

Identifying recent *Mycobacterium tuberculosis* transmission in the setting of high HIV and TB burden

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ABSTRACT

Background Accurate diagnosis of latent tuberculosis infection (LTBI) in recently exposed HIV-infected tuberculosis (TB) contacts is a public health priority because of the high risk of progression to active TB but is hampered by the high background prevalence of LTBI in high-burden populations and poor sensitivity of tuberculin skin testing (TST) in HIV co-infection.

Methods The prevalence of LTBI in 222 recent household contacts of TB cases and 176 household contacts of community controls without TB in Harare, Zimbabwe were compared using TST and interferon γ enzyme-linked immunospot (ELISpot) responses to ESAT-6 (early secretory antigenic target-6) and CFP-10 (culture filtrate protein-10). TST and ELISpot results were correlated with markers of recent TB exposure and the impact of HIV co-infection was assessed.

Results In this high-incidence population, the proportion of ELISpot-positive contacts was not significantly different from community controls. However, ELISpot, unlike TST, revealed a higher prevalence of LTBI in recent contacts of sputum smear-positive cases than in contacts of controls. ELISpot results correlated significantly with positive sputum smear and culture status of the index case (adjusted OR 2.40, CI 1.12 to 5.14), even in the subgroup of HIV-infected contacts (adjusted OR 5.36, CI 1.11 to 25.93), and were independent of contacts' HIV status. TST results were also associated with positive smear and culture status of the index case (adjusted OR 4.41, CI 1.82 to 10.67) but were negatively associated with contacts' HIV status (adjusted OR 0.25, CI 0.10 to 0.60).

Conclusions Contact investigations in high-burden populations should focus on contacts of sputum smear-positive cases in whom recent infection can be detected by ELISpot, even in the presence of HIV co-infection.

INTRODUCTION

The devastating synergy between HIV and tuberculosis (TB) co-infection is a huge burden on public health especially in sub-Saharan Africa, to the extent that TB is the leading cause of death in HIV-infected patients.¹ Treatment of latent tuberculosis infection (LTBI) in HIV-infected persons substantially decreases the risk of developing active TB.^{2,3} Because recently infected TB contacts and HIV-infected people are at especially high risk of developing active TB,^{4,5} accurately targeting those recently infected with *Mycobacterium tuberculosis* (MTB) is a high priority for improving TB control.

However, the high background prevalence of LTBI in the general population in high-burden

settings makes it difficult to identify recently infected persons. Moreover, the sensitivity of the tuberculin skin test (TST) for diagnosis of LTBI is severely compromised in HIV-infected individuals.⁶ Specificity is also poor in BCG-vaccinated persons and in populations with high environmental mycobacterial exposure as in Africa.⁶ New blood tests (interferon γ release assays (IGRAs)), which either measure the frequency of T cells secreting interferon γ (IFN γ ; enzyme-linked immunospot (ELISpot)) or the amount of IFN γ released from whole blood (ELISA) in response to MTB-specific antigens absent from BCG and most environmental mycobacteria, have been developed. Given the absence of a gold standard test for LTBI, validation of these IGRAs for diagnosing LTBI has been based largely on the consistent correlation of test results with TB exposure in several studies in low and medium prevalence countries.^{8–15} However, in high TB prevalence countries, only three studies have investigated whether IGRAs are a valid marker of LTBI by correlating test results with TB exposure,^{16–18} and none has done so in HIV-infected TB contacts.

