public included general community locations, health facilities, markets, transport terminals, and a shopping mall (Table 1). At general community screening sites, a median of 39% (interquartile range [IQR]: 36–42%) of attendees were male, and a median of 41% (IQR 36–44%) of attendees were working-age adults. In comparison, transport terminal sites had significantly higher percentages of both male attendees and working-age attendees. In addition, the mobile units were stationed at five sites where screening was restricted to staff and residents of specific institutions known to have predominantly young and male populations, including an army barrack, a police complex, two companies, and a technical college. These sites also had significantly higher percentages of male and working-age attendees.

**Table 1:** Percent male and working-age attendees, by type of screening site

Type of site	Number of sites	Percent male attendees			Percent working-age attendees (age 15-44)		
		Median	IQR	p-value	Median	IQR	p-value
General community	156	39	36–42	reference	41	36–44	reference
Health facilities	32	34	31–39	<0.001	39	36–43	0.508
Markets	12	40	37–41	0.528	40	36–44	0.837
Transport terminals	9	65	62–69	<0.001	46	44–51	<0.001
Company or institution	5	61	56–64	<0.001	89	80–90	<0.001
Shopping mall	1	38	N/A	0.854	61	N/A	0.013

IQR = interquartile range. N/A = not applicable. P-value from Wilcoxon rank sum test.

## Effectiveness

During the evaluation period, the intervention diagnosed 393 cases of TB, of which 343 (87%) were among people living in the intervention area. Average case notifications were 13% higher than expected during 4 intervention quarters in District A, 4% higher than expected

during three intervention quarters in District B, and 17% higher than expected during 1 intervention quarter in District C (Table 2). If all additional cases were attributable to the intervention, then an estimated 27%, 12%, and 45% of cases detected by the intervention in Districts A, B, and C respectively would not otherwise have been detected. The overall effect estimate for the intervention was an increase of 11% (95% CI 6–16%) in case notifications during quarters when the intervention was being implemented, after adjusting for secular changes in case notifications over time.

**Table 2:** Impact of intervention based on average quarterly TB case notifications in intervention and control districts during 2015-2019

	District A	District B	District C
Average case notifications per pre-intervention quarter (starting 2015)	72	169	79
Change in cases per quarter based on linear regression	+0.6	+0.9	+0.2
Expected average cases per intervention quarter (2019)	78	177	81
Actual average cases notified per intervention quarter	88	184	95
Difference between actual and expected	+13%	+4%	+17%
Absolute difference in total and expected notifications over all intervention quarters	+41	+19	+14
Cases detected by intervention in residents of district	153	159	31
Estimated percent of cases detected by intervention that represent additional cases	27%	12%	45%

Of the 393 TB diagnoses, 388 (99%) had a valid Xpert result, with 315 (81%) having a positive result (including trace positive results). All 388 also had smear microscopy performed on the same sputum sample, with only 99 (26%) having a positive result.

### Adoption

During the evaluation period, the intervention team approached 32 health facilities in the three districts to ask if the mobile unit could be stationed outside the health facility to screen clients and staff. All (100%) accepted. These facilities included both hospitals, 29 of the 51



(57%) public health facilities overseen by the DIRIS Lima Norte, and one of the four (25%) EsSalud primary care facilities. A report noted that the intervention team received requests for additional screening locations than it could not accommodate (Table 3).

**Table 3:** Observations relating to adoption and maintenance recorded in meeting minutes and reports

RE-AIM construct: theme	Quotation from meeting minutes
Adoption: requests for intervention services by health system	“We have received numerous requests to bring the van to screen in different areas of Lima; although we have not been able to accommodate these requests, they demonstrate the demand for such services.” (Q1 2019 report)
Adoption: challenges to having TB diagnoses accepted by health system	“While the screening program operated successfully, we have encountered challenges with delayed treatment initiation for people diagnosed with TB. This has happened because the doctors are requesting more procedures (such as CT) before deciding to initiate treatment, and many of them have limited knowledge of GeneXpert.” (Q4 2019 report)
	“Some people with positive GeneXpert results have to wait to see a pulmonologist, delaying treatment initiation.” (November 2019 meeting minutes)
Adoption: facilitators to having TB diagnoses accepted	“We held some meetings with [an infectious disease doctor from the United States] in which he talked about GeneXpert Ultra and its use. This helped the doctors in the primary care facilities of Carabayllo understand better the response to these cases.” (September 2019 meeting minutes)
Maintenance: expansion of intervention to other areas with Ministry of Health support	“The TB Movil intervention is being offered to the Ministry of Health in the municipality of La Victoria.” (January 2020 meeting minutes)
	“There is a possibility that the Ministry of Health will give us access to 8 cases of Xpert cartridges that are currently in [another city]. The objective is to use them in north Lima and also other screenings that the Ministry of Health coordinates. We are discussing whether to do the Xpert testing in the Socios En Salud laboratory or a Ministry of Health laboratory.” (January 2020 meeting minutes)
Maintenance: integration of intervention approach into policy	“We have had meetings with the Ministry of Health and the National TB Program in which they expressed interest in developing a directive for TB active case-finding. We presented the approach of TB Móvil. The meeting was with [Dr. X], with whom we have another meeting scheduled for next week to discuss the coordination of the activities of TB Móvil and the Ministry of Health.” (November 2019 meeting minutes)

Among patients with Xpert-positive rifampin-susceptible TB who initiated treatment, the median time from screening to treatment initiation was 6 days (IQR 3–11 days). Time to treatment initiation was not significantly different for those with rifampin-resistant TB (median 7, IQR 3–18 days;  $p=0.607$ ). However, time to treatment initiation was longer for those without

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3 a positive Xpert result (median 9, IQR 4–23 days;  $p=0.026$ ) and those with trace positive Xpert  
4 results (median 11, IQR 4–28 days,  $p=0.003$ ). Given that the median time between screening and  
5 Xpert result availability was only 1 day (IQR 0–1 day), delays in treatment initiation reflected  
6 clinical decision delays rather than laboratory delays.  
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12 Challenges in having diagnoses from the intervention accepted by the health system were  
13 documented in meeting minutes and reports (Table 3). One reason for delay was that people  
14 diagnosed with TB were referred for re-evaluation by pulmonologists at the government  
15 hospitals, even if they had positive Xpert results, underlining a lack of knowledge about this  
16 diagnostic test and its significantly higher sensitivity as compared to sputum smear microscopy.  
17 The utility of education for providers in reducing treatment delays was also documented.  
18 Meetings in which health facility physicians were trained with regards to the role of radiography  
19 and Xpert in TB diagnosis were noted to have improved the acceptability of diagnoses coming  
20 from the intervention and reduced treatment initiation delays.  
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### 35 **Implementation**

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37 Of the 63,899 attendees registered over 1 year, 58,268 (91%) had chest radiography  
38 performed (Figure 1). Each unit performed a median of 114 (IQR 90–134) radiographs per day.  
39 One new TB diagnosis was made per 148 people screened by chest radiography, and one Xpert-  
40 positive diagnosis per 44 people tested by Xpert. We were able to confirm treatment initiation  
41 for 323 (82%) of the 393 TB diagnoses.  
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49 The two key implementation fidelity indicators that fell below 85% were the percent of  
50 people with abnormal chest radiographs for whom sputum samples were submitted and the  
51 percent of people diagnosed with TB who initiated treatment. When we analyzed sputum  
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3 submission by age, we found that 88% of people age  $\geq 10$  years old submitted a sputum sample,  
4 compared to 17% of children  $< 10$  years old, suggesting that the suboptimal value of this  
5 indicator was driven by young children's inability to produce sputum.  
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10 We found that the percentage of people initiating TB treatment varied depending on the  
11 basis of the TB diagnosis (Figure 2). Treatment initiation was documented for 95% of people  
12 with Xpert-positive rifampin-susceptible TB. The percentage of people who initiated treatment  
13 was significantly lower for all other types of diagnoses (86% for rifampin-resistant TB,  $p=0.019$ ;  
14 64% for those with trace positive Xpert results,  $p<0.001$ ; 53% for those without a positive Xpert  
15 result, who were diagnosed based on clinical and/or radiographic criteria,  $p<0.001$ ). Rejection of  
16 the intervention's TB diagnosis by a health facility physician was documented for 9% of those  
17 with trace positive Xpert results and 26% of those without positive Xpert results.  
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### 31 **Maintenance**

32 Meeting minutes noted that the Ministry of Health had agreed to let the intervention team  
33 use its Xpert machines and cartridges to expand the screening program beyond the intervention  
34 districts (Table 3). A meeting with the National TB Program was also reported which examined  
35 the possibility of incorporating the X-ray van strategy into a new active case-finding policy. As  
36 of January 2021 (2 years after the intervention began), the program had expanded to multiple  
37 districts within and outside Lima, with the Ministry of Health providing Xpert testing and  
38 clinical staff.  
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### 51 **DISCUSSION**

