High laboratory cost per TB case diagnosed predicted with increased case-finding without a triage strategy

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**Conflicts of interest**

The authors declare that they have no financial or non-financial conflicts of interests.

***Setting***

Cape Town, South Africa.

***Objective***

To model the effects of increased case-finding and triage strategies on laboratory costs per TB case diagnosed.

***Methods***

We used a validated operational model and published laboratory cost data. We modelled the effect of varying the proportion with TB amongst presumptive cases and Xpert cartridge price reductions on cost per TB case and per additional TB case diagnosed in the Xpert-based vs smear/culture-based algorithms.

***Results***

At our current scenario (18.3% with TB amongst presumptive cases), the proportion of cases diagnosed increased by 8.7% (16.7% vs 15.0%) and cost per case diagnosed increased by 142% (US$ 121 vs US$50). The cost per additional case diagnosed was $986. This would increase to $1619 if the proportion with TB amongst presumptive cases was 10.6%. At 25.9% to 30.8% with TB amongst presumptive cases and 50% reduction in Xpert cartridge price the cost per TB case diagnosed would range between US$50 to US$59 (comparable to the US$48.77 found in routine practice with smear/culture)

***Conclusion***

The operational model illustrates the effect of increased case-finding on laboratory costs per TB case diagnosed. Unless triage strategies are identified, the approach will not be sustainable, even if Xpert cartridge prices are reduced.**Introduction**

Despite a 22% reduction in deaths in the last 15 years, in 2015, tuberculosis (TB) was still one of the top 10 causes of death worldwide. Although the global TB incidence rate declined by 1.4% per year in this period, 10.4 million incident cases were reported globally in 2015.1 There are still major gaps in TB case finding and diagnosis with the World Health Organization (WHO) estimating that one third of incident TB cases are either missed through current TB screening and diagnostic efforts or are not notified.2

As part of the End-TB strategy three people-centred targets were introduced which consist of reaching 90% of all people who need TB treatment, including 90% of people in key populations, and achieving at least 90% treatment success rates. The strategy recommends that countries set an operational target of reaching at least 90% of people in key populations through improved access to services, systematic screening where required, and new case-finding methods and for providing all people in need with effective and affordable treatment.1,3

The South African Department of Health plans to substantially scale up case-finding efforts based on the End-TB strategy. This has cost implications as the cost per presumptive TB case tested and diagnosed with TB is higher with Xpert (which was introduced in 2013) than with the previous smear/culture-based algorithm. Two studies in South Africa reported Xpert costs per test performed of $25.90 (in 2010 US$)4 and $14.93 (in 2012 US$) compared to $1.58 and $3.40 respectively for smear.5 A study conducted in Cape Town, South Africa found that the cost per TB case diagnosed increased by 157% from $48.77 in the previous smear/culture-based algorithm to $125.32 in the newly introduced Xpert-based algorithm.6 A study conducted in India evaluated the cost of various pulmonary tuberculosis diagnostic strategies and found that the strategy with Xpert as the first line test had the highest cost per TB case diagnosed.7

The scale up of case-finding efforts and introduction of alternative case-finding strategies, such as improved sensitivity and specificity of pre-screening strategies8 or a triage-screening test9,10, will have an effect on the proportion with TB amongst the presumptive cases being tested.

As case-finding efforts are scaled up and more people are screened for TB, the proportion with TB amongst those tested is likely to decline and cost per TB case diagnosed will consequently increase. There is little evidence at present on what the proportion of TB amongst presumptive cases should be in order to optimise the cost of diagnosing a case of TB.

The aim of this study is to use an operational model to simulate the effect of a decrease (scale up of case-finding) and an increase (triage screening test) in the proportion with TB cases amongst presumptive cases tested on laboratory cost (1) **per TB case diagnosed** and (2) **per *additional* TB case diagnosed** in the Xpert-based compared to the smear/culture-based algorithm. We also assessed the effect on laboratory cost if the Xpert cartridge price was reduced.