The diagnostic sensitivity of ELISpot in active TB^{19–22} and rates of positive IGRA results in persons undergoing HIV screening in a high TB prevalence country²³ were unaffected by HIV co-infection; moreover, positive IGRA results in HIV-infected patients in Austria were recently shown to be prognostic of subsequent development of active TB.²⁴ However, the utility of IGRAs for detecting LTBI in recent TB contacts in a population with a high prevalence of both HIV and TB has not hitherto been assessed. This is an important deficit in the current clinical evidence base since, along with child TB contacts, this is a large and growing population that stands to gain the greatest healthcare benefit from improved diagnosis of LTBI. We therefore addressed this clinical and epidemiological question in a population with extremely high burdens of both HIV and TB in sub-Saharan Africa. Our study was conducted in Harare, Zimbabwe, where the estimated prevalence of HIV infection among adults is 20%²⁵ and the estimated prevalence rate of TB in 2006 was 597 per 100 000 population.²⁶ We tested for LTBI using ELISpot and TST, correlated test results with TB exposure in household contacts of TB cases and assessed the impact of HIV co-infection on test results in these contacts. On account of the high rates of MTB transmission in the general population we also assessed the prevalence of MTB infection in

contacts of healthy community controls from households without TB cases.

METHODS

Study participants

Participants were recruited from February 2002 to November 2004 from within the framework of a larger longitudinal study, described elsewhere,²⁷ on the delivery of voluntary counselling and testing for HIV and a package of primary healthcare among factory workers in Harare, Zimbabwe. Small and medium sized enterprises in the two main industrial areas in Harare, covering a range of products, for example, food industry, textiles and telecommunications, were identified with the assistance of an HIV prevention project working with businesses (Zimbabwe AIDS Prevention Project), and were eligible if they had (1) 100–600 employees, (2) an occupational or first aid clinic and (3) individual-based absenteeism records. Index controls were randomly selected from the same payroll of the same factories as the index cases. Workers starting treatment for TB disease between January 2002 and November 2004 were invited to participate in this study along with their household contacts. Household contacts were all consenting individuals over the age of 10 years living with the TB cases. Contacts of controls were household contacts of workers with no evidence of TB disease randomly selected from the same factories as the TB cases; these contacts lived with the controls and were all consenting individuals over the age of 10 years.

Tuberculin skin tests

A two-step TST protocol was used to provide a suitable baseline for identifying subsequent TST conversions.^{28–29} As recommended by the manufacturer, 2 units of RT-23 PPD (purified protein derivative) in Tween-80 (Statens Serum Institut, Copenhagen, Denmark) were injected intradermally into the forearm and results read at 48–72 h. Placement and assessment followed recommended techniques.³⁰ If the first reaction was <10 mm, then a second TST was placed after 7–14 days. Results were expressed as the greater of the two reactions. Reaction sizes ≥ 10 mm were considered positive.

HIV testing

Blood was drawn from individuals >16 years old for anonymous HIV testing at the time that the first TST was placed. Prevalence for children 12–16 years old in Zimbabwe in 2003 was 0.86% (95% CI 0.58 to 1.13; Sophie Pascoe and Frances Cowan, personal communication). Children aged 10–16 years were not tested and were assumed to be HIV negative. Serum samples were prepared and tested in parallel using Determine (Abbott, Wiesbaden, Germany) and Unigold (Trinity Biotech, Dunblane, UK). No discordant results were recorded. Voluntary counselling and testing was offered to all participants from whom HIV serology was requested for study purposes.

ELISpot assays

Blood was drawn for ELISpot testing before or after the TST was placed. ELISpot assays were carried out as described elsewhere.¹⁴ Duplicate wells contained no antigen (negative control), phytohaemagglutinin (positive control) (ICN Biomedical, Aurora, Ohio, USA) at 5 $\mu\text{g/ml}$ or 13 pairs of duplicate wells each containing one of 13 peptide pools incorporating 5–7 overlapping 15-mer peptides spanning the length of early secretory antigenic target-6 and culture filtrate protein-10, on which T-SPOT.TB is based. The final concentration of each

peptide was 10 $\mu\text{g/ml}$. ELISpot plates were sent to Oxford for automated spot counting (AID, Strassberg, Germany). Persons performing and reading the assays were blind to all personal identifiers and TST results.

