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Cost to perform door-to-door universal sputum screening for TB in a high-burden community

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SUMMARY

BACKGROUND: Population-based active case-finding (ACF) identifies people with TB in communities but can be costly.

METHODS: We conducted an empiric costing study within a door-to-door household ACF campaign in an urban community in Uganda, where all adults, regardless of symptoms, were screened by sputum Xpert Ultra testing. We used a combination of direct observation and self-reported logs to estimate staffing requirements. Study budgets were reviewed to collect costs of overheads, equipment, and consumables. Our primary outcome was the cost per person diagnosed with TB.

RESULTS: Over a 28-week period, three teams of two people collected sputum from 11,341 adults, of whom 48 (0.4%) tested positive for TB. Screening 1,000 adults required 258 person-hours of effort at a cost of US$35,000, 70% of which was for GeneXpert cartridges. The estimated cost per person screened was $36 (95% uncertainty range [95% UR] 34–38), and the cost per person diagnosed with Xpert-positive TB was $8,400 (95% UR 8,000–8,900). The prevalence of TB in the underlying community was the primary modifiable determinant of the cost per person diagnosed.

CONCLUSION: Door-to-door screening can be feasibly performed at scale, but will require effective triage and identification of high-prevalence populations to be affordable and cost-effective.

KEY WORDS: tuberculosis; cost analysis; door-to-door screening

TB causes an estimated 10 million cases and 1.5 million deaths annually.[1] Despite ambitious targets to end the TB epidemic,[2] global TB incidence was falling by only 2%/year before the COVID-19 pandemic and has likely stagnated since.[1] An estimated one third of people with TB are not diagnosed, are not notified, or do not start treatment.[3] Systematic screening, or active case-finding (ACF), is therefore widely recognised as an important component of any strategy to end TB.[4,5]

Approaches to ACF take various forms – including targeted screening of key populations (e.g., people living in prisons, people with HIV) and community-based screening (e.g., door-to-door, venue events, mobile vans) – and use different diagnostic algorithms (molecular testing, chest X-ray, symptoms).[3,5–7] Community-based ACF campaigns augment detection of people with TB, especially in moderate-to-high TB prevalence settings.[4,8] If conducted with sufficient intensity and/or duration, community-based ACF may reduce prevalence and mortality, although evidence of this effect is less definitive.[5,8] As such, global recommendations currently suggest that community-based ACF can be performed in settings with an expected prevalence of at least 500 per 100,000 population.[3]

Successful implementation of community-based ACF depends strongly on cost and feasibility. ACF requires a substantial investment of human resources and logistics;[9,10] for programs to appropriately decide whether to make such investments, it is important to understand the financial and staffing requirements for community-based ACF.[11] A cost analysis of ACF from the programmatic perspective has not been reported.[6] We therefore aimed to quantify the costs to conduct door-to-door household ACF in an urban community in Uganda – including both financial and human resource requirements.

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METHODS

Study setting and overview

We conducted a costing study as a part of a large, community-based, repeated cross-sectional study of TB transmission (STOMP-TB; NIH R01HL138728).[12] During two community-wide case-finding campaigns, study staff moved systematically through a prespecified, geographically defined study area, visiting both residential and commercial locations and inviting all adults ($\geq$15 years) to provide expectorated sputum for Xpert Ultra testing (Cepheid, Sunnyvale, CA, USA), regardless of symptoms or treatment history. The study area was a densely populated, largely residential urban community in Kampala, Uganda (contiguous land area of 2.2 km^2), with an adult population of 34,000 estimated by collecting household data from residents and neighbours at all residential locations visited. We performed two rounds of community-wide case-finding in 2019 and 2021. Staff and study procedures remained the same between the first and second rounds. We collected costs for the present analysis during the second round (in 2021) after the team had gained experience in study procedures for the first round. Study activities also included venue-based screening and contact investigation, but the costs of those activities are not estimated here due to small sample sizes in the second round. The estimated prevalence of TB among participating adults was 0.9% in 2019[12] and 0.6% in 2021.

