

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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ABSTRACT

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

Methods Reach, effectiveness, adoption, implementation and maintenance evaluation.

Setting 3-district region of Lima, Peru.

Participants 63 899 people attended the mobile units from 7 February 2019 to 6 February 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 three-district region that attended the mobile units. Effectiveness was defined as the change in tuberculosis case notifications over a historical 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 to 16) increase in quarterly case notifications, adjusting for the increasing trend in notifications over the previous 3 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

Strengths and limitations of this study

- An implementation science evaluation of a large programme that screened over 60 000 people for tuberculosis in a middle-income country allowed us to both assess the performance of the programme 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 analyse 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 programme or population changes that might have contributed to increased case notifications.
- The assessment of adoption and maintenance is limited by a reliance on secondary data sources rather than focus groups or interviews.

coordination among stakeholders and targeted provider training to ensure that people diagnosed with tuberculosis by new modalities receive prompt treatment.

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, underutilisation 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 non-infectious,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 1930s–1960s, mobile X-ray units were an integral part of TB programmes in industrialised 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 programmes,^{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 programmes 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 programme 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 reach, effectiveness, adoption, implementation and maintenance (RE-AIM) evaluation¹⁴ of the first year of implementation of TB Móvil, a programme that uses mobile screening units with X-ray vans for TB active case finding in community settings. TB Móvil is an ongoing programme 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 organisation Socios En Salud in collaboration with the Ministry of Health, municipal governments and community organisations.

Study population and setting

The intervention area comprised three districts with a combined population of 1.1 million¹⁶ 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 (Dirección de Redes Integradas de Salud 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 centres operated by EsSalud, a government insurance programme 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 V.6 (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 centres and markets. We partnered with health facility decision-makers to operate screening sites immediately outside the facility to screen both health facility attendees and healthcare workers. We also partnered with transportation companies to operate screening sites at the terminals of major bus lines with the goal of making screening accessible to working adults as they commute. Finally, we partnered with companies and institutions to screen staff and residents. A structured community engagement strategy was used to inform and educate local residents about the programme and encourage attendance.¹⁹

Individuals ≥ 4 years old were eligible for screening provided they were not receiving TB treatment (online supplemental figure S1). Children < 4 years old were eligible for screening only if they were close contacts of patients with TB; this is because the CAD4TB V.6 software was validated only for individuals ≥ 4 years old. All attendees registered for screening, at which point we collected information on their age, sex and district of

residence. After registration, attendees waited for chest radiography; during the wait time, which ranged from 5 to 50 min depending on attendance, attendees received education about TB symptoms, transmission, and diagnosis. Chest radiography was performed in the X-ray van by a radiography technician and scored automatically by CAD4TB. People with abnormal radiographs were referred to a physician at the screening unit for clinical evaluation and were asked for a sputum sample for testing by GeneXpert MTB/RIF (Cepheid, Sunnyvale, California, USA; referred to as 'Xpert'). Field staff used their discretion in requesting sputum from young children given children's general inability to produce sputum.²⁰ Xpert testing was performed at the Socios En Salud laboratory initially using standard cartridges and switching to 'Ultra' cartridges after 6 months. People could be diagnosed with TB based on a positive Xpert result or by the physician at the screening unit based on clinical and radiographic evidence. All people diagnosed with TB were accompanied by community health workers (community members with basic training in health issues) to public health facilities for treatment initiation, and radiographs and Xpert results were given to the health facility doctors. All procedures were free of cost. Data on all procedures were directly entered into an electronic data collection system; data on treatment initiation reflect results obtained by 13 March 2020.

RE-AIM evaluation

We used the RE-AIM framework¹⁴ to evaluate how the intervention's approach to TB active case finding performed within the Peruvian health system. We chose the RE-AIM framework because it assesses implementation and effectiveness outcomes at individual and health system levels, making it well suited for identifying barriers and facilitators to integrating a new intervention into a 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 bacteriological testing. Evaluation focused on understanding how well the health system was able to incorporate these new approaches and their impact on TB diagnosis.