Data analysis

Personal data, TST and HIV results were captured with EpiInfo 2002 (Centers for Disease Control, Atlanta, Georgia, USA) into ACCESS databases. Data were double-entered and checked. ELISpot counts were captured with EXCEL. We scored responses as positive if test wells contained a mean of at least five spot-forming cells more than the mean of the negative control wells and were at least twice the mean of the negative control wells. This predefined cut-off point is the standard threshold used with our assay format in 10 studies including a total of 2700 participants.^{8–12, 14–15, 19, 20, 31–34} Data analysis was carried out with STATA 9.0 (StataCorp, College Station, Texas, USA). Associations between categorical variables were tested for significance by χ^2 or the Fisher exact method as appropriate, and κ values were calculated for agreement between tests. Univariate and multivariate analysis of categorical values was carried out by logistic regression.

Written informed consent was obtained from all individuals, and from guardians of children <18 and ≥ 10 years old. Children <10 years were not enrolled into the study. HIV tests were run and stored under dedicated laboratory numbers with no other personal identifiers.

RESULTS

Characteristics of the study population

We enrolled 129 factory workers treated for TB disease during the study period. For diagnosis, 104 underwent sputum smear microscopy for MTB by auramine fluorescence and Ziehl–Neelsen staining as well as sputum culture on LJ medium; 49 index cases had a positive MTB smear and culture, 18 cases had a negative smear but positive culture and 37 index cases were negative on both smear and culture testing. Twenty-five cases did not have a culture taken before TB treatment was started, but met clinical and radiological case definitions of TB, including documented response to TB treatment after 1 month. Characteristics of the 129 index cases and their 222 household contacts and 149 index controls and their 176 contacts are shown in table 1. Factory workers diagnosed with TB disease were predominantly young or middle-aged adult males with a high (77%) prevalence of HIV co-infection. Household contacts of index cases, representing mainly their spouses and children, were predominantly female, with a broader distribution of age. Children <10 years old did not undergo venepuncture for ELISpot assays and are not included in the study population. Children between 10 and 16 years old represented 27% and 24% of contacts of TB cases and controls, respectively, and were assumed to be HIV negative. HIV prevalence was significantly higher among household contacts of TB cases than among contacts of controls (25% vs 10%, $p < 0.001$). For both groups, household contacts were significantly more likely to be HIV positive if the index case was also positive (table 1). Eighty-six per cent of our cohort had BCG scars.

Prevalence of positive ELISpot and TST results in contacts and controls

The prevalence of positive TST results was generally higher than the prevalence of positive ELISpot results in both contacts of index cases and contacts of community controls. Within each

Table 1 Study group characteristics

	Index cases			Index controls			
	HIV positive	HIV negative	p Value*	HIV positive	HIV negative	p Value*	p Value†
n	99 (77%)	30		29 (19%)	120		<0.001
Number male (%)	95 (96%)	29 (97%)	1.00	25 (90%)	110 (92%)	0.48	<0.001
Age in years, median (range)	40 (24–57)	37 (22–58)	0.16	46 (23–61)	37 (19, 65)	0.03	0.80
	Contacts of index cases			Contacts of index controls			
	HIV positive	HIV negative‡	p Value*	HIV positive	HIV negative‡	p Value*	p Value§
n	55 (25%)	167		18 (10%)	158		<0.001
Number male (%)	4 (7%)	65 (39%)	<0.001	4 (22%)	64 (41%)	0.2	<0.001
Age in years, median (range)	30 (17–47)	19 (10–82)	<0.001	30 (22–48)	21 (10–77)	<0.001	0.95
HIV status of index case							
Positive	49	123		8	16		
Negative	6	44	0.02	10	142	<0.001	0.81
Smear status of index cases¶							
Smear negative, culture negative	4	13		–	–		
Smear negative, culture positive	7	27		–	–		
Smear positive, culture positive	22	62		–	–		

*p Values computed with Fisher exact test or test for trend.

†p Value for difference between index cases and index controls.

‡Children ≤16 years old were assumed to be HIV negative. They were not tested for their HIV status.

§p Value for difference between contacts of index cases and contacts of index controls.