52 We found that an intervention using community-based mobile X-ray screening units was  
53 effective for increasing TB diagnoses and diagnosing TB that was negative by smear  
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3 microscopy. In its first year, the intervention reached 6% of the population of a region of around  
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5 1 million inhabitants. The intervention was associated with an 11% (95% CI 6-16%) increase in  
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7 quarterly case notifications after adjusting for the increasing trend in notifications over the  
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9 previous four years. Although decision-makers at many health facilities were eager to  
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11 collaborate with the intervention, we encountered challenges with individual physicians at local  
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13 clinics not accepting TB diagnoses based on X-ray and Xpert. Our experience illustrates the  
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15 complexities involved in health-system adoption of a new standard of care that differs  
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17 substantially from routinized practice.  
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21 The high implementation fidelity we observed for procedures that took place at the  
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23 screening site suggest both demand for free TB diagnostic services and acceptability of mobile  
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25 X-ray screening units as a way to deliver these services. Despite long wait times, attendees  
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27 generally completed the screening and evaluation procedures. Moreover, high attendance  
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29 resulted in a large number of people screened. Our implementation strategy compared favorably  
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31 to interventions using mobile X-ray units in community settings elsewhere (8, 9, 26). However,  
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33 men and working-age adults were underrepresented among attendees, resulting in uneven reach  
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35 of the intervention. While offering screening at transport terminals and places of work increased  
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37 attendance for both of these demographic groups, feedback from the implementation team  
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39 suggested larger structural barriers at play. In Peru, people working in the informal economic  
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41 sector have no protection from loss of income or employment should they be diagnosed with TB,  
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43 thus disincentivizing uptake of TB screening. This observation underscores the importance of  
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45 legal and social protection programs, in addition to expanded case-finding interventions, for  
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47 increasing detection of stigmatized diseases like TB (27).  
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3 The major implementation barriers we encountered occurred at local health facilities  
4 when people diagnosed with TB by the mobile units went to initiate treatment. Many TB  
5 diagnoses based on trace positive Xpert results or clinical/radiographic criteria were rejected by  
6 the local physicians, and patients experienced delays in treatment initiation. Similar challenges  
7 were observed in other countries when Xpert was first introduced as a replacement for smear  
8 microscopy. In India, the willingness of providers to make clinical diagnoses decreased once  
9 Xpert was introduced, in part because Xpert was viewed as a “gold standard” with perfect  
10 sensitivity (28). Moreover, variable knowledge about Xpert among providers led to  
11 disagreements over the use of Xpert testing for TB diagnosis (29). In other countries, treatment  
12 initiation delays for patients with positive Xpert results were observed because of confusion over  
13 guidelines for reporting Xpert-positive patients (30). While Xpert had been used at a small scale  
14 in Peru’s public health system prior to the present intervention, a lack of knowledge about Xpert  
15 at the primary care level contributed to some reluctance in accepting Xpert diagnoses, especially  
16 when trace positive results were obtained. Together, these challenges emphasize the importance  
17 of clear practice guidelines and regular training for primary-level clinicians when new diagnostic  
18 practices are introduced.

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40 This initial evaluation suggests that the community-based mobile X-ray unit strategy is  
41 effective for increasing TB case detection in Peru. However, our effectiveness analysis is subject  
42 to some important limitations. While we used four years of case notification data to establish a  
43 temporal trend against which case against which the intervention period could be compared, we  
44 cannot rule out the possibility that TB program improvements unrelated to the intervention might  
45 have contributed to an increase in notifications. Our analysis also cannot explain the  
46 heterogeneity of impact in the different districts, particularly why District B experienced such a  
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3 small increase in case notifications despite a large number of TB diagnoses by the intervention.  
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5 One possibility is that in District B, security concerns limited program operation in community  
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7 settings, and a larger proportion of people were screened and diagnosed at sites outside health  
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9 facilities; because they were already seeking health care, these people might have been  
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11 diagnosed by the health system anyway. Finally, because our intervention introduced multiple  
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13 components that differed from routine practice, we cannot assess the relative importance of each  
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15 component. However, it is likely that the effects of different components depend on the presence  
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17 of the others. For instance, in isolation, the introduction of Xpert into a health system as a  
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19 replacement for smear microscopy has generally not led to increases in case detection (31, 32);  
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21 however, in our intervention, using Xpert may have contributed to case notifications by  
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23 providing rapid bacteriologic confirmation for cases that might otherwise have been contested  
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25 clinical diagnoses, especially given the low prevalence of smear positivity.  
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31 We did not assess costs in our evaluation. However, models fit to the epidemics of China  
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33 and South Africa – two other upper-middle-income countries like Peru – have suggested that a 2-  
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35 year active case-finding program that increases case detection by 25% would be highly cost-  
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37 effective at a cost of 3800-9400 USD per case detected (33). If the campaign is sustained for  
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39 longer periods of time, they remain highly cost effective at even higher costs per case detected,  
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41 despite declining gains in case detection over time. Moreover, the health system strengthening  
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43 that accompanies the implementation of a large-scale campaign such as ours also contributes to a  
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45 decrease in tuberculosis morbidity and mortality, separately from the intervention itself (Shrestha  
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47 S, Achieving a “step change” in the tuberculosis epidemic through comprehensive community-  
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49 wide intervention: a model-based analysis).  
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Other limitations of this initial evaluation reflect time and resource constraints. We did not perform qualitative research through interviews or focus groups to better explain the barriers to adoption of the intervention approach by the health system. For example, we do not know whether clinical diagnoses of TB in patients with clinical and radiographic findings but a negative Xpert result were rejected because doctors perceived Xpert as having perfect sensitivity or because of low inter-rater reliability for chest radiographs, both of which have been observed in other settings (28, 34). In addition, we did not collect data about the specific health care providers or health care facilities managing each patient, which could have allowed us to determine whether treatment initiation challenges were associated with certain provider or facility characteristics. Finally, the timeframe of the evaluation limited our ability to quantify durability of impact over time. Thus, while providing useful knowledge for integrating mobile X-ray units into TB programs in settings with high TB burdens, our study also highlights areas in which further implementation research is needed.

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Local coalitions seeking to rapidly drive down TB will have to introduce new strategies to transform routine services and systems. While new innovations in diagnostic technologies are needed, increasing and improving the implementation of evidence-based approaches in settings with high TB burdens is also important. We found that deploying mobile X-ray units with automated detection software across a high-risk area constituted a feasible and effective strategy to extend TB diagnostic services into communities and improve early case detection. Effective deployment however requires advance coordination among stakeholders and targeted provider training to ensure that people diagnosed with TB by new modalities receive prompt treatment. These implementation lessons can be applied by other TB elimination coalitions around the world, as part of the mutual aid and exchange of resources among coalitions.

## FIGURE LEGENDS

**Figure 1: TB diagnostic and treatment cascade for the TB Móvil screening program.** Green boxes indicate key implementation indicators.

**Figure 2: Treatment initiation among people diagnosed with TB by the intervention, by Xpert result (N=393).** MTB = Mycobacterium tuberculosis, Rif = rifampin

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## **AUTHOR CONTRIBUTIONS**

CMY, SK, and MCB conceptualized the study. CMY, DP, JTG, LL, and MCB led the implementation of the intervention. AKM, CT, RIC, MBB, JJ, CC, and TN supported implementation. CMY and DP planned and supervised data collection. CT and TCN helped to collect and clean data. CMY performed the analysis and wrote the first draft of the manuscript, and all authors revised critically.

## **COMPETING INTERESTS**

The authors declare no competing interests.

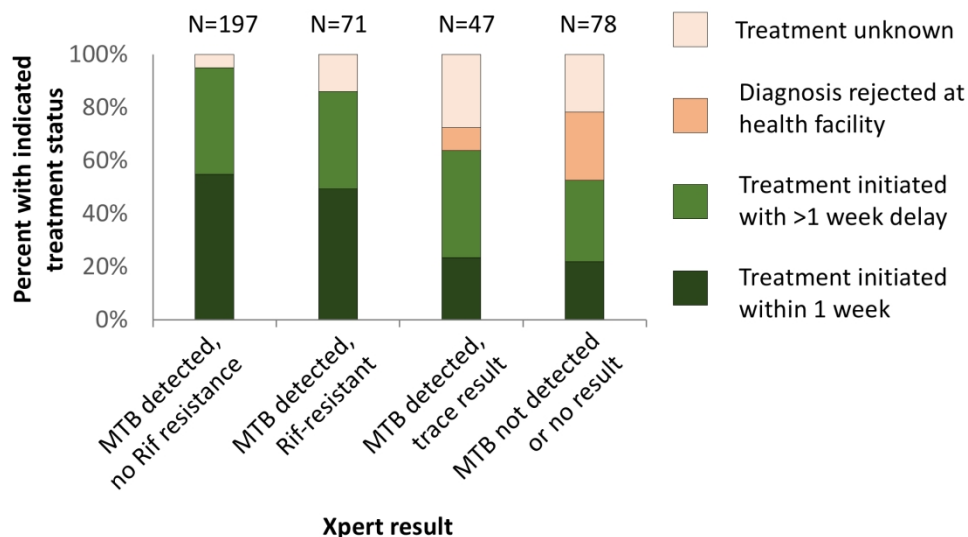
## **DATA SHARING**

Data are available upon reasonable request. Contact the corresponding author for a data request form.