We estimated the costs of door-to-door ACF as performed by four entry-level and two managerial-level staff over a 28-week period (February to August 2021). During these 28 weeks, 12,295 individuals were contacted during door-to-door screening, 11,341 (92%) consented and submitted sputum specimens, and 48 individuals with Xpert-positive sputum were identified. This period included a 42-day national lockdown in June and July 2021, during which both public and private transportation was limited;[13,14] however, study activities were allowed by Ugandan authorities to continue.

Data collection

We collected cost data through three mechanisms: self-reported logs, direct observation, and budgetary review. Self-reported logs were collected on a weekly basis from all six participating staff members throughout the full 28-week period. Logs asked staff members to estimate their total time spent on door-to-door ACF, across four activity categories (administrative, design and implementation, procurement and logistics, and operation). These categories were designed to capture activities unlikely to be identified through direct observation (described below) because they occurred off-site or outside of observation hours; such activities included advertisement in the community, meetings with community members, procurement of supplies, supporting other staff members, and interactions with participants found to have positive results on Xpert (Supplementary Table S1).

Additional direct observations – i.e., time and motion (TAM) studies – were performed once per week for 7 weeks of the study (late June through early August 2021). Our six staff members were divided into three two-person teams who performed direct screening activities equally regardless of their skill level (managerial- or entry-level). Days for direct observation were selected randomly (1 day per week); during the selected day, one of the three teams was selected at random for observation. This team was then directly observed by a dedicated observer, from the beginning to the end of the workday. Study data were collected and managed using REDCap (Research Electronic Data Capture) tools hosted at the Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA.[15,16] All activities were categorised into eight categories of patient interaction and field operations that were developed and refined through pilot testing in the study area (Supplementary Table S2).

Finally, we performed a detailed review of all study budgets, including monthly overhead costs and unit prices of equipment and consumables. When no direct estimates of unit costs were available, estimates were generated based on market prices and interviews with study staff.

Analysis

Costs for human resources were assessed as monthly salaries using published Ugandan pay scales,[17] and converted to costs per hour based on reported/observed numbers of hours worked on each activity. Unit costs for laboratory supplies were assessed based on the total cost of supplies used for the 28-week period, divided by the number of individuals screened (or people diagnosed with TB, where appropriate), thus accounting for realistic levels of wastage. The cost of sputum cups was assessed on a per-unit basis. The unit cost for overheads and other consumable laboratory supplies was assessed based on a 7-month screening period, again divided by the number of people screened and/or diagnosed during that time period. The unit cost for Xpert was based on a volume-negotiated price charged by the central laboratory, which did not have a detailed breakdown available. All costs were collected as Ugandan shillings (UGX) in 2021 and subsequently converted to 2021 US dollars using the mid-year 2021 exchange rate.[18]

Our aim was to evaluate programmatic costs, not including the effort required for activities specific to research. As such, we categorised all costs as either research-only or having a programmatic component; we excluded research-only costs from all further analyses. For activities that include a mixture of research and programmatic features, staff were asked to estimate the proportion of those activities

Table 1 Time required for door-to-door TB screening activities in Kampala, Uganda (direct observation)