¶47 contacts were exposed to index cases that did not have a smear or culture taken.

contact group the prevalence of positive TST results was significantly lower in contacts infected with HIV than in HIV-negative contacts, whilst there was no significant difference in the prevalence of positive ELISpot results between HIV-positive and HIV-negative contacts (table 2). There was no significant difference in the prevalence of positive TST or ELISpot results between contacts of index cases compared with contacts of community controls, even when stratified by HIV status

(table 2). However, a significantly higher proportion of contacts exposed to smear- and culture-positive index cases were ELISpot positive than contacts of controls (42/84 vs 53/176, $p=0.002$) whilst the proportion of TST-positive contacts exposed to smear- and culture-positive TB cases remained non-significantly different from contacts of controls (71/84 vs 132/176, $p=0.08$), reflecting the very high background rates of positive TST results in contacts of controls. TST did not boost responses in the

Table 2 TST and ELISpot results in contacts of TB cases and contacts of controls, and the impact of HIV infection

	Contacts of patients with TB		Contacts of controls		p Value contacts vs controls*
	Positive n (%)	p Value impact of HIV co-infection	Positive n (%)	p Value impact of HIV co-infection	
TST results					
All	161 (73)	<0.001	132 (75)	<0.001	0.58
HIV positive	27 (49)	–	6 (33)	–	0.29
HIV negative	134 (80)	–	126 (80)	–	0.91
Exposed to smear-negative and culture-negative index cases	34 (60%)	–	–	–	–
Exposed to smear-negative and culture-positive index cases	23 (68%)	–	–	–	–
Exposed to smear-positive index cases	71 (85%)	–	–	–	–
ELISpot results					
All	79 (36)	0.85	53 (30)	0.28	0.25
HIV positive	19 (35)	–	3 (17)	–	0.24
HIV negative	60 (36)	–	50 (32)	–	0.42
Exposed to smear-negative and culture-negative index cases	16 (28%)	–	–	–	–
Exposed to smear-negative and culture-positive index cases	8 (24%)	–	–	–	–
Exposed to smear-positive and culture-positive index cases	42 (50%)	–	–	–	–

*p Value for difference in rates of positive test results between contacts of TB cases and contacts of controls. ELISpot, enzyme-linked immunospot; TB, tuberculosis; TST, tuberculin skin testing.

ELISpot assay as the proportion of contacts and controls positive to ELISpot did not differ statistically in those who had the TST before the ELISpot test compared with those that had the ELISpot before the TST test ($p=0.84$).

Association of ELISpot and TST results with amount of exposure to TB

Table 3 shows univariate and multivariate analyses of factors associated with positive ELISpot and TST results among household contacts of index cases, using contacts of sputum smear- and culture-negative index cases as the reference group. In both univariate and multivariate analyses positive ELISpot results were significantly associated with age (multivariate OR 1.05, CI 1.02 to 1.09) and being a contact of a smear-positive, culture-positive index case (multivariate OR 2.40, CI 1.12 to 5.14). Moreover, positive ELISpot results specifically in HIV-positive household contacts were more strongly associated with TB exposure (multivariate OR 5.36, CI 1.11 to 25.93; table 3). ELISpot results in contacts were independent of their sex and HIV infection status, as well as of the HIV status of the index case. TST results among contacts were associated with smear and culture positivity of the index case (multivariate OR 4.41, CI 1.82 to 10.67; table 3) but were inversely associated with HIV status of the contact (multivariate OR 0.25, CI 0.10 to 0.60). TST results were independent of HIV status of the index case and sex (multivariate OR 1.10, CI 0.44 to 2.75; OR 1.91, CI 0.72 to 5.05, respectively).

Impact of HIV infection on TST and ELISpot results

Overall agreement between TST and ELISpot results was modest or poor (κ ranging from 0.15 to 0.19, table 4). This poor agreement was mainly driven by the large number of discordant results in contacts of patients with TB and contacts of controls who were TST positive and ELISpot negative, probably reflecting the confounding effects of BCG vaccination and environmental mycobacterial exposure on TST. Agreement between TST and ELISpot results was substantially greater among HIV-positive individuals in each study group (κ ranging from 0.29 to 0.41, table 4) than among HIV-negative individuals

(κ ranging from 0.08 to 0.17, table 4). These results suggest that the sensitivity of ELISpot is unaffected by HIV co-infection whereas the sensitivity of TST is significantly reduced.