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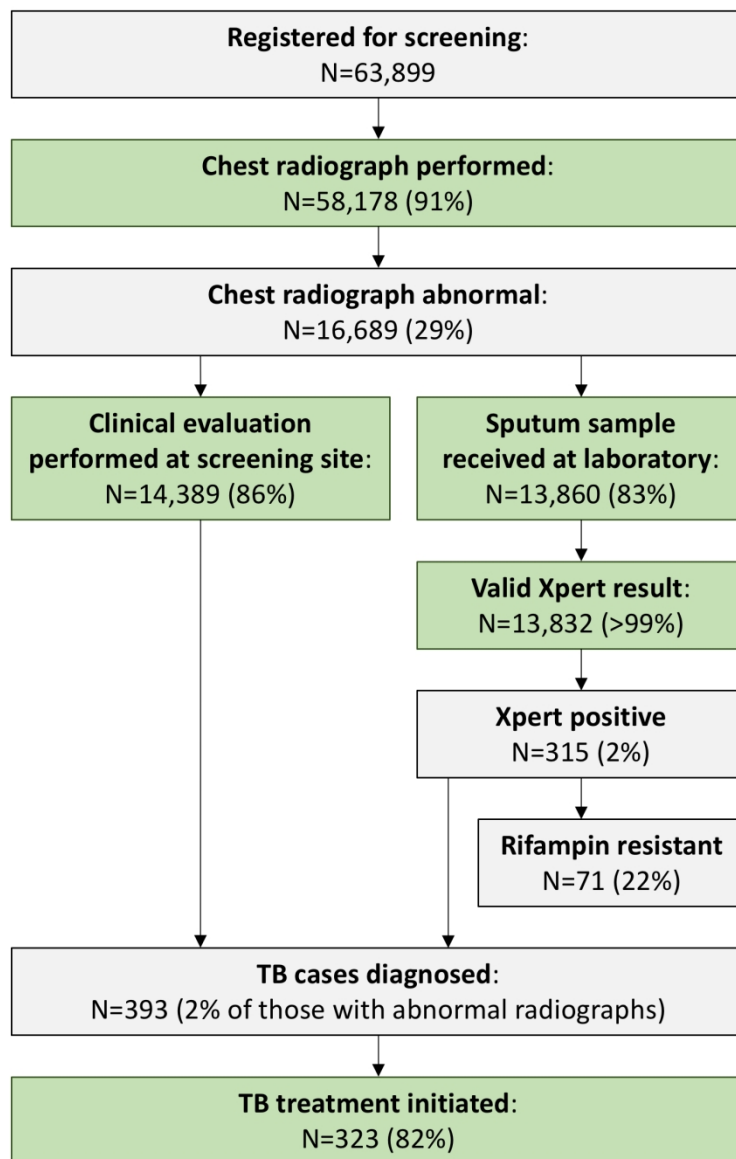
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TB diagnostic and treatment cascade for the TB Móvil screening program. Green boxes indicate key implementation indicators.

185x112mm (300 x 300 DPI)



Treatment initiation among people diagnosed with TB by the intervention, by Xpert result (N=393). MTB = Mycobacterium tuberculosis, Rif = rifampin

132x200mm (300 x 300 DPI)

Supplementary figures for “Identifying barriers and facilitators to implementation of community-based tuberculosis active case-finding with mobile X-ray units in Lima, Peru: a RE-AIM evaluation”

Figure S1: Screening algorithm used at mobile screening units

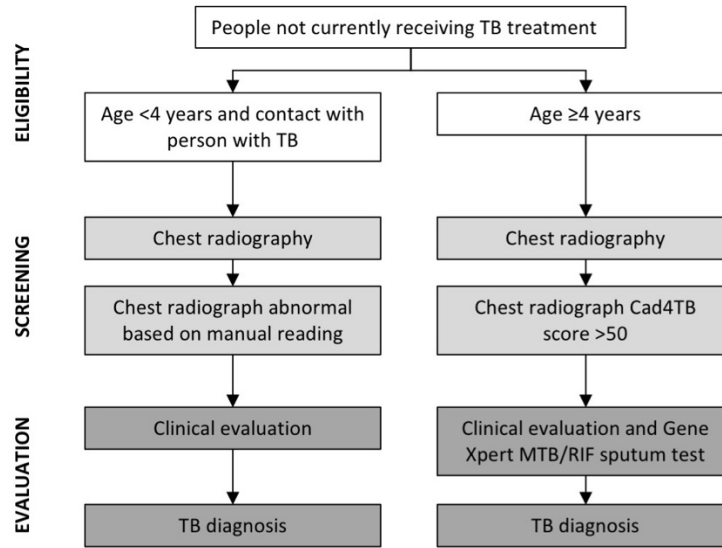
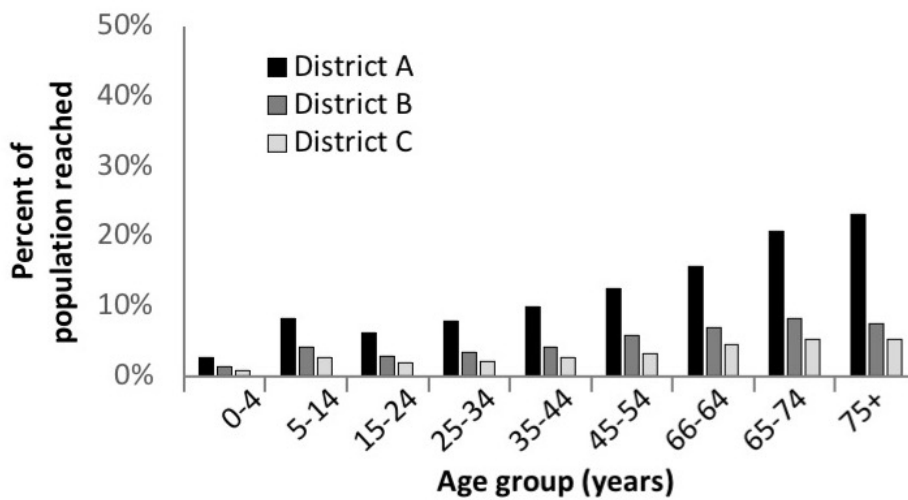


Figure S2: Percent of intervention area residents reached, by district and age



# BMJ Open

## Identifying barriers and facilitators to implementation of community-based tuberculosis active case-finding with mobile X-ray units in Lima, Peru: a RE-AIM evaluation

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## Identifying barriers and facilitators to implementation of community-based tuberculosis active case-finding with mobile X-ray units in Lima, Peru: a RE-AIM evaluation

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## ABSTRACT

**Objectives:** Identify barriers and facilitators to integrating community tuberculosis screening with mobile X-ray units into a health system.

**Methods:** RE-AIM (Reach, Effectiveness, Adoption, Implementation, Maintenance) evaluation.

**Setting:** 3-district region of Lima, Peru.

**Participants:** 63,899 people attended the mobile units during February 7, 2019–February 6, 2020.

**Interventions:** Participants were screened by chest radiography, which was scored for abnormality by computer-aided detection. People with abnormal X-rays were evaluated clinically and by GeneXpert MTB/RIF (Xpert) sputum testing. People diagnosed with tuberculosis at the mobile unit were accompanied to health facilities for treatment initiation.

**Primary and secondary outcome measures:** Reach was defined as the percentage of the population of the 3-district region that attended the mobile units. Effectiveness was defined as the change in tuberculosis case notifications over a historic baseline. Key implementation fidelity indicators were the percentages of people who had chest radiography performed, were evaluated clinically, had sputum samples collected, had valid Xpert results, and initiated treatment.