**Methods**

**Setting**

The operational model was developed for the TB diagnostic algorithms implemented in Cape Town, one of the large cities in South Africa, with a population of 3 740 025 in 2011 (National Census 2011). In 2011, 28 644 TB cases were reported (case notification rate of 752/100 000 population) and amongst the 97% of cases tested for human immunodeficiency virus (HIV), 47% of TB cases were co-infected with the HIV (Source: Routine TB Programme Data, Cape Town Health Directorate, April 2016).

Municipal and provincial health authorities provided TB diagnostic services at 142 primary health care (PHC) facilities. All sputum samples collected for TB testing at PHC facilities were couriered to the central National Health Laboratory Services (NHLS) on a daily basis for testing and results returned to facilities via courier and fax.

A smear/culture-based algorithm (Figure 1) was used in all facilities until August 2011 with all presumptive cases required to submit two spot sputum samples an hour apart. Previously treated presumptive cases as well as new smear-negative case co-infected with HIV had culture tests (BACTEC™ MGIT™ 960) undertaken.

Between August 2011 and February 2013, an Xpert-based algorithm (Figure 1) was phased in with Xpert replacing smear microscopy for all presumptive cases and after February 2013, all facilities used the Xpert-based algorithm. The first of two sputum samples submitted were tested with Xpert. In HIV-infected cases with negative Xpert results, the second sample underwent culture.

**Definitions**

*Presumptive case: For this model presumptive cases were those who accessed the PHC facilities and had sputum samples collected for TB testing.*

*TB case: We defined a TB cases in the model as an individual with culture positive TB, irrespective of how the individual was ultimately diagnosed (i.e test positive by either sputum smear microscopy, culture or Xpert). False positive cases were thus excluded.*

**Model development**

A comprehensive operational model representing TB diagnosis in Cape Town PHC facilities has been developed using the Witness package, a discrete event and continuous process simulator11.The model was validated for both the historic smear/culture and newly introduced Xpert-based algorithm using routine programmatic data 13 and findings published.12 The model incorporated patient pathways and sample flow from specimen collection, laboratory test procedures, to a result being provided to the patient and treatment initiation at the PHC facility.

**Laboratory cost data**

Laboratory cost data per test in each algorithm were obtained from a costing evaluation undertaken at the high throughput central laboratory (NHLS) in Cape Town.6 An ingredients-based costing approach was used with test cost based on building cost per square meter, equipment, consumables, staff and overheads (Table 1).6

Costs were calculated only for sputum smear microscopy, culture and Xpert and used to estimate diagnostic costs in each algorithm as appropriate. The cost of drug sensitivity testing was not considered in the current model.

**Model inputs**

In order to make a direct comparison of cost per TB case diagnosed between algorithms we modelled both algorithms with identical input parameters for the proportion with TB amongst the presumptive cases being tested, HIV status, history of previous TB treatment and adherence to testing protocols.12

The model input parameters used for both the smear/culture and Xpert-based algorithms are summarised in Table 2.

*Simulated scenarios:*

We modelled scenarios where we decreased and increased the proportion with TB amongst presumptive cases being tested. From our previous analysis, the most likely estimate for the proportion with TB amongst presumptive cases tested was 18.3%, which we selected as our starting point.12 We varied the proportion to a low of 3.0% (scenarios 6-11) and a high of 30.8% (scenarios 1-5).

We also assessed the effect on cost per TB case diagnosed if the price per Xpert cartridge was reduced by 10%, 25% and 50%.

**Model outputs and analysis**

Outputs from the model on the number of tests performed per algorithm and the number of TB cases diagnosed under different scenarios and cost per test from our costing study6 were summarised in Microsoft Excel and used to calculate overall diagnostic costs per algorithm, cost per TB case diagnosed *and* cost per additional TB case diagnosed in the Xpert-based algorithm compared to in the smear/culture-based algorithm.

We used the validated model to predict the costs per TB cases diagnosed under various conditions.

**Ethics statement**

The Health Research Ethics Committee at Stellenbosch University (IRB0005239) (N10/09/308) and Ethics Advisory Group at The International Union Against Tuberculosis and Lung Disease (59/10) approved the study. The City of Cape Town Health Directorate, Western Cape Health Department and National Health Laboratory Service granted permission to use routine health data.