In some countries a ≥ 5 mm TST reaction is considered a positive result.³⁰ Reducing the cut-off threshold for a positive result from 10 to 5 mm did not identify significantly more HIV-positive contacts or controls as being latently infected with TB ($p=0.70$ and $p=0.49$, respectively). Reducing the cut-off value in active TB cases co-infected with HIV has also been found to be of limited benefit.³⁵

Amongst the HIV-negative contacts and contacts of controls, there was a distinct non-zero distribution of TST induration peaking at ~ 15 – 19 and 10 – 14 mm, respectively. In this HIV-negative population there was only a small proportion of non-reactors (12% and 15%, respectively). In contrast, there were a greater proportion of non-reactors amongst the HIV-positive contacts and contacts of controls (43% and 56%, respectively), but the overall distributions of TST indurations above zero were similar.

DISCUSSION

HIV-infected persons recently infected with MTB are at a very high risk of progressing to active TB⁴ and, given the large and growing global burden of HIV and TB, prompt and accurate diagnosis of recently acquired LTBI in HIV-infected persons is a public health priority. Despite this, no studies have hitherto assessed the potential utility of IGRAs to detect recently infected close TB contacts in a setting of high HIV and TB prevalence. In such a setting, we found that the prevalence of positive ELISpot and TST results did not differ between household TB contacts and contacts of community controls as a whole, but there was a higher prevalence of positive ELISpot results in contacts specifically exposed to smear-positive index cases than in contacts of community controls. In recent household TB contacts positive ELISpot results were associated with TB exposure and, unlike TST, ELISpot results were not significantly adversely affected by HIV co-infection. Moreover, the relationship of positive ELISpot results to TB exposure

Table 3 Univariate and multivariate ORs of relationships between risk factors and *M tuberculosis* infection as determined by ELISpot and TST among household contacts of index cases

Characteristic	Category	ELISpot		TST	
		Univariate OR (95% CI)	Multivariate OR (95% CI)	Univariate OR (95% CI)	Multivariate OR (95% CI)
All contacts* n=175					
Age		1.05 (1.02 to 1.07)	1.05 (1.02 to 1.09)	0.98 (0.95 to 1.00)	0.99 (0.96 to 1.03)
Sex	Female	1	1	1	1
	Male	0.83 (0.42 to 1.63)	0.97 (0.44 to 2.14)	3.10 (1.28 to 7.48)	1.91 (0.72 to 5.05)
Smear and culture status of index case	Smear negative, culture negative	1	1	1	1
	Smear negative, culture positive	0.79 (0.30 to 2.10)	0.73 (0.25 to 2.07)	1.41 (0.58 to 3.45)	1.36 (0.50 to 3.68)
	Smear positive, culture positive	2.56 (1.25 to 5.26)	2.40 (1.12 to 5.14)	3.69 (1.67 to 8.17)	4.41 (1.82 to 10.67)
HIV status of contacts	Negative	1	1	1	1
	Positive	1.05 (0.52 to 2.13)	0.70 (0.30 to 1.62)	0.24 (0.12 to 0.49)	0.25 (0.10 to 0.60)
HIV status of index cases	Negative	1	1	1	1
	Positive	0.60 (0.30 to 1.17)	0.61 (0.28 to 1.31)	0.66 (0.30 to 1.47)	1.10 (0.44 to 2.75)
HIV-positive contacts† n=44					
Smear and culture status of index case	Smear negative, culture negative	1	1	1	1
	Smear negative, culture positive	1.6 (0.20 to 12.69)	1.87 (0.22 to 16.16)	1.5 (0.24 to 9.46)	1.09 (0.13 to 9.42)
	Smear positive, culture positive	4.8 (1.05 to 21.91)	5.36 (1.11 to 25.93)	3.5 (0.88 to 13.93)	3.43 (0.76 to 15.52)

*47 contacts exposed to the 25 index cases that did not have both a smear and culture taken have been excluded from this analysis.