**Results:** The intervention reached 6% of the target population and was associated with an 11% (95%CI 6-16%) increase in quarterly case notifications, adjusting for the increasing trend in notifications over the previous three years. Implementation indicators for screening, sputum collection, and Xpert testing procedures all exceeded 85%. Only 82% of people diagnosed with tuberculosis at the mobile units received treatment; people with negative or trace Xpert results were less likely to receive treatment. Suboptimal treatment initiation was driven by health facility doctors' lack of familiarity with Xpert and lack of confidence in diagnoses made at the mobile unit.

**Conclusion:** Mobile X-ray units were a feasible and effective strategy to extend tuberculosis diagnostic services into communities and improve early case detection. Effective deployment however requires advance coordination among stakeholders and targeted provider training to ensure that people diagnosed with tuberculosis by new modalities receive prompt treatment.

## SUMMARY

### Strengths and limitations of the study

- An implementation science evaluation of a large program that screened over 60,000 people for TB in a middle-income country allowed us to both assess the performance of the program and draw conclusions about how to incorporate mobile X-ray units for tuberculosis screening into existing health systems in similar settings.
- Individual-level programmatic data allowed us not only to assess overall reach and implementation fidelity but also to analyze heterogeneity in these areas.
- The assessment of effectiveness adjusts for temporal trends but is limited by an inability to control for the effects of other program or population changes that might have contributed to increased case notifications.
- The assessment of adoption and maintenance are limited by a reliance on secondary data sources rather than focus groups or interviews.

## INTRODUCTION

Globally, around 10 million people develop tuberculosis (TB) each year, and up to 30% of people who develop TB each year are not diagnosed and treated (1). While better diagnostic technologies and treatments are urgently needed, underutilization of strategies with demonstrated effectiveness also contributes to the slow pace of decline in global TB incidence (2). One such strategy is targeted active case-finding, where health systems seek out people at high risk for TB through screening of high-risk groups (3). Since effective treatment renders TB noninfectious (4), active case-finding has the potential to reduce TB transmission by diagnosing people earlier in their disease course and in larger numbers.

There are many possible approaches to active case-finding, one of which is using mobile units equipped with X-ray equipment. This strategy can help close the gap in missed diagnoses both by making it convenient for people to get screened in their own communities, and by using a sensitive screening method (chest radiography) that can detect TB before they perceive symptoms (5). In the 1930-1960s mobile X-ray units were an integral part of TB programs in industrialized countries (6, 7). In the past decade, some middle-income countries in Asia have incorporated mobile X-ray units for active case-finding into their TB programs (8-11), and other countries have used mobile X-ray units in prevalence surveys and pilot projects. However, this strategy is not yet used widely in countries with high TB burdens.

As with the introduction of any new technology, integration of mobile X-ray units into TB programs that have never used them comes with implementation challenges. Implementation research, which systematically and rigorously assesses the implementation of evidence-based interventions in real-world settings, can help to guide the introduction of new practices at a programmatic scale (12). However, as is the case for many TB interventions (13), there is a

dearth of implementation research around the use of mobile X-ray units in communities with high TB burdens. To address this gap, in Lima, Peru, we used an implementation science framework to evaluate an active case-finding program that introduced mobile X-ray units with computer-aided detection in a setting where routine TB diagnostic services used a different approach. We sought to assess the impact of the intervention and to identify barriers and facilitators to integrating the intervention approach into the local health system.

## METHODS

We conducted a RE-AIM evaluation (14) of the first year of implementation of TB Móvil, a program that uses mobile screening units with X-ray vans for TB active case-finding in community settings. TB Móvil is an ongoing program that is part of the Zero TB Initiative (15), an alliance of implementers committed to creating islands of TB elimination through the deployment of a comprehensive strategy that includes searching actively for cases using sensitive diagnostics, treating active cases as quickly as possible with the correct medications, and preventing disease through the treatment of TB infection and infection control in congregate settings (2). During the evaluation period, TB Móvil was implemented by an intervention team from the non-governmental organization Socios En Salud in collaboration with the Ministry of Health, municipal governments, and community organizations.

### Study population and setting

The intervention area comprised three districts with a combined population of 1.1 million (16), and annual TB case notification rates of 120-130 per 100,000. TB Móvil started implementation in February 2019 in northern Lima. During the first year, the intervention

operated for 12 months in Carabayllo district (District A), 9 months in Comas district (District B), and 3 months in Independencia district (District C).

In the intervention area, TB services are concentrated in 51 public health facilities operated by the DIRIS Lima Norte (the regional authority of the Ministry of Health). The intervention area also contains a regional referral hospital operated by the Ministry of Health, as well as a regional hospital and four primary care centers operated by EsSalud, a government insurance program for people employed in or retired from the formal economy. There is no private-sector TB treatment in Peru (17). During the evaluation period, the routine approach to TB detection was a two-step process of screening for respiratory symptoms among people seeking care at health facilities and then using sputum smear microscopy to diagnose TB; this approach is known to have limited sensitivity (18). Although radiography has higher sensitivity for TB detection, only hospitals and large health facilities had X-ray capacity.

### **Intervention**

We operated two mobile screening units for 8 hours per day for 28 days a month, spending the number of months described above in each district. X-ray vans were equipped with CAD4TB v6 (Delft Imaging, 's-Hertogenbosch, Netherlands) automated detection software to efficiently triage attendees such that only those with abnormal radiographs consistent with TB underwent further evaluation procedures. We worked with local community leaders to choose screening locations with high foot traffic such as parks, community centers, and markets. We partnered with health facility decision-makers to operate screening sites immediately outside the facility to screen both health facility attendees and health care workers. We also partnered with transportation companies to operate screening sites at the terminals of major bus lines with the

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2  
3 goal of making screening accessible to working adults as they commute. Finally, we partnered  
4 with companies and institutions to screen staff and residents. A structured community  
5 engagement strategy was used to inform and educate local residents about the program and  
6 encourage attendance (19).  
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12 People  $\geq 4$  years old were eligible for screening provided they were not receiving TB  
13 treatment (Figure S1). Children  $< 4$  years old were eligible for screening only if they were close  
14 contacts of TB patients; this is because the CAD4TB v6 software was validated only for children  
15  $\geq 4$  years old. All attendees registered for screening, at which point we collected information on  
16 their age, sex, and district of residence. After registration, attendees waited for chest  
17 radiography; during the wait time, which ranged from 5-50 minutes depending on attendance,  
18 attendees received education about TB symptoms, transmission, and diagnosis. Chest  
19 radiography was performed in the X-ray van by a radiography technician and scored  
20 automatically by CAD4TB. People with abnormal radiographs were referred to a physician at  
21 the screening unit for clinical evaluation and were asked for a sputum sample for testing by  
22 GeneXpert MTB/RIF (Cepheid, Sunnyvale, CA, USA; referred to as “Xpert”). Field staff used  
23 their discretion in requesting sputum from young children given children’s general inability to  
24 produce sputum (20). Xpert testing was performed at the Socios En Salud laboratory initially  
25 using standard cartridges and switching to “Ultra” cartridges after 6 months. People could be  
26 diagnosed with TB based on a positive Xpert result or by the physician at the screening unit  
27 based on clinical and radiographic evidence. All people diagnosed with TB were accompanied  
28 by community health workers (community members with basic training in health issues) to  
29 public health facilities for treatment initiation, and radiographs and Xpert results were given to  
30 the health facility doctors. All procedures were free of cost. Data on all procedures were directly  
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3 entered into an electronic data collection system; data on treatment initiation reflects results  
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5 obtained by 13 March 2020.  
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## 10 **RE-AIM evaluation**

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12 We used the RE-AIM framework (14) to evaluate how the intervention's approach to TB  
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14 active case-finding performed within the Peruvian health system. We chose the RE-AIM  
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16 framework because it assesses implementation and effectiveness outcomes at individual and  
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18 health system levels, making it well suited for identifying barriers and facilitators to integrating a  
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20 new intervention into a health system. Several components of the intervention approach differed  
21  
22 from routine practice within the local TB services: (1) screening and evaluation services were  
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24 provided within community settings, (2) people without symptoms or risk factors could be  
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26 screened, (3) chest radiography was used for screening and to aid diagnosis, and (4) Xpert was  
27  
28 used for bacteriologic testing. Evaluation focused on understanding how well the health system  
29  
30 was able to incorporate these new approaches and their impact on TB diagnosis.  
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## 38 **Reach**

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40 To assess reach, we divided the number of people who registered for screening and who  
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42 reported living in each of the three districts by the number of residents in these districts. We  
43  
44 further stratified analysis by age and sex. We specifically assessed reach among males and  
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46 people 15-44 years old (referred to as "working-age adults"), as these demographic groups  
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48 comprise the majority of TB cases diagnosed in Peru (17). We used a Wilcoxon rank-sum test to  
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50 compare the proportion of attendees who were male and the proportion who were working-age  
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adults among different types of screening sites, using an exact test for categories with  $\leq 5$  sites, and considering  $p < 0.05$  as significant.