Reach

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 demographical groups comprise the majority of TB cases diagnosed in Peru.¹⁷ 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 ≤ 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 programme-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 and 2019.²¹ We coded each quarter as preintervention or intervention and calculated the average difference between actual case notifications during intervention quarters and expected notifications assuming a linear trend based on the preintervention 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 preintervention 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 marker for more advanced disease,²³ 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 screening programme in the Philippines that used a similar diagnostic algorithm found nearly half of people diagnosed with TB to have positive smear results based on the spot sputum specimens collected at the screening site.⁸

Adoption

We assessed two quantitative measures of adoption. The first measure was the percentage of health facilities that accepted having the mobile unit stationed outside to screen their staff and clients. We considered this to be an indicator of the acceptability of the intervention to the health system, which is an important driver of adoption. The second measure was the time between screening and treatment initiation for people diagnosed with TB by the intervention. We considered the promptness of treatment initiation to be an indicator of the health system's ability

to incorporate the intervention approach into existing services. We assessed differences in time to treatment initiation among patient groups by Wilcoxon rank-sum test.

To better understand drivers of these two adoption measures, we qualitatively analysed meeting minutes from monthly coordination calls (13 documents) and quarterly reports to intervention funders during 2019 (four documents) using a framework analysis approach.²⁴ We extracted into matrices all passages related to the intervention coordinators' interactions with health facilities or other organisations, as well as passages related to treatment initiation. We then coded these passages according to whether they described acceptance or rejection of the intervention or barriers or facilitators to treatment initiation for patients diagnosed by the intervention.

Implementation

To assess implementation, we quantified performance indicators using a framework for evaluation of TB active case finding.^{25 26} 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. We assessed differences between participant groups by χ^2 test.

Maintenance

Our maintenance assessment focused on the extent to which the intervention was institutionalised into the routine TB services. Given that the intervention was grant funded and implemented by a non-governmental organisation 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 programme reports from the evaluation

period for evidence of investment by the Ministry of Health in maintaining or expanding the intervention beyond the initial year.

RESULTS

Reach

In 1 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 programme 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%; and C, 3% vs 2%; $p < 0.001$ for all comparisons). Coverage was higher among older adults compared with younger adults (online supplemental 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% (IQR: 36%–42%) of attendees was male, and a median of 41% (IQR 36%–44%) of attendees was 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.

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

Table 1 Percentage of male and working-age attendees, by type of screening site

Type of site	Number of sites	Percentage of male attendees			Percentage of 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

P value from Wilcoxon rank-sum test.

Table 2 Impact of intervention based on average quarterly tuberculosis (TB) case notifications in intervention and control districts during 2015–2019

	District A	District B	District C
Average case notifications per preintervention 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 (2019)	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%

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 and online supplemental 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 to 16) in case notifications during quarters when the intervention was being implemented, after adjusting for secular changes in case notifications over time.

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 that it could not accommodate (table 3).

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 and IQR 3–18 days, $p=0.607$). However, time to treatment initiation was longer for those without a positive Xpert result (median 9 and IQR 4–23 days, $p=0.026$) and those with trace positive Xpert results (median 11 and 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 with 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 regard 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-positive diagnosis per 44 people tested by Xpert. We were able to confirm treatment initiation for 323 (82%) of the 393 TB diagnoses.

The two key implementation fidelity indicators that fell below 85% were the percent of people with abnormal chest radiographs for whom sputum samples were submitted and the percent of people diagnosed with TB who initiated treatment. When we analysed sputum submission by age, we found that 88% of people age ≥ 10 years old submitted a sputum sample, compared with 17% of children < 10 years old, suggesting that the suboptimal value of this indicator was driven by young children's inability to produce sputum.

We found that the percentage of people initiating TB treatment varied depending on the basis of the TB diagnosis (figure 2). Treatment initiation was documented for 95% of people with Xpert-positive rifampicin-susceptible TB. The percentage of people who initiated treatment was significantly lower for all other types of diagnoses (86% for rifampicin-resistant TB, $p=0.019$; 64% for those with trace positive Xpert results, $p<0.001$; and 53% for

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 programme 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 USA] 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 Móvil 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 eight 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 Programme 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)

RE-AIM, reach, effectiveness, adoption, implementation and maintenance; TB, tuberculosis.

those without a positive Xpert result, who were diagnosed based on clinical and/or radiographic criteria, $p < 0.001$). Rejection of the intervention's TB diagnosis by a health facility physician was documented for 9% of those with trace positive Xpert results and 26% of those without positive Xpert results.