Activities	Person-minutes per activity* Mean (min, max)	Number of activities per day Mean (min, max)	Person-minutes per day Mean (95% uncertainty range)	Person-hours per 1,000 people screened† Mean (%) (95% uncertainty range)
Participant interaction				
Eligibility screening	4.8 (2.0, 18.0)	25.4 (10.0, 29.0)	121.3 (59.8–183.2)	25.0 (17) (12.3–37.7)
Obtaining household data	3.7 (2.0, 28.0)	22.7 (8.0, 29.0)	85.0 (21.0–148.6)	17.5 (12) (4.3–30.6)
Sample collection	4.1 (2.0, 22.0)	24.9 (11.0, 29.0)	102.1 (43.8–160.0)	21.0 (14) (9.0–32.9)
Scheduling additional visits	3.1 (2.0, 6.0)	4.6 (3.0, 6.0)	14.2 (7.8–20.6)	2.9 (2) (1.6–4.2)
Sample packing and verification	133.0 (110.0, 156.0)	1.0 (1.0, 1.0)	133.0 (119.3–147.0)	27.4 (19) (24.5–30.3)
Field operations				
Daily team meeting	63.7 (20.0, 116.0)	1.0 (1.0, 1.0)	63.7 (36.4–91.0)	13.1 (9) (7.5–18.7)
Travel‡	28.8 (2.0, 166.0)	5.3 (2.0, 9.0)	152.2 (32.8–337.0)	31.3 (22) (6.7–69.3)
Visits to empty or uninterested households	5.0 (2.0, 28.0)	6.1 (1.0, 9.0)	30.7 (5.3–56.2)	6.3 (4) (1.1–11.6)
Total				145.5 (67.4–236.4)

* Person-minutes for all activities listed in this table were assumed to be required for programmatic implementation (i.e., not research-specific).
† On average, 405 people were screened per week.
‡ Includes travel between headquarters, the community, and the laboratory; travel between households; and travel between sectors of the community.

that would be required for programmatic implementation; costs for these activities were then multiplied by this proportion for analysis. Overhead costs (e.g., building rent) were included in programmatic components. To estimate the total cost of each activity, we multiplied all estimates by the number of weeks during which that activity was performed and the number of staff who participated in that activity, accounting for the relative amounts of time spent by different staff members. Finally, to provide more generalisable estimates of effort, we transformed all estimates to numbers required per 1,000 participants screened. We represented uncertainty by calculating the 2.5th and 97.5th percentiles of each data quantity.

Sensitivity analysis

We conducted a probabilistic sensitivity analysis in which we varied each parameter value by ±10% from the base value. We drew 1,000 independent sets of parameter values from these ranges using simple random sampling, and we estimated the average cost per person diagnosed with TB independently for each simulation. As a multivariable one-way sensitivity analysis, we reported outcomes according to the decile of each parameter value across these 1,000 simulations.

Given the importance of TB prevalence in our estimates of cost-effectiveness, we conducted an additional sensitivity analysis that used a broader plausible range for prevalence (i.e., the number of persons diagnosed with TB among the number of people screened) in community-based settings. We also varied the number of people screened per day, based on the range of observed values across days in the parent study, and re-evaluated these values' influence on the total cost.

Ethical considerations

The study was approved by the Johns Hopkins Bloomberg School of Public Health Institutional Review Board, Baltimore, MD, USA; and the Higher Degrees, Research and Ethics Committee (HDREC) of the Makerere University School of Public Health, Kampala, Uganda. The primary study obtained written informed consent from adult participants (and written assent and parental consent from participants aged 15–17 years) who participated in extended interviews. Following discussion with HDREC, written informed consent was not required of staff participants in the costing exercises.

RESULTS

Over 28 weeks of door-to-door screening, two managerial-level and four entry-level staff completed screening and collected sputum samples from 8,083 individuals belonging to 5,895 households, plus 3,258 individuals who were not at their homes.

Per 1,000 participants screened, a mean 145.5 person-hours of programmatic activities were directly observed (95% uncertainty range [95% UR] 67.4–236.4) (Table 1). Of this time, travelling between households/communities and between the office and the study sites took the largest portion (22%) of time, requiring 31.3 h (95% UR 6.7–69.3). Sample packing and preparation for shipment to the laboratory (27.4 h, 95% UR 24.5–30.3) and sputum sample collection (21.0 h, 95% UR 9.0–32.9) were the next most time-intensive activities (Table 1).