## Effectiveness

To assess effectiveness, we considered two main objectives of active case-finding: to diagnose additional cases and to diagnose cases earlier. To assess additionality, we obtained quarterly case notifications from Ministry of Health facilities in each of the three districts during 2015-2019. During this period, there were no major program-wide changes to TB services or to the TB surveillance system in these facilities; nationally, numbers of people evaluated for TB and case notification rates in the Ministry of Health system remained stable between 2016-2019 (21). We coded each quarter as pre-intervention or intervention and calculated the average difference between actual case notifications during intervention quarters and expected notifications assuming a linear trend based on the pre-intervention quarters; the appropriateness of a linear trendline was confirmed by plotting residuals of the linear regression. We included in this analysis only health facilities that notified TB cases during both the pre-intervention and intervention periods to eliminate bias from changing catchment populations. An overall effect estimate of the intervention was generated using a Poisson regression to model quarterly case notifications during 2016-2019 from each of the three intervention districts as a function of quarter and whether the intervention was being implemented, using the average quarterly case notifications in 2015 as an offset.

To assess whether cases were diagnosed early, we calculated the percentage of cases that had a positive sputum smear microscopy result based on the same sputum sample used for Xpert testing. Smear positivity is associated with increased sputum bacillary load (22), which is a

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3 marker for more advanced disease (23), so a low proportion of smear positivity could indicate  
4 earlier diagnosis. Given that only a single spot sputum sample was tested, smear microscopy is  
5 expected to have lower sensitivity than under ideal conditions; however, a community-based  
6 screening program in the Philippines that used a similar diagnostic algorithm, found nearly half  
7 of people diagnosed with TB to have positive smear results based on the spot sputum specimens  
8 collected at the screening site (8).  
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## 19 **Adoption**

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21 We assessed two quantitative measures of adoption. The first measure was the percentage  
22 of health facilities that accepted having the mobile unit stationed outside to screen their staff and  
23 clients. We considered this to be an indicator of the acceptability of the intervention to the health  
24 system, which is an important driver of adoption. The second measure was the time between  
25 screening and treatment initiation for people diagnosed with TB by the intervention. We  
26 considered the promptness of treatment initiation to be an indicator of the health system's ability  
27 to incorporate the intervention approach into existing services. We assessed differences in time  
28 to treatment initiation among patient groups by Wilcoxon rank-sum test.  
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32 To better understand drivers of these two adoption measures, we qualitatively analyzed  
33 meeting minutes from monthly coordination calls (13 documents) and quarterly reports to  
34 intervention funders during 2019 (4 documents) using a Framework Analysis approach (24). We  
35 extracted into matrices all passages related to the intervention coordinators' interactions with  
36 health facilities or other organizations, as well as passages related to treatment initiation. We  
37 then coded these passages according to whether they described acceptance or rejection of the  
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3 intervention, or barriers or facilitators to treatment initiation for patients diagnosed by the  
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## 10 **Implementation**

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12 To assess implementation, we quantified performance indicators using a framework for  
13 evaluation of TB active case-finding (25, 26). We focused on five key indicators that reflect  
14 implementation fidelity: percentage of people registered who were screened by chest  
15 radiography, percentage of people with abnormal chest radiographs who were evaluated  
16 clinically, percentage of people with abnormal chest radiographs who had sputum samples  
17 collected for Xpert testing, percentage of sputum samples with valid Xpert results, and  
18 percentage of people diagnosed with TB who initiated treatment. Where any of these fell below  
19 85%, we probed operational data to identify reasons for suboptimal fidelity. We assessed  
20 differences between participant groups by chi-squared test.  
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## 35 **Maintenance**

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37 Our maintenance assessment focused on the extent to which the intervention was  
38 institutionalized into the routine TB services. Given that the intervention was grant-funded and  
39 implemented by an NGO for this first year, the maintenance of the intervention was dependent  
40 on the Ministry of Health incorporating the approach into its programming. To assess the extent  
41 to which this occurred, we reviewed call minutes and program reports from the evaluation period  
42 for evidence of investment by the Ministry of Health in maintaining or expanding the  
43 intervention beyond the initial year.  
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## Patient and public involvement

Patients and the public were involved in multiple aspects of program implementation and research. Patient and community preferences were taken into account when developing the implementation plan for the intervention. During program implementation, our community engagement strategy involved meeting with community leaders prior to the arrival of the screening program in a community to gain community buy-in and disseminate information. In addition, recruitment of people to the screening program was mostly done by community members, including community health workers, TB survivors, and community-based artists. Results of the intervention have been progressively disseminated to the community via social media. As with all studies implemented by Socios En Salud, the research plan was presented to a community advisory board for approval.

## Ethical considerations

The intervention and evaluation were approved by the Ethics Committee of the Universidad Peruana Cayetano Heredia. A waiver of informed consent for screening procedures and data collection was granted on the basis that procedures posed minimal risk to participants and that informed consent could not feasibly be administered in the context of a high-volume community screening program.

## RESULTS

### Reach

In one year, the two mobile units registered 63,899 attendees at 215 screening locations in north Lima. Of these, 58,962 (92%) reported residing in the intervention area. We estimate

that the mobile unit screening reached 6% of residents in the intervention area, including 9% of District A residents, 4% of District B residents, and 3% of District C residents. The higher coverage in District A was due to the longer duration of implementation; on average, the program reached 3% of District A residents, 2% of District B residents, and 5% of District C residents per 100 days spent in each respective district. Coverage was higher for females versus males in all districts (A: 11% vs 7%; B: 5% vs 3%; C: 3% vs 2%;  $p < 0.001$  for all comparisons). Coverage was higher among older adults compared to younger adults (Figure S2).

Sites where screening was open to the public included general community locations, health facilities, markets, transport terminals, and a shopping mall (Table 1). At general community screening sites, a median of 39% (interquartile range [IQR]: 36–42%) of attendees were male, and a median of 41% (IQR 36–44%) of attendees were working-age adults. In comparison, transport terminal sites had significantly higher percentages of both male attendees and working-age attendees. In addition, the mobile units were stationed at five sites where screening was restricted to staff and residents of specific institutions known to have predominantly young and male populations, including an army barrack, a police complex, two companies, and a technical college. These sites also had significantly higher percentages of male and working-age attendees.

**Table 1:** Percent male and working-age attendees, by type of screening site

Type of site	Number of sites	Percent male attendees			Percent working-age attendees (age 15–44)		
		Median	IQR	p-value	Median	IQR	p-value
General community	156	39	36–42	reference	41	36–44	reference
Health facilities	32	34	31–39	<0.001	39	36–43	0.508
Markets	12	40	37–41	0.528	40	36–44	0.837
Transport terminals	9	65	62–69	<0.001	46	44–51	<0.001
Company or institution	5	61	56–64	<0.001	89	80–90	<0.001
Shopping mall	1	38	N/A	0.854	61	N/A	0.013

IQR = interquartile range. N/A = not applicable. P-value from Wilcoxon rank sum test.

## Effectiveness

During the evaluation period, the intervention diagnosed 393 cases of TB, of which 343 (87%) were among people living in the intervention area. Average case notifications were 13% higher than expected during four intervention quarters in District A, 4% higher than expected during three intervention quarters in District B, and 17% higher than expected during one intervention quarter in District C (Table 2, Figure S3). If all additional cases were attributable to the intervention, then an estimated 27%, 12%, and 45% of cases detected by the intervention in Districts A, B, and C respectively would not otherwise have been detected. The overall effect estimate for the intervention was an increase of 11% (95% CI 6–16%) in case notifications during quarters when the intervention was being implemented, after adjusting for secular changes in case notifications over time.

**Table 2:** Impact of intervention based on average quarterly TB case notifications in intervention and control districts during 2015-2019

	District A	District B	District C
Average case notifications per pre-intervention quarter (starting 2015)	72	169	79
Change in cases per quarter based on linear regression	+0.6	+0.9	+0.2
Expected average cases per intervention quarter (2019)	78	177	81
Actual average cases notified per intervention quarter	88	184	95
Difference between actual and expected	+13%	+4%	+17%
Absolute difference in total and expected notifications over all intervention quarters	+41	+19	+14
Cases detected by intervention in residents of district	153	159	31
Estimated percent of cases detected by intervention that represent additional cases	27%	12%	45%

Of the 393 TB diagnoses, 388 (99%) had a valid Xpert result, with 315 (81%) having a positive result (including trace positive results). All 388 also had smear microscopy performed on the same sputum sample, with only 99 (26%) having a positive result.