**Results**

At our published best estimate of 18.3%12,13 with TB amongst presumptive cases tested, the proportion diagnosed with TB increased from 15.0% in the smear/culture-based algorithm to 16.3% in the Xpert-based algorithm, a relative increase of 8.7%. The cost per TB case diagnosed increased from US$50 in the smear/culture-based algorithm to US$121 in the Xpert-based algorithm, a relative increase in cost of 142% (Table 3 and Figure 2). The cost per additional TB case diagnosed in the Xpert-based algorithm compared to the smear/culture-based algorithm was US$986 (Table 3 and Figure 3).

***The effect of varying the proportion with TB* amongst presumptive cases tested**

When the proportion with TB amongst presumptive cases tested was lowered to 3.0% (scenario 11) or increased to 30.8% (scenario 1) in the model, the proportion of TB cases diagnosed ranged from 2.5% to 25.3% in the smear/culture-based algorithm and 2.7% to 27.4% in the Xpert-based algorithm.

The cost per TB case diagnosed ranged from US$299 to US$30 in the smear/culture algorithm and from US$727 to US$73 in the Xpert-based algorithm (Table 3 and Figure 2). At the lowest proportion of TB amongst presumptive cases tested (3.0% - scenario 11) the cost per additional TB case diagnosed was US$9245 and at the highest TB proportion (30.8% - scenario 1) the cost per additional TB case diagnosed was US$603 in the Xpert-based algorithm compared to the smear/culture-based algorithm (Table 3 and Figure 3).

***The effect of Xpert cartridge price***

At the current best-estimated proportion of 18.3% with TB amongst presumptive cases tested, the cost per TB case diagnosed would be US$114, US$102 and US$83 in the Xpert-based algorithm if the price of the Xpert cartridge was reduced by 10%, 25% and 50% (Table 4 and Figure 2). The cost per additional TB case diagnosed in the Xpert-based algorithm compared to the smear/culture algorithm would be US$886, U$737 and U$489 at respective cartridge price reductions (Table 4, Figure 3).

***The effect of varying both the proportion with TB* amongst presumptive cases *and Xpert cartridge price***

At 3.0% (scenario 11) of TB amongst presumptive cases tested, the cost per TB case diagnosed in the Xpert-based algorithm was US$682, US$613 and US$499 if the price of the Xpert cartridge was reduced by 10%, 25% and 50%. At 30.8% (scenario 1) of TB amongst presumptive cases tested (scenario 1) the cost per TB case diagnosed was US$68, US$61 and US$50 if the price of the Xpert cartridge was reduced by 10%, 25% and 50% (Table 4 and Figure 2).

The cost per additional TB case diagnosed in the Xpert-based algorithm compared to the smear/culture algorithm was US$8290, US$6857 and US$4470 at 3.0% (scenario 11) of TB amongst presumptive cases tested and if the price of the Xpert cartridge was reduced by 10%, 25% and 50% respectively. At 30.8% (scenario 1) of TB amongst presumptive cases tested the cost per additional TB case diagnosed in the Xpert-based algorithm compared to the smear/culture algorithm was US$543, US$454 and US$304 if the price of the Xpert cartridge was reduced by 10%, 25% and 50% respectively (Table 4, Figure 3).

**Discussion**

It was hoped that with the roll-out of Xpert as a replacement for smear microscopy the proportion of TB cases diagnosed would increase due to the higher test sensitivity of Xpert.14–16 A population-level decision model study estimated that with full Xpert coverage the total TB diagnostic cost for South Africa would increase annually by 53-57% per year with the increase in cost been offset by a 30-37% increase in TB cases diagnosed.17

However, the results from our operational model and laboratory and cost data collected for 142 PHC facilities showed that at the current best estimate of 18.3% of TB amongst presumptive cases tested there was a 142% relative increase in the cost per TB case diagnosed in the Xpert-based algorithm compared to the smear/culture-based algorithm with only a 8.7% relative increase in the number of TB cases diagnosed. The increase in the cost per TB case diagnosed was slightly lower in our study compared to the 157% reported in a study conducted in Cape Town using routine laboratory data. The Cape Town study however reported a temporal decline in TB diagnostic yield from 20.4% to 16.6% for the period of 2010 to 2013 due to a possible decline in TB prevalence attributed to the rapid scale-up of antiretroviral treatment and costs were partially influenced by this.13 An advantage of our model is that we were able to compare outputs when input parameters between algorithms were similar.