Maintenance

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

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. The intervention was associated with an 11% (95% CI 6 to 16) increase in quarterly case notifications after adjusting for the increasing trend in notifications over the previous 4 years. 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 routinised practice.

The high implementation fidelity we observed for procedures that took place at the screening site suggests 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

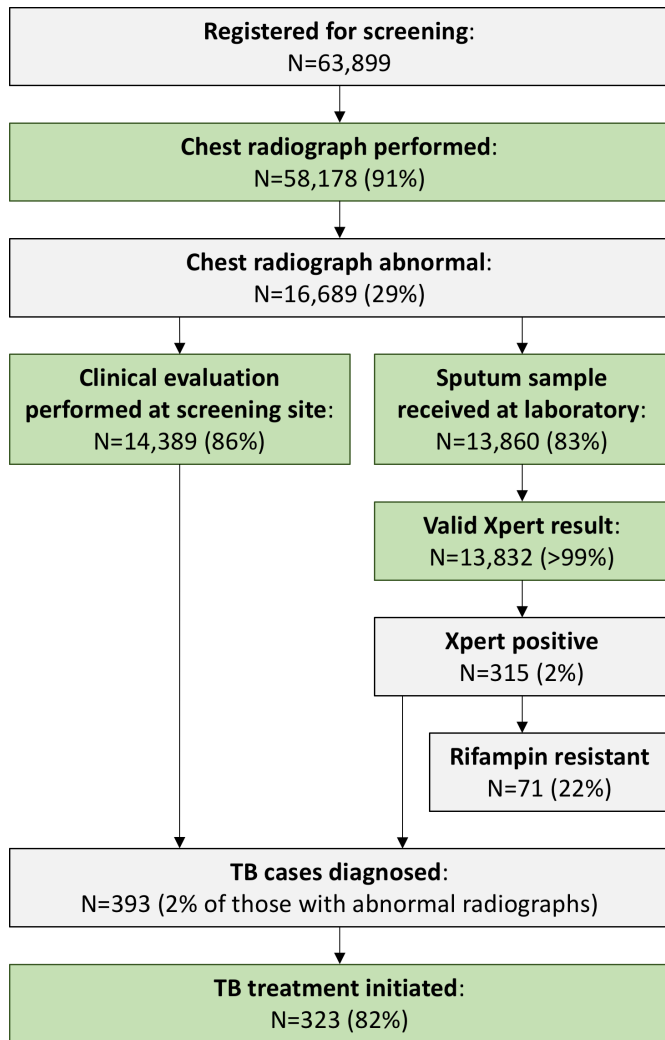


Figure 1 Tuberculosis (TB) diagnostic and treatment cascade for the TB Móvil screening programme. Green boxes indicate key implementation indicators.

people screened. Our implementation strategy compared favourably to interventions using mobile X-ray units in community settings elsewhere.^{8 9 27} However, men and working-age adults were under-represented among attendees, resulting in uneven reach of the intervention.

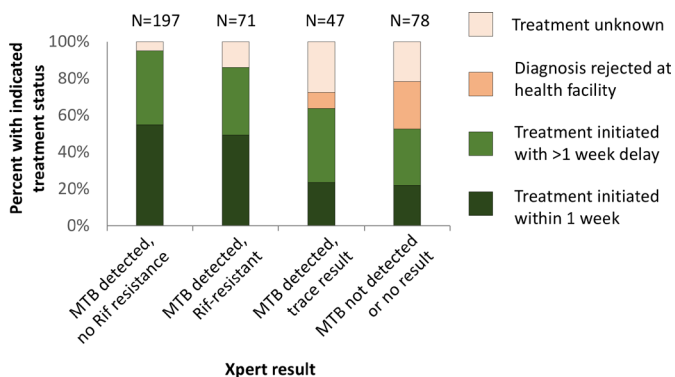


Figure 2 Treatment initiation among people diagnosed with tuberculosis by the intervention, by Xpert result (n=393). MTB=*Mycobacterium tuberculosis*; Rif=rifampicin