## Adoption

During the evaluation period, the intervention team approached 32 health facilities in the three districts to ask if the mobile unit could be stationed outside the health facility to screen clients and staff. All (100%) accepted. These facilities included both hospitals, 29 of the 51 (57%) public health facilities overseen by the DIRIS Lima Norte, and one of the four (25%) EsSalud primary care facilities. A report noted that the intervention team received requests for additional screening locations than it could not accommodate (Table 3).

**Table 3:** Observations relating to adoption and maintenance recorded in meeting minutes and reports

RE-AIM construct: theme	Quotation from meeting minutes
Adoption: requests for intervention services by health system	“We have received numerous requests to bring the van to screen in different areas of Lima; although we have not been able to accommodate these requests, they demonstrate the demand for such services.” (Q1 2019 report)
Adoption: challenges to having TB diagnoses accepted by health system	“While the screening program operated successfully, we have encountered challenges with delayed treatment initiation for people diagnosed with TB. This has happened because the doctors are requesting more procedures (such as CT) before deciding to initiate treatment, and many of them have limited knowledge of GeneXpert.” (Q4 2019 report)
	“Some people with positive GeneXpert results have to wait to see a pulmonologist, delaying treatment initiation.” (November 2019 meeting minutes)
Adoption: facilitators to having TB diagnoses accepted	“We held some meetings with [an infectious disease doctor from the United States] in which he talked about GeneXpert Ultra and its use. This helped the doctors in the primary care facilities of Carabayllo understand better the response to these cases.” (September 2019 meeting minutes)
Maintenance: expansion of intervention to other areas with Ministry of Health support	“The TB Movil intervention is being offered to the Ministry of Health in the municipality of La Victoria.” (January 2020 meeting minutes)
	“There is a possibility that the Ministry of Health will give us access to 8 cases of Xpert cartridges that are currently in [another city]. The objective is to use them in north Lima and also other screenings that the Ministry of Health coordinates. We are discussing whether to do the Xpert testing in the Socios En Salud laboratory or a Ministry of Health laboratory.” (January 2020 meeting minutes)
Maintenance: integration of intervention approach into policy	“We have had meetings with the Ministry of Health and the National TB Program in which they expressed interest in developing a directive for TB active case-finding. We presented the approach of TB Móvil. The meeting was with [Dr. X], with whom we have another meeting scheduled for next week to discuss the coordination of the activities of TB Móvil and the Ministry of Health.” (November 2019 meeting minutes)



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Among patients with Xpert-positive rifampin-susceptible TB who initiated treatment, the median time from screening to treatment initiation was 6 days (IQR 3–11 days). Time to treatment initiation was not significantly different for those with rifampin-resistant TB (median 7, IQR 3–18 days;  $p=0.607$ ). However, time to treatment initiation was longer for those without a positive Xpert result (median 9, IQR 4–23 days;  $p=0.026$ ) and those with trace positive Xpert results (median 11, IQR 4–28 days,  $p=0.003$ ). Given that the median time between screening and Xpert result availability was only 1 day (IQR 0–1 day), delays in treatment initiation reflected clinical decision delays rather than laboratory delays.

Challenges in having diagnoses from the intervention accepted by the health system were documented in meeting minutes and reports (Table 3). One reason for delay was that people diagnosed with TB were referred for re-evaluation by pulmonologists at the government hospitals, even if they had positive Xpert results, underlining a lack of knowledge about this diagnostic test and its significantly higher sensitivity as compared to sputum smear microscopy. The utility of education for providers in reducing treatment delays was also documented. Meetings in which health facility physicians were trained with regards to the role of radiography and Xpert in TB diagnosis were noted to have improved the acceptability of diagnoses coming from the intervention and reduced treatment initiation delays.

## Implementation

Of the 63,899 attendees registered over 1 year, 58,268 (91%) had chest radiography performed (Figure 1). Each unit performed a median of 114 (IQR 90–134) radiographs per day. One new TB diagnosis was made per 148 people screened by chest radiography, and one Xpert-

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3 positive diagnosis per 44 people tested by Xpert. We were able to confirm treatment initiation  
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5 for 323 (82%) of the 393 TB diagnoses.  
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8 The two key implementation fidelity indicators that fell below 85% were the percent of  
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10 people with abnormal chest radiographs for whom sputum samples were submitted and the  
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12 percent of people diagnosed with TB who initiated treatment. When we analyzed sputum  
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14 submission by age, we found that 88% of people age  $\geq 10$  years old submitted a sputum sample,  
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16 compared to 17% of children  $< 10$  years old, suggesting that the suboptimal value of this  
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18 indicator was driven by young children's inability to produce sputum.  
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21 We found that the percentage of people initiating TB treatment varied depending on the  
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23 basis of the TB diagnosis (Figure 2). Treatment initiation was documented for 95% of people  
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25 with Xpert-positive rifampin-susceptible TB. The percentage of people who initiated treatment  
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27 was significantly lower for all other types of diagnoses (86% for rifampin-resistant TB,  $p=0.019$ ;  
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29 64% for those with trace positive Xpert results,  $p<0.001$ ; 53% for those without a positive Xpert  
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31 result, who were diagnosed based on clinical and/or radiographic criteria,  $p<0.001$ ). Rejection of  
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33 the intervention's TB diagnosis by a health facility physician was documented for 9% of those  
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35 with trace positive Xpert results and 26% of those without positive Xpert results.  
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## 42 Maintenance

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44 During the evaluation period, meeting minutes noted that the Ministry of Health had  
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46 agreed to let the intervention team use its Xpert machines and cartridges to expand the screening  
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48 program beyond the intervention districts (Table 3). A meeting with the National TB Program  
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50 was also reported which examined the possibility of incorporating the X-ray van strategy into a  
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52 new active case-finding policy. As of June 2021 (2.5 years after the intervention began), the  
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3 program had expanded to 23 additional districts within and outside Lima. After the end of the  
4 original grant-funded period, program costs were covered by the Ministry of Health (staff, Xpert  
5 testing, implementation costs), internal funding from Socios En Salud (staff, implementation  
6 costs), and local municipalities (transport to bring attendees from underserved areas),  
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## 14 **DISCUSSION**