The cost per TB case diagnosed is directly influenced by the proportion with TB amongst the presumptive cases tested. As case-finding efforts are scaled up and the number of individuals tested for TB increases, the proportion with TB amongst those tested will decrease and therefore the cost per TB case diagnosed will increase. This increase in cost has serious implications for South Africa’s efforts to increase case-finding and alternative strategies would need to be considered in order to reduce costs.

One approach to decrease the cost per TB case diagnosed, would be to increase the proportion with TB amongst the presumptive cases being tested. This could be accomplished by implementing an improved triage or testing strategy.9 A study using a decision analytical model showed that with a hypothetical triage test with sensitivity equivalent to that of the Xpert test, 75% specificity and cost of US$5 per test would reduce the total diagnostic cost by 39% in South Africa.18 Currently there is no triage test available and this has been identified as one of the priorities in the development of new diagnostics for TB.19 It has been shown that pre-screening with smear microscopy could reduce the cost per TB case diagnosed by more than 20%.8

A further approach to decrease the cost would be a reduction in the price of the Xpert cartridge. Our model shows that with a 50% reduction in the price of Xpert cartridges and with the proportion with TB amongst presumptive cases tested at 3%, the cost per TB case diagnosed would be US$499, which is extremely high. At a more realistic proportion of 10.6% with TB amongst presumptive cases tested and a 50% reduction in the price of Xpert cartridges, the cost per TB case diagnosed is still high at US$142.

The best approach to improve affordability would therefore be a combination of increasing the proportion with TB amongst the presumptive cases tested, through either a triage test or other pre-screening strategies, and a decrease in the price of Xpert cartridges. Our model shows that if the proportion with TB amongst presumptive cases tested was 25.9% to 30.8% and price of the Xpert cartridge reduced by 50% the cost per TB case diagnosed would range from US$50 to US$59, a level that is comparable to the cost per TB case diagnosed in the smear/culture-based algorithm (US$48.77) found in a laboratory costing study.6

**Strengths and limitations**

The strengths of the current study are that we used a validated model (based on real data on testing and diagnosis) to estimate the cost per TB cases diagnosed in the smear/culture and Xpert-based algorithms. Our study provides a better estimate of the cost per TB case diagnosed. The previous laboratory costing study included false positive cases in the cost calculation. Our model suggests that the proportion of false positive cases is lower in the Xpert-based than in the smear/culture-based algorithm.12

The model was validated using routine programmatic data from Cape Town, which is a well-resourced urban setting where there is extensive use of culture. This may limit the generalization of findings to other settings. We did not consider costs for MDR-TB diagnosis and the added benefit of the Xpert test to identifying rifampicin resistance at screening; this will be reported in a future study. The impact of new TB diagnostic algorithms on patient costs is extremely important and was not considered in this study, however patient costs from the broader PROVE-IT study have been published.20

**Recommendation**

We recommend that alternative, more cost effective, strategies should be implemented in settings where the proportion with TB amongst presumptive cases tested is low or declining over time as would occur with increased case-finding efforts. Recommended strategies would include better pre-screening or a triage-screening test in order to increase the proportion with TB amongst the presumptive cases tested with Xpert. Substantial further reductions in the price of Xpert cartridges are also recommended to make the use of Xpert affordable in low resource settings. Further operational research is required to determine the most effective triage strategies to make the use of Xpert more sustainable and affordable.

**Conclusion**

An analysis of routine laboratory data has shown that in our setting, the introduction of Xpert as a replacement test for smear microscopy has resulted in a much higher cost per TB case diagnosed.6 The high cost is not offset by a substantially higher number of TB cases diagnosed despite the increased sensitivity of the Xpert test.13

The operational model illustrates the effect of increased case-finding efforts on laboratory costs per TB case diagnosed. It is clear that unless alternative triage strategies are identified, the approach will not be sustainable, even if Xpert cartridge prices are reduced. Additional studies are required to assess the cost-effectiveness of alternative strategies and their impact on transmission.