Staff members submitted a median of 16 self-reported logs over 28 weeks (range 6–19). Outside of direct screening activities, for every 1,000 people screened, managerial-level staff spent an estimated 64.8 additional person-hours, and entry-level staff spent an additional 47.4 person-hours – for a total of 257.7 person-hours spent per 1,000 people screened. Of managers' self-reported time, 26% was spent managing laboratory inspection, assessment and

Table 2 Time required for additional TB active case-finding activities, managerial-level staff*

Activities	Person-hours per week Mean (min, max)	Percentage programmatic† %	Programmatic person-hours per 1,000 screened‡ Mean (%) (95% uncertainty range)
Preparation			
Advertise community screening to community	0.6 (0.5, 1.0)	100	3.0 (5) (2.5–4.9)
Communicate with community leaders/chairmen	0.9 (0.5–2.0)	100	4.4 (7) (2.5–9.9)
Preparation at the office	4.4 (1.5–6.5)	25	5.4 (8) (1.9–8.0)
Administration			
Laboratory reports	1.2 (0.5–2.5)	25	1.5 (2) (0.6–3.1)
Procurement paperwork	1.6 (0.5–2.0)	50	4.0 (6) (1.2–4.9)
Budget plan/site map/COVID plan	2.5 (0.5–5.0)	50	6.2 (10) (1.2–12.3)
Progress reports	1.9 (1.0–3.0)	25	2.3 (4) (1.2–3.7)
Training/hiring	1.7 (0.5–4.0)	25	2.1 (3) (0.6–4.9)
Technical support (e.g., repairs)	1.5 (0.5–2.0)	50	3.6 (6) (1.2–4.9)
Field operations			
Laboratory inspection, assessment, stock management	3.4 (1.5–11.5)	100	16.7 (26) (7.4–56.8)
Laboratory procurement	1.4 (0.5–2.5)	100	6.7 (10) (2.5–12.3)
Miscellaneous visits§	1.9 (1.0–4.5)	75	7.1 (11) (3.7–16.7)
Participant interaction			
Returning laboratory results	1.6 (0.5–2.5)	25	1.9 (3) (0.6–3.1)
Total			64.8 (27.2–145.7)

* Data from weekly self-reported logs.
† Effort required for activities specific to program operation, excluding research-specific components.
‡ On average, 405 people were screened per week.
§ Includes return visits to answer participant questions, interactions with other stakeholders, etc.

stock management (Table 2). No single activity accounted for more than 20% of entry-level staff reported time (Table 3).

To screen 11,341 individuals, the door-to-door programme incurred a total programmatic cost of 1 billion Ugandan shillings (UGX), equivalent to US$402,000 (US$35,000 per 1,000 screened) (Table 4). The estimated cost per person screened was $36 (95% UR 34–38), and the cost per Xpert-positive person identified was $8,400 (95% UR 8,000–8,900). Xpert testing accounted for 70% of this cost, and human resources accounted for 26%. Multivariable sensitivity analysis showed that cost was affected most by the prevalence of TB in the community, followed by the unit cost per Xpert test and the number of participants who could be screened per day (Table 4, Figure). When TB prevalence in the screened population varied from 0.1% to 1%, the estimated cost per TB diagnosis ranged from $26,000 (prevalence 0.9–1.0%) to $4,000 (prevalence 0.1–0.2%).

Table 3 Time required for additional TB active case-finding activities, entry-level staff*

Activities	Person-hours per week Mean (min, max)	Proportion programmatic† %	Programmatic person-hours per 1,000 screened‡ Mean (%) (95% uncertainty range)
Preparation			
Advertise community screening to community	0.4 (0.3, 1.5)	100	3.7 (8) (2.5–14.8)
Communicate with community leaders/chairmen	0.5 (0.2, 0.8)	100	4.5 (9) (2.4–7.4)
Preparation at the office	1.7 (0.3, 2.8)	25	4.2 (9) (0.6–6.8)
Administration			
Laboratory reports	1.9 (0.1, 9.0)	25	4.6 (10) (0.3–22.2)
Budget plan/site map/COVID plan	0.5 (0.3, 2.0)	50	2.6 (5) (1.2–9.9)
Progress statistics	1.4 (0.5, 3.0)	25	3.4 (7) (1.2–7.4)
Training/hiring	1.2 (0.3, 3.0)	25	2.9 (6) (0.6–7.4)
Field operations			
Laboratory inspection, assessment, stock management	0.3 (0.3, 0.3)	100	2.5 (5) (2.2–2.7)
Miscellaneous visits§	1.9 (1.5, 2.3)	75	14.1 (30) (11.1–16.7)
Participant interaction			
Laboratory result return	2.0 (0.3, 8.5)	25	5.0 (11) (0.6–21.0)
Total			47.5 (23.1, 72.0)