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16 We found that an intervention using community-based mobile X-ray screening units was  
17 effective for increasing TB diagnoses and diagnosing TB that was negative by smear  
18 microscopy. In its first year, the intervention reached 6% of the population of a region of around  
19 1 million inhabitants. The intervention was associated with an 11% (95% CI 6-16%) increase in  
20 quarterly case notifications after adjusting for the increasing trend in notifications over the  
21 previous four years. Although decision-makers at many health facilities were eager to  
22 collaborate with the intervention, we encountered challenges with individual physicians at local  
23 clinics not accepting TB diagnoses based on X-ray and Xpert. Our experience illustrates the  
24 complexities involved in health-system adoption of a new standard of care that differs  
25 substantially from routinized practice.  
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40 The high implementation fidelity we observed for procedures that took place at the  
41 screening site suggest both demand for free TB diagnostic services and acceptability of mobile  
42 X-ray screening units as a way to deliver these services. Despite long wait times, attendees  
43 generally completed the screening and evaluation procedures. Moreover, high attendance  
44 resulted in a large number of people screened. Our implementation strategy compared favorably  
45 to interventions using mobile X-ray units in community settings elsewhere (8, 9, 27). However,  
46 men and working-age adults were underrepresented among attendees, resulting in uneven reach  
47 of the intervention. While offering screening at transport terminals and places of work increased  
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3 attendance for both of these demographic groups, feedback from the implementation team  
4 suggested larger structural barriers at play. In Peru, people working in the informal economic  
5 sector have no protection from loss of income or employment should they be diagnosed with TB,  
6 thus disincentivizing uptake of TB screening. This observation underscores the importance of  
7 legal and social protection programs, in addition to expanded case-finding interventions, for  
8 increasing detection of stigmatized diseases like TB (28).  
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12 The major implementation barriers we encountered occurred at local health facilities  
13 when people diagnosed with TB by the mobile units went to initiate treatment. Many TB  
14 diagnoses based on trace positive Xpert results or clinical/radiographic criteria were rejected by  
15 the local physicians, and patients experienced delays in treatment initiation. Similar challenges  
16 were observed in other countries when Xpert was first introduced as a replacement for smear  
17 microscopy. In India, the willingness of providers to make clinical diagnoses decreased once  
18 Xpert was introduced, in part because Xpert was viewed as a “gold standard” with perfect  
19 sensitivity (29). Moreover, variable knowledge about Xpert among providers led to  
20 disagreements over the use of Xpert testing for TB diagnosis (30). In other countries, treatment  
21 initiation delays for patients with positive Xpert results were observed because of confusion over  
22 guidelines for reporting Xpert-positive patients (31). While Xpert had been used at a small scale  
23 in Peru’s public health system prior to the present intervention, a lack of knowledge about Xpert  
24 at the primary care level contributed to some reluctance in accepting Xpert diagnoses, especially  
25 when trace positive results were obtained. Together, these challenges emphasize the importance  
26 of clear practice guidelines and regular training for primary-level clinicians when new diagnostic  
27 practices are introduced.  
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3 This initial evaluation suggests that the community-based mobile X-ray unit strategy is  
4 effective for increasing TB case detection in Peru. However, our effectiveness analysis is subject  
5 to some important limitations. While we used four years of case notification data to establish a  
6 temporal trend against which case against which the intervention period could be compared, we  
7 cannot rule out the possibility that TB program improvements unrelated to the intervention might  
8 have contributed to an increase in notifications. Our analysis also cannot explain the  
9 heterogeneity of impact in the different districts, particularly why District B experienced such a  
10 small increase in case notifications despite a large number of TB diagnoses by the intervention.  
11 One possibility is that in District B, security concerns limited program operation in community  
12 settings, and a larger proportion of people were screened and diagnosed at sites outside health  
13 facilities; because they were already seeking health care, these people might have been  
14 diagnosed by the health system anyway. Finally, because our intervention introduced multiple  
15 components that differed from routine practice, we cannot assess the relative importance of each  
16 component. However, it is likely that the effects of different components depend on the presence  
17 of the others. For instance, in isolation, the introduction of Xpert into a health system as a  
18 replacement for smear microscopy has generally not led to increases in case detection (32, 33);  
19 however, in our intervention, using Xpert may have contributed to case notifications by  
20 providing rapid bacteriologic confirmation for cases that might otherwise have been contested  
21 clinical diagnoses, especially given the low prevalence of smear positivity.  
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46 We did not assess costs in our evaluation. However, models fit to the epidemics of China  
47 and South Africa – two other upper-middle-income countries like Peru – have suggested that a 2-  
48 year active case-finding program that increases case detection by 25% would be highly cost-  
49 effective at a cost of 3800-9400 USD per case detected (34). If the campaign is sustained for  
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3 longer periods of time, they remain highly cost effective at even higher costs per case detected,  
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5 despite declining gains in case detection over time. Moreover, the health system strengthening  
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7 that accompanies the implementation of a large-scale campaign such as ours also contributes to a  
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9 decrease in tuberculosis morbidity and mortality, separately from the intervention itself (Shrestha  
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11 S, Achieving a “step change” in the tuberculosis epidemic through comprehensive community-  
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13 wide intervention: a model-based analysis).  
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17 Other limitations of this initial evaluation reflect time and resource constraints. We did  
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19 not perform qualitative research through interviews or focus groups to better explain the barriers  
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21 to adoption of the intervention approach by the health system. For example, we do not know  
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23 whether clinical diagnoses of TB in patients with clinical and radiographic findings but a  
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25 negative Xpert result were rejected because doctors perceived Xpert as having perfect sensitivity  
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27 or because of low inter-rater reliability for chest radiographs, both of which have been observed  
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29 in other settings (29, 35). In addition, we did not collect data about the specific health care  
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31 providers or health care facilities managing each patient, which could have allowed us to  
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33 determine whether treatment initiation challenges were associated with certain provider or  
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35 facility characteristics. Finally, the timeframe of the evaluation limited our ability to quantify  
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37 durability of impact over time. Thus, while providing useful knowledge for integrating mobile  
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39 X-ray units into TB programs in settings with high TB burdens, our study also highlights areas in  
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41 which further implementation research is needed.  
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47 Local coalitions seeking to rapidly drive down TB will have to introduce new strategies  
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49 to transform routine services and systems. While new innovations in diagnostic technologies are  
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51 needed, increasing and improving the implementation of evidence-based approaches in settings  
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53 with high TB burdens is also important. We found that deploying mobile X-ray units with  
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3 automated detection software across a high-risk area constituted a feasible and effective strategy  
4 to extend TB diagnostic services into communities and improve early case detection. Effective  
5 deployment however requires advance coordination among stakeholders and targeted provider  
6 training to ensure that people diagnosed with TB by new modalities receive prompt treatment.  
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8 These implementation lessons can be applied by other TB elimination coalitions around the  
9 world, as part of the mutual aid and exchange of resources among coalitions.  
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## 19 **FIGURE LEGENDS**

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21 **Figure 1: TB diagnostic and treatment cascade for the TB Móvil screening program.** Green  
22 boxes indicate key implementation indicators.  
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28 **Figure 2: Treatment initiation among people diagnosed with TB by the intervention, by**  
29 **Xpert result (N=393).** MTB = Mycobacterium tuberculosis, Rif = rifampin  
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39  
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41 Health, the DIRIS Lima Norte, and the municipal governments of Carabayllo, Comas, and  
42 Independencia districts.  
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## 24 **AUTHOR CONTRIBUTIONS**

25  
26 CMY, SK, and MCB conceptualized the study. CMY, DP, JTG, LL, and MCB led the  
27 implementation of the intervention. AKM, CT, RIC, MBB, JJ, CC, and TN supported  
28 implementation. CMY and DP planned and supervised data collection. CT and TCN helped to  
29 collect and clean data. CMY performed the analysis and wrote the first draft of the manuscript,  
30 and all authors revised critically.  
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## 40 **COMPETING INTERESTS**

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42 The authors declare no competing interests.  
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## 47 **DATA SHARING**

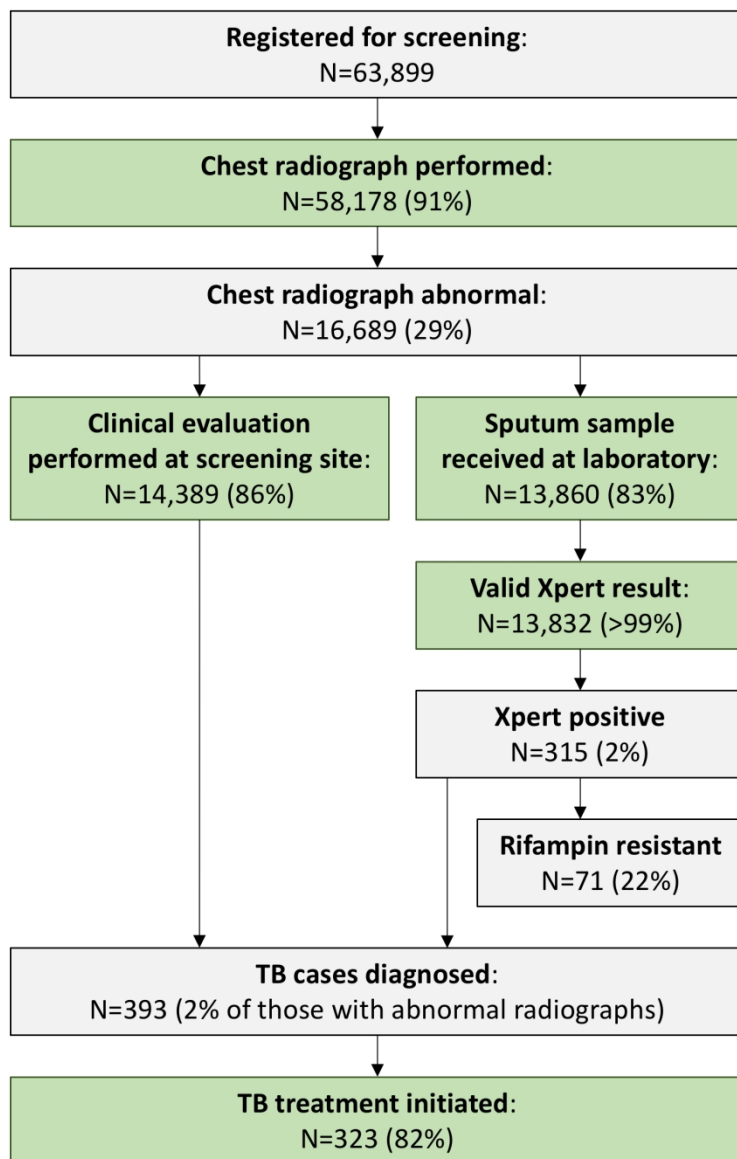
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49 Data are available upon reasonable request. Contact the corresponding author for a data request  
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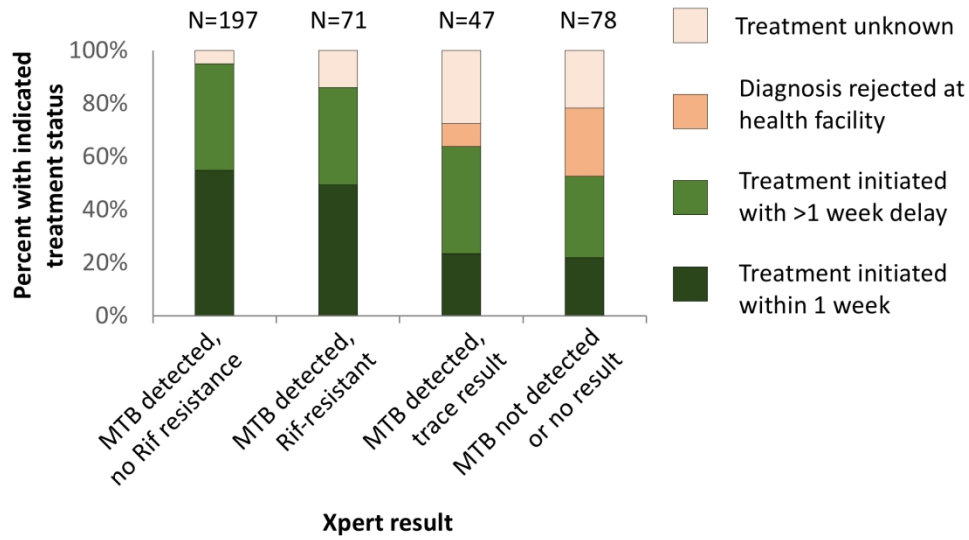
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TB diagnostic and treatment cascade for the TB Móvil screening program. Green boxes indicate key implementation indicators.