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Authors contributions: RD, PN, NB, and IL designed the study. RD conducted the modelling and data analysis and wrote the first draft of the Article. All authors reviewed.

**References**

1. World Health Organization. Global Tuberculosis Report 2016. 2016.

2. World Health Organization. Systematic screening for active tuberculosis: principles and recommendations. 2015.

3. World Health Organization. The end TB strategy: Global strategy and targets for tuberculosis prevention, care and control after 2015. 2014.

4. Vassall A, van Kampen S, Sohn H, Michael JS, John KR, den Boon S, et al. Rapid diagnosis of tuberculosis with the Xpert MTB/RIF assay in high burden countries: a cost-effectiveness analysis. PLoS Med. 2011;8(11):e1001120.

5. Shah M, Chihota V, Coetzee G, Churchyard G, Dorman SE. Comparison of laboratory costs of rapid molecular tests and conventional diagnostics for detection of tuberculosis and drug-resistant tuberculosis in South Africa. BMC Infect Dis. 2013;13:352.

6. Naidoo P, Dunbar R, Toit E, Niekerk M Van, Squire SB, Beyers N, et al. Comparing laboratory costs of smear / culture and Xpert W MTB / RIF-based tuberculosis diagnostic algorithms. Int J Tuberc Lung Dis. 2016;20(10):1377–85.

7. Chadha VK, Sebastian G, Kumar P. Cost analysis of different diagnostic algorithms for pulmonary tuberculosis varying in placement of Xpert MTB/RIF. Indian J Tuberc. 2016 Jan;63(1):19–27.

8. Theron G, Pooran A, Peter J, van Zyl-Smit R, Kumar Mishra H, Meldau R, et al. Do adjunct tuberculosis tests, when combined with Xpert MTB/RIF, improve accuracy and the cost of diagnosis in a resource-poor setting? Eur Respir J. 2012;40(1):161–8.

9. García-Basteiro AL, Cobelens F. Triage tests: A new priority for tuberculosis diagnostics. The Lancet Respiratory Medicine. 2015.

10. Murray M, Cattamanchi A, Denkinger C, van’t Hoog A, Pai M, Dowdy D. Cost-effectiveness of triage testing for facility-based systematic screening of tuberculosis among Ugandan adults. BMJ Glob Heal. 2016;1(2).

11. Lanner. WITNESS Service and Process Performance Edition [Internet]. Redditch, UK; Available from: http://www.lanner.com/en/witness.cfm

12. Dunbar R, Naidoo P, Beyers N, Langley I. Operational modelling: the mechanisms influencing TB diagnostic yield in an Xpert(®) MTB/RIF-based algorithm. Int J Tuberc Lung Dis. 2017;21(4):381–8.

13. Naidoo P, Dunbar R, Lombard C, du Toit E, Caldwell J, Detjen A, et al. Comparing Tuberculosis Diagnostic Yield in Smear/Culture and Xpert® MTB/RIF-Based Algorithms Using a Non-Randomised Stepped-Wedge Design. PLoS One. 2016;11(3):e0150487.

14. Theron G, Zijenah L, Chanda D, Clowes P, Rachow A, Lesosky M, et al. Feasibility, accuracy, and clinical effect of point-of-care Xpert MTB/RIF testing for tuberculosis in primary-care settings in Africa: a multicentre, randomised, controlled trial. Lancet. 2014;383(9915):424–35.

15. Steingart KR, Sohn H, Schiller I, Kloda LA, Boehme CC, Pai M, et al. Xpert® MTB/RIF assay for pulmonary tuberculosis and rifampicin resistance in adults. Cochrane database Syst Rev. 2013;1:CD009593.

16. Middelkoop K, Bekker LG, Myer L, Whitelaw A, Grant A, Kaplan G, et al. Antiretroviral program associated with reduction in untreated prevalent tuberculosis in a South African township. Am J Respir Crit Care Med. 2010;

17. Meyer-Rath G, Schnippel K, Long L, MacLeod W, Sanne I, Stevens W, et al. The impact and cost of scaling up GeneXpert MTB/RIF in South Africa. PLoS One. 2012 Jan 31;7(5):e36966.