While offering screening at transport terminals and places of work increased attendance for both of these demographical 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 disincentivising uptake of TB screening. This observation underscores the importance of legal and social protection programmes, in addition to expanded case-finding interventions, for increasing detection of stigmatised diseases like TB.²⁸

The major implementation barriers we encountered occurred at local health facilities when people diagnosed with TB by the mobile units went to initiate treatment. Many TB diagnoses based on trace positive Xpert results or clinical/radiographic criteria were rejected by the local physicians, and patients experienced delays in treatment initiation. Similar challenges were observed in other countries when Xpert was first introduced as a replacement for smear microscopy. In India, the willingness of providers to make clinical diagnoses decreased once Xpert was introduced, in part because Xpert was viewed as a ‘gold standard’ with perfect sensitivity.²⁹ Moreover, variable knowledge about Xpert among providers led to disagreements over the use of Xpert testing for TB diagnosis.³⁰ In other countries, treatment initiation delays for patients with positive Xpert results were observed because of confusion over guidelines for reporting Xpert-positive patients.³¹ While Xpert had been used at a small scale in Peru’s public health system prior to the present intervention, a lack of knowledge about Xpert at the primary care level contributed to some reluctance in accepting Xpert diagnoses, especially when trace positive results were obtained. Together, these challenges emphasise the importance of clear practice guidelines and regular training for primary-level clinicians when new diagnostic practices are introduced.

This initial evaluation suggests that the community-based mobile X-ray unit strategy is effective for increasing TB case detection in Peru. However, our effectiveness analysis is subject to some important limitations. While we used 4 years of case notification data to establish a temporal trend against which case the intervention period could be compared, we cannot rule out the possibility that TB programme improvements unrelated to the intervention might have contributed to an increase in notifications. Our analysis also cannot explain the heterogeneity of impact in the different districts, particularly why District B experienced such a small increase in case notifications despite a large number of TB diagnoses by the intervention. One possibility is that in District B, security concerns limited programme operation in community settings, and a larger proportion of people was screened and diagnosed at sites outside health facilities; because they were already seeking healthcare, these people might have been diagnosed by the health system anyway. Finally, because our intervention introduced multiple components that differed from routine practice, we cannot assess



the relative importance of each component. However, it is likely that the effects of different components depend on the presence of the others. For instance, in isolation, the introduction of Xpert into a health system as a replacement for smear microscopy has generally not led to increases in case detection^{32 33}; however, in our intervention, using Xpert may have contributed to case notifications by providing rapid bacteriological confirmation for cases that might otherwise have been contested clinical diagnoses, especially given the low prevalence of smear positivity.

We did not assess costs in our evaluation. However, models fit to the epidemics of China and South Africa—two other upper-middle-income countries like Peru—have suggested that a 2-year active case-finding programme that increases case detection by 25% would be highly cost-effective at a cost of US\$3800–9400 per case detected.³⁴ If the campaign is sustained for longer periods of time, they remain highly cost-effective at even higher costs per case detected, despite declining gains in case detection over time. Moreover, the health system strengthening that accompanies the implementation of a large-scale campaign such as ours also contributes to a decrease in TB morbidity and mortality, separately from the intervention itself (Shrestha S, ‘Achieving a “step change” in the tuberculosis epidemic through comprehensive community-wide intervention: a model-based analysis’).

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.^{29 35} In addition, we did not collect data about the specific healthcare providers or healthcare 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 programmes in settings with high TB burdens, our study also highlights areas in which further implementation research is needed.

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 are 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.

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

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Competing interests None declared.

Patient and public involvement statement Patients and the public were involved in multiple aspects of programme implementation and research. Patient and community preferences were taken into account when developing the implementation plan for the intervention. During programme implementation, our community engagement strategy involved meeting with community leaders prior to the arrival of the screening programme in a community to gain community buy-in and disseminate information. In addition, recruitment of people to the screening programme 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.

Patient consent for publication Not required.

Ethics approval The intervention and evaluation were approved by the ethics committee of the Universidad Peruana Cayetano Heredia (protocol 18004). 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 programme.

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Data availability statement Data are available upon reasonable request. Please contact the corresponding author for a data request form.

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