132x200mm (300 x 300 DPI)



Treatment initiation among people diagnosed with TB by the intervention, by Xpert result (N=393). MTB = Mycobacterium tuberculosis, Rif = rifampin

185x112mm (300 x 300 DPI)

Supplementary figures for “Identifying barriers and facilitators to implementation of community-based tuberculosis active case-finding with mobile X-ray units in Lima, Peru: a RE-AIM evaluation”

Figure S1: Screening algorithm used at mobile screening units

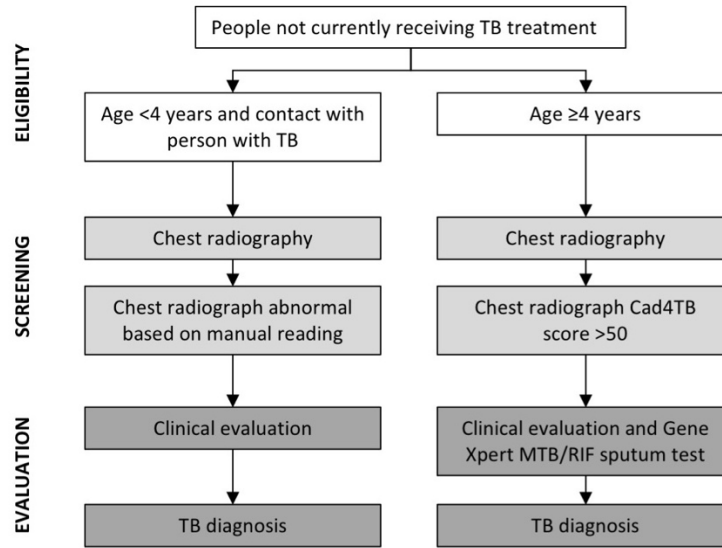
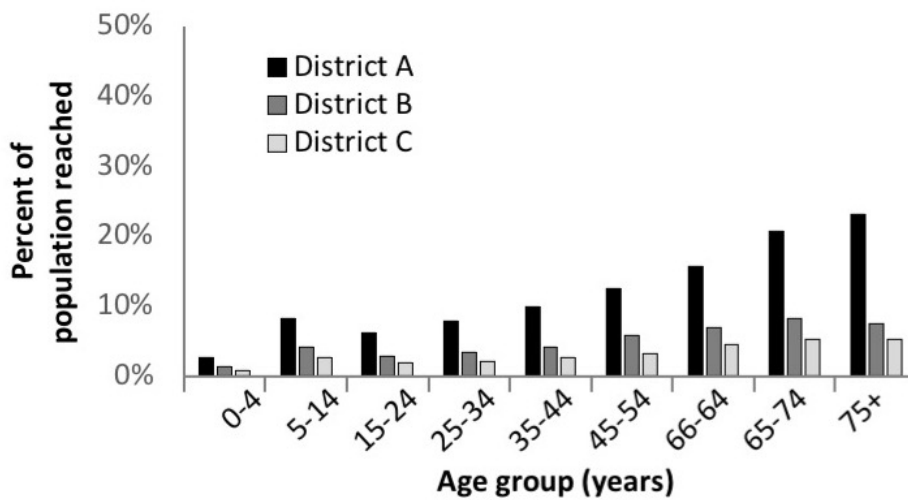
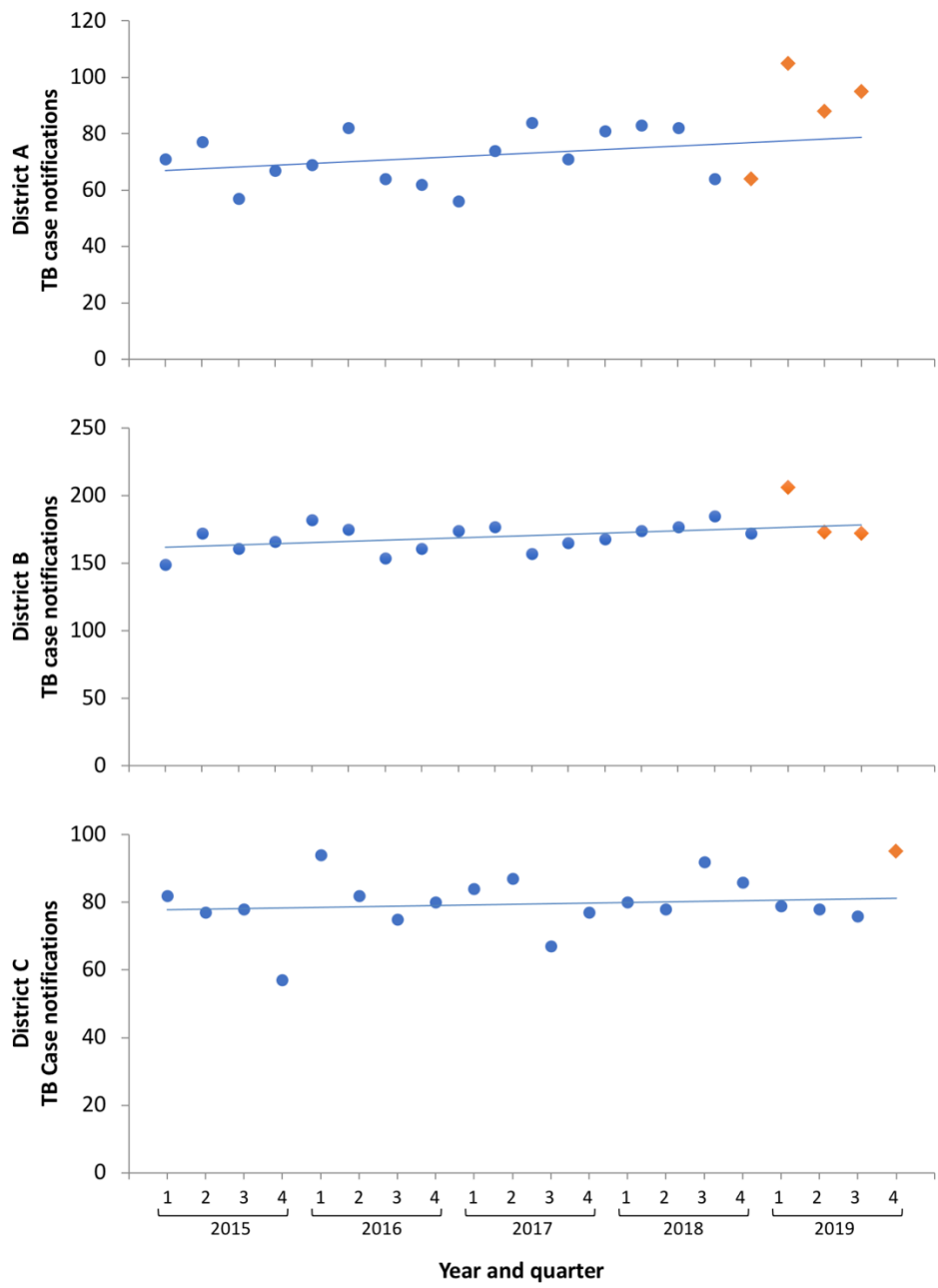


Figure S2: Percent of intervention area residents reached, by district and age



**Figure S3: Quarterly case notifications in intervention districts.** Blue circles represent pre-intervention quarters, orange diamonds represent intervention quarters. The blue line represents the linear trend established by the pre-intervention quarters.



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