* Data from weekly self-reported logs.
† The effort required for activities specific to program operation excluding research-specific components
‡ On average, 405 people were screened per week.
§ Includes return visits for household members not present on initial screening, visits to the local health facility to verify engagement in care, etc.

Table 4 Estimated cost and cost-effectiveness for door-to-door TB screening among 11,341 residents of an urban Ugandan community

				Cost per person screened			
Cost component	Unit cost (USD)	Number of units	Total cost (USD)	USD*	UGX*	Proportion of total %	Cost per diagnosis† (USD)
Human resources							
Managerial-level staff	2,600/month	14 months	36,600	3.70	12,300	10.4	900
Entry-level staff	2,000/month	28 months	54,800	5.56	18,500	15.6	1,300
Building/overhead							
Office rent	400/month	7 months	2,700	0.28	900	0.8	66
Utilities	130/month	7 months	900	0.09	300	0.3	22
Supplies							
Stationery and paper	180/month	7 months	1,300	0.13	400	0.4	31
Data tablets	300/tablet	2 tablets	630	0.06	200	0.2	15
Laboratory							
Xpert testing	22/test	11,341 tests	245,000	24.90	83,000	70.1	5,900
Sputum cups	0.2/cup	11,341 cups	1,800	0.18	600	0.5	43
Other laboratory supplies‡	Various	Various	600	0.08	196	0.4	15
Other direct costs							
Local transportation	800/month	7 months	5,500	0.56	1900	1.6	130
Mobile airtime	2/month	42 months	100	0.01	31	<0.1	2
Total			402,000	36	118,400		8,400

* Conversion in 2021: USD1 = UGX3,586.6.
† For every person identified with Xpert-positive TB, 236 people were screened (i.e., prevalence of 423 per 100,000 in the screened population).
‡ Other laboratory supplies include gloves, N95 masks, cotton wool, zip-lock bags and alcohol swabs.
USD = United States dollar; UGX = Ugandan shillings.