18. van’t Hoog AH, Cobelens F, Vassall A, van Kampen S, Dorman SE, Alland D, et al. Optimal triage test characteristics to improve the cost-effectiveness of the Xpert MTB/RIF assay for TB diagnosis: a decision analysis. PLoS One. 2013;8(12):e82786.

19. World Health Organization. High-priority target product profiles for new tuberculosis diagnostics. 2015.

20. du Toit E, Squire SB, Dunbar R, Machekano R, Madan J, Beyers N, et al. Comparing multidrug-resistant tuberculosis patient costs under molecular diagnostic algorithms in South Africa. Int J Tuberc Lung Dis. 2015;19(8):960–8.

21. Mase SR, Ramsay A, Ng V, Henry M, Hopewell PC, Cunningham J, et al. Yield of serial sputum specimen examinations in the diagnosis of pulmonary tuberculosis: a systematic review. Int J Tuberc Lung Dis. 2007;11(5):485–95.

22. Steingart KR, Henry M, Ng V, Hopewell PC, Ramsay A, Cunningham J, et al. Fluorescence versus conventional sputum smear microscopy for tuberculosis: a systematic review. Lancet Infect Dis. 2006;6(9):570–81.

23. Department of Health. National Tuberculosis Management Guidelines 2014. Pretoria, South Africa; 2014. Available from: http://www.hst.org.za/publications/national-tuberculosis-management-guidelines-2014

Table 1: Test costs for sputum smear microscopy, culture and Xpert by algorithm

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **Smear microscopy**(Bleach treated) | **Smear microscopy & culture** | **Culture confirmation** | **Xpert MTBRif** |
| Smear/culture-based algorithm  | Building space | $0.02 | $0.14 | $0.05 | - |
| Equipment | $0.11 | $0.72 | $0.02 | - |
| Consumables | $0.36 | $3.87 | $0.84 | - |
| Staff | $0.55 | $2.21 | $0.57 | - |
| Overheads# | $1.80 | $1.80 | $0.00 | - |
| Cost per test | **$2.85** | **$8.75** | **$1.49** | - |
| Xpert-based algorithm | Building space | $0.02 | $0.14 | $0.05 | $0.06 |
| Equipment | $0.13 | $0.74 | $0.02 | $0.40 |
| Consumables | $0.36 | $3.87 | $0.84 | $14.62 |
| Staff | $0.55 | $2.21 | $0.57 | $1.32 |
| Overheads# | $2.64 | $2.64 | $0.00 | $2.64 |
| Cost per test | **$3.70** | **$9.62** | **$1.49** | **$19.03** |

*Test costs are for the central National Health Laboratory only. All costs are expressed in 2013 CPI-adjusted values. Overhead costs included costs for buildings, equipment, consumables and staff involved in specimen sorting and registration, results processing, procurement, stores, training, supervision and management. Specimen transport, electricity, water, sanitation, municipal and biohazardous waste disposal, cleaning and janitorial services, security services and telephone and internet costs were also included. In each scenario tested, we determined the number of tests performed per algorithm, applied the above costs and calculated the cost per TB case diagnosed.
Reprinted with permission of the International Union Against Tuberculosis and Lung Disease. Copyright © The Union. Naidoo P, Dunbar R, Toit E, Niekerk M Van, Squire SB, Beyers N, et al. Comparing laboratory costs of smear / culture and Xpert W MTB / RIF-based tuberculosis diagnostic algorithms. Int J Tuberc Lung Dis. 2016;20(10):1377–85.* Table 2: Input parameters used comparing the smear/culture and Xpert-based algorithms