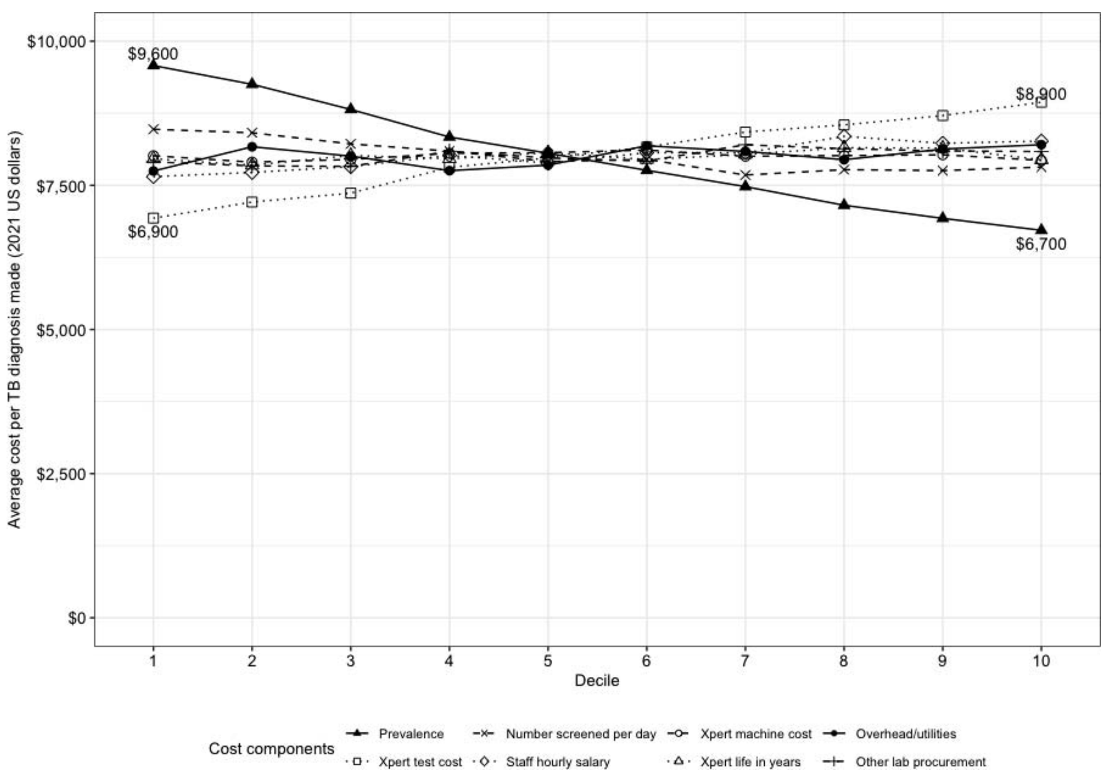

Figure Average cost per additional person diagnosed with TB: multivariable sensitivity analysis. We estimated the cost per TB diagnosis made across 1,000 independent simulations in which all parameters were varied by ±10% from the reference value The left-most set of points provides the estimated cost-effectiveness (cost per TB diagnosis made) across the 1,000 simulations with the lowest values for each parameter given. The next set provides the estimated cost-effectiveness across the 1,000 simulations with the next-highest values of that parameter, etc. Across the 1,00 simulations with the lowest TB prevalence (median: 346/100,000), the median estimated cost per TB diagnosis made was $9,600, vs. $6,700 across the simulations with the highest TB prevalence (median: 499/100,000) (solid line with triangles). Similarly, the median cost per TB diagnosis ranged from $6,900 to $8,900 from the lowest decile of Xpert test costs (median: $20.5 per test) to the highest (median: $29.5) (dotted lines with squares). Otherwise, estimated cost-effectiveness was not highly sensitive to other parameter values, as indicated by relatively flat lines.

DISCUSSION

We conducted a costing analysis to estimate the resources required to implement a door-to-door, sputum-based TB screening programme in an urban Ugandan community. We estimated that, to screen 1,000 residents using Xpert Ultra (of whom approximately four would be diagnosed with TB), a total of 257.7 person-hours and a budget of $35,000 would be required. Without any triage test or specimen pooling, 70% of all costs were laboratory costs, primarily for Xpert testing. These estimates can provide decision-makers with information regarding the resources required for community-based TB screening. Our cost estimates also illustrate the importance of evaluating the cost-effectiveness of alternative diagnostic algorithms (e.g., triage using chest X-ray, pooled Xpert testing) that could reduce consumable costs, but at the expense of additional complexity and human resource requirements.

From the perspective of staffing, these results speak to the feasibility of performing door-to-door screening in an urban African setting. With a team of six individuals fully dedicated to screening, for example, over 1,000 residents could be effectively screened in less than 2 weeks. Nevertheless, human resource constraints in health are an important consideration;[9,10,19,20] to screen a population of 100,000 people in the course of a year, for example, about 15 staff members would need to be hired, trained and retained. Whether scarce human resources should be utilised for TB screening in high-burden settings is an important consideration for future research and programmatic decision-making.

To note, the purpose of the current study was to estimate the financial resources required for a comprehensive door-to-door TB screening programme (designed to screen every individual in the community), not to demonstrate a cost-effective approach. As such, our estimated cost per additional person diagnosed with TB was substantially higher than other studies that implemented other algorithms (e.g., symptom screening) or focused on targeted high-risk populations (e.g., household contacts).[21–23] Our sensitivity analyses showed that the cost per additional person diagnosed with TB was the most sensitive to changes in TB prevalence, consistent both with the results of other modelling studies,[23,24] and current WHO guidance that uses prevalence as consideration for whether to perform systematic screening.[5]

Our results should be interpreted in the light of certain limitations. First, we may have underestimated the time spent by staff because observations were performed after staff were already trained and well-practiced at screening procedures (through experience with the first wave of screening activities). This may bias both our estimates of the cost per person screened and the contribution of human resources to the overall cost downward, especially if used to estimate the costs required to launch and implement a new screening programme. By contrast, as prevalence was lower in the second round, the cost per person diagnosed with TB was likely overestimated, relative to the first round. Second, our estimates depend on the accurate attribution of time and resources to screening-only activities and to their programmatically relevant components. For example, our weekly logs, although collected prospectively and validated through our direct observation activities, are subject to recall and social desirability bias. Third, some of our observations were performed during a COVID-19 lockdown, strictly banning transportation and limiting movement. This could result in our estimates being higher (as our study team had to implement procedures to limit infection) or lower (as more people were at home than would normally be true). Fourth, a detailed breakdown of unit costs for Xpert testing was unavailable; however, the price charged by the laboratory was consistent with a prior bottom-up evaluation of Xpert costs in Uganda.[25] Fifth, cost data relevant to human resources were collected from a small number of staff members ($n=6$), reflecting the size of our team. This concern may be partially mitigated by the consistency of measurements across staff members and our large number of individual-level observations on repeated activities. Finally, caution should be exercised when generalising our estimates from urban Uganda to other settings, including rural settings where distances between houses may be substantially greater.

In summary, we provide empirical estimates of the financial and human resource requirements to perform community-based screening for TB in an urban Ugandan community. Our findings demonstrate the feasibility of performing door-to-door screening in high-burden settings but also highlight the importance of implementing efficient screening algorithms to reduce per-participant costs, considering human resource constraints in the design of screening programmes, and targeting populations with a high underlying prevalence of TB. As ACF is increasingly recognised as a critical component of multifaceted strategies to end TB, a clear understanding of the resources required will be essential to inform national priority settings and mobilise the funding and people necessary to implement ACF in a variety of high-burden settings.

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Conflicts of interest: none declared.

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RÉSUMÉ

CONTEXTE : La recherche active de cas (ACF) dans la population permet d'identifier les personnes atteintes de TB dans les communautés, mais elle peut être coûteuse.

MÉTHODES : Nous avons réalisé une étude empirique d'évaluation des coûts dans le cadre d'une campagne ACF de porte-à-porte auprès des ménages d'une communauté urbaine en Ouganda, où tous les adultes, indépendamment de leurs symptômes, ont été dépistés à l'aide d'un test Xpert Ultra® sur échantillon d'expectorations. Nous avons utilisé une combinaison d'observations directes et de notes auto-rapportées dans un journal de bord afin d'estimer les besoins en personnel. Les budgets ont été réexaminés afin de recueillir les coûts des frais généraux, des équipements et des consommables. Notre critère de jugement principal était le coût par personne diagnostiquée comme atteinte de TB.

RÉSULTATS : Sur une période de 28 semaines, trois équipes de deux personnes ont recueilli les échantillons d'expectorations de 11 341 adultes, parmi lesquels 48 (0,4%) ont été testés positifs pour la TB. Le dépistage de 1 000 adultes a nécessité 258 heures-personnes pour un coût de 35 000 USD, dont 70% pour les cartouches du test GeneXpert®. Le coût estimé par personne dépistée était de 36 USD (intervalle d'incertitude à 95% [UR 95%] 34-38), et le coût par personne diagnostiquée comme atteinte de TB par test Xpert positif était de 8 400 USD (UR 95% 8 000-8 900). La prévalence de la TB dans la communauté sous-jacente était le principal déterminant modifiable du coût par personne diagnostiquée.

CONCLUSION : Le dépistage porte-à-porte peut être réalisé à grande échelle, mais nécessitera un triage efficace et l'identification des populations à forte prévalence afin d'être abordable et rentable.