|  |  |
| --- | --- |
|  | Input values (%) |
| History of previous TB treatment | 25 |
| HIV status | New presumptive cases | HIV-positive | 36 |
| HIV-negative | 64 |
| Previously treated presumptive cases | HIV-positive | 53 |
| HIV-negative | 47 |
| Proportion knowing their HIV status | 50 |
| Best estimated proportion of TB cases amongst presumptive cases | 18.3\* |
| Adherence to smear/culture-based Algorithm | New presumptive cases with 2 smears | 85 |
| Previously treated presumptive cases with culture | 85 |
| Adherence to Xpert-based Algorithm | All presumptive cases with Xpert test done | 85 |
| Proportion smear or Xpert- negative with culture testing | Smear/Culture-based algorithm | New presumptive cases | HIV-positive | 85 |
| HIV-negative | 0 |
| Previously treated presumptive cases | HIV-positive | 85 |
| HIV-negative | 0 |
| Xpert-based algorithm | New presumptive cases | HIV-positive | 85 |
| HIV-negative | 0 |
| Previously treated presumptive cases | HIV-positive | 85 |
| HIV-negative | 0 |
| Accuracy of smear microscopy21,22 | Sensitivity | HIV-positive | 65 |
| HIV-negative | 75 |
| Specificity | HIV-positive | 99 |
| HIV-negative | 99 |
| Accuracy of Xpert MTB/RIF15 | Sensitivity | HIV-positive | 80 |
| HIV-negative | 89 |
| Specificity | HIV-positive | 98 |
| HIV-negative | 98 |

*\** Best estimated proportion of TB cases amongst presumptive cases*.*12,13 *As part of the PROVE IT Study, NHLS data from presumptive cases had previously been collected and analysed to compare TB yield in the smear/culture-based algorithm to that in the Xpert-based algorithm. Input parameters for the model used probability distributions derived from this analysis.*

*Data on HIV status was only recorded for 2013 and showed that 50% of presumptive cases knew their HIV-status and similar proportions were assumed for the model.*12,13

Table 3: Cost per TB case diagnosed in the smear/culture and the Xpert-based algorithms and the cost per additional TB case diagnosed as the proportion of TB amongst presumptive cases tested varies (N = 100 000).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|   | Proportion with TB amongst presumptive cases (%) | Smear/culture-based algorithm | Xpert-based algorithm | Changes with the Xpert-based algorithm | eCost per additional TB case diagnosed\*$$\left(\frac{d-b}{c-a}\right)$$ |
| aTB cases diagnosed(%)  | bTotal laboratory cost (Cost per TB case diagnosed) | cTB cases diagnosed(%) | dTotal laboratory cost (Cost per TB case diagnosed) |
| TB cases diagnosed%(c – a) | Cost per TB case diagnosed(d – b) |
| Scenario 1 | 30.8 | 25315(25.3) | 750 903(30) | 27362(27.4) | 1 984 981(73) | 2.0 | 42.88 | 603 |
| Scenario 2 | 28.4 | 23335(23.3) | 751 703(32) | 25245(25.2) | 1 981 627(78) | 1.9 | 46.28 | 644 |
| Scenario 3 | 25.9 | 21334(21.3) | 752 504(35) | 23104(23.1) | 1 978 708(86) | 1.8 | 50.37 | 693 |
| Scenario 4 | 23.3 | 19157(19.2) | 753 144(39) | 20748(20.7) | 1 974 388(95) | 1.6 | 55.85 | 768 |
| Scenario 5 | 20.8 | 17059(17.1) | 754 001(44) | 18474(18.5) | 1 970 809(107) | 1.4 | 62.48 | 860 |
| **Best estimatea** | **18.3** | **15024****(15.0)** | **755 034****(50)** | **16254****(16.3)** | **1 967 340****(121)** | **1.2** | 70.78 | **986** |
| Scenario 6 | 15.8 | 12993(13.0) | 756 041(58) | 14019(14.0) | 1 963 148(140) | 1.0 | 81.85 | 1 177 |
| Scenario 7 | 13.2 | 10813(10.8) | 756 365(70) | 11685(11.7) | 1 958 961(168) | 0.9 | 97.70 | 1 379 |
| Scenario 8 | 10.6 | 8721(8.7) | 757 687(87) | 9461(9.5) | 1 955 514(207) | 0.7 | 119.81 | 1 619 |
| Scenario 9 | 8.0 | 6658(6.7) | 758 825(114) | 7173(7.2) | 1 951 139(272) | 0.5 | 158.04 | 2 315 |
| Scenario 10 | 5.5 | 4595(4.6) | 759 585(165) | 4882(4.9) | 1 947 306(399) | 0.3 | 233.57 | 4 138 |
| Scenario 11 | 3.0 | 2544(2.5) | 760 312(299) | 2672(2.7) | 1 943 670 (727) | 0.1 | 428.56 | 9 245 |

All costs are expressed in 2013 CPI-adjusted values and in US$.

\*Cost per additional TB case diagnosed in the Xpert-based algorithm compared to in the smear/culture-based algorithm.

*aBest estimate of proportion of TB cases amongst presumptive cases based on the proportion of TB cases diagnosed from 2013 routine data.*12,13

*Proportion of TB cases diagnosed amongst presumptive cases tested.*

Table 4: Cost per TB case diagnosed and the cost per additional TB case diagnosed in the Xpert-based algorithm with a reduction in Xpert cartridge price and with varying the proportion with TB amongst presumptive cases tested.

|  |  |  |  |
| --- | --- | --- | --- |
|   | TB cases amongst presumptive cases (%) | Xpert-based algorithm cost per TB case diagnosed(US $)\* | Cost per additional TB case diagnosed (US $)\*# |
| Reduction in Xpert cartridge price |
| 10% | 25% | 50% | 10% | 25% | 50% |
| Scenario 1 | 30.8 | 68 | 61 | 50 | 543 | 454 | 304 |
| Scenario 2 | 28.4 | 74 | 66 | 54 | 580 | 484 | 324 |
| Scenario 3 | 25.9 | 80 | 72 | 59 | 624 | 520 | 347 |
| Scenario 4 | 23.3 | 89 | 80 | 66 | 691 | 576 | 383 |
| Scenario 5 | 20.8 | 100 | 90 | 74 | 774 | 644 | 428 |
| **Best estimate**a | **18.3** | **114** | **102** | **83** | **886** | **737** | **489** |
| Scenario 6 | 15.8 | 131 | 118 | 96 | 1057 | 879 | 581 |
| Scenario 7 | 13.2 | 157 | 141 | 115 | 1239 | 1029 | 678 |
| Scenario 8 | 10.6 | 194 | 174 | 142 | 1453 | 1206 | 793 |
| Scenario 9 | 8.0 | 255 | 229 | 187 | 2078 | 1722 | 1128 |
| Scenario 10 | 5.5 | 374 | 336 | 274 | 3712 | 3074 | 2009 |
| Scenario 11 | 3.0 | 682 | 613 | 499 | 8290 | 6857 | 4470 |

*All costs are expressed in 2013 CPI-adjusted values.*

*#Cost per additional TB case diagnosed in the Xpert-based algorithm compared to in the smear/culture-based algorithm*

*aBest current estimate of proportion with TB amongst presumptive cases tested.*12,13



Figure 1: TB diagnostic algorithms

Diagnostic algorithms as stipulated by the South African National TB program.23 The simplified sequence of diagnostic tests in each algorithm and the action taken based on test results is shown.
Abbreviations: TB - tuberculosis; HIV – human immunodeficiency virus; MTB – mycobacterium tuberculosis.

Figure 2: Diagnostic yield and cost per TB case diagnosed as proportion of TB amongst presumptive cases is varied and Xpert costs are reduced.
All costs per TB case diagnosed are expressed in 2013 CPI-adjusted values. “Current” cost are at levels reported from the laboratory cost study6. Xpert cartridge prices were reduced by 10%, 25% and 50%.
The primary y-axis shows current costs in each algorithm and the cost per TB case diagnosed as the proportion with TB amongst presumptive cases tested is increased at different Xpert cartridge prices (with reductions of 10%, 25% and 50%).The secondary y-axis shows the proportion of TB cases diagnosed as the proportion with TB amongst presumptive cases tested is increased in the smear/culture and the Xpert-based algorithms.

Figure 3: Cost per additional TB case diagnosed in the Xpert-based algorithm compared to in the smear/culture-based algorithm as proportion with TB amongst presumptive cases tested is varied and Xpert prices are reduced.
All cost per TB case diagnosed are expressed in 2013 CPI-adjusted values. “Current” cost is reported from the laboratory cost study6. Xpert cartridge price were decreased by 10%, 25% and 50%.