†11/47 contacts exposed to the 25 index cases that did not have both a smear and culture taken and excluded from this analysis were HIV positive.

ELISpot, enzyme-linked immunospot; TST, tuberculin skin testing.

Table 4 Agreement between TST and ELISpot results and impact of HIV infection

		Contacts of patients with TB				Contacts of controls			
		ELISpot+	ELISpot–	% ELISpot+	κ	ELISpot+	ELISpot–	% ELISpot+	κ
Overall	TST+	67	94	42	0.15	50	82	38	0.19
	TST–	12	49	20	$p=0.001$	3	41	7	$p<0.001$
HIV+	TST+	15	12	56	0.41	2	4	33	0.29
	TST–	4	24	14	$p<0.001$	1	11	8	$p=0.09$
HIV–	TST+	52	82	39	0.08	48	78	38	0.17
	TST–	8	25	24	$p=0.06$	2	30	6	$p<0.001$

ELISpot, enzyme-linked immunospot; TB, tuberculosis; TST, tuberculin skin testing.

within households remained strongly significant in the subgroup of HIV-positive contacts. These findings suggest a means for accurate diagnostic assessment of persons at highest risk of progression to TB in communities with a high burden of TB and HIV.

Although association of IGRA results with TB exposure in low prevalence countries is now well established,^{8–15} only three other studies have investigated whether IGRA results are associated with TB exposure in a high TB prevalence setting.^{16–18} The prevalence of HIV in these studies was low. Ours is the first study to demonstrate that IGRA results correlate with recent TB exposure in the most vulnerable group, HIV-infected close contacts.

There was a significant increase in positive ELISpot results with age, consistent with the cumulative risk of acquiring LTBI with increasing age and ongoing TB exposure and transmission in high prevalence areas with a high annual risk of infection. This is in contrast to a contact tracing study in a low prevalence country which found that TST results but not IGRA results were associated with age.³⁶ Positive TST results in the older individuals in that study were probably due to remotely acquired LTBI whereas the increasing prevalence of LTBI with age in our population probably reflects a mixture of both remote and recently acquired LTBI.

Our observation that the proportion of household contacts that were ELISpot positive was not significantly higher than the proportion of contacts of controls is also consistent with high levels of TB exposure and transmission in the community outside the households of TB cases.³⁷ However, among the household contacts exposed to smear- and culture-positive index cases, a significantly higher proportion had positive ELISpot results than did contacts of controls, suggesting that even in an ultrahigh prevalence setting, ELISpot detects contacts with significant recent TB exposure. Thus, in a high-burden setting testing for recently acquired LTBI should be targeted at close contacts of sputum- and smear-positive index cases.

ELISpot results were not significantly different in HIV-infected compared with HIV-uninfected household contacts. In contrast, the proportion of TST-positive contacts was significantly lower in HIV-infected contacts compared with HIV-uninfected contacts. Unlike TST, ELISpot results in the contacts of community controls were also unaffected by HIV status, similar to the observation that rates of positive ELISpot results and, to a lesser extent, ELISA results were robust to HIV infection in South African adults undergoing screening for HIV infection.²³ CD4 counts of the HIV-infected participants of this study were not determined. Although to date ELISpot results have been shown to be independent of CD4 T cell counts in patients with HIV-1,^{22 38 39} it is possible that very low CD4 counts might adversely affect ELISpot results.

The prevalence of HIV in household contacts was significantly higher than among contacts of controls. This may be explained by the fact that contacts of both patients with TB and controls were significantly more likely to be HIV positive if the index case or control were also positive, and the prevalence of HIV in the index cases was significantly higher than the prevalence in the controls. These very high rates of HIV co-infection are comparable with those reported in another study in Harare.⁴⁰ Moreover, most of the contacts of index cases were spouses. Eighty-six per cent of our cohort had BCG scars, similar to the proportion of BCG scars observed in 1997 when BCG coverage was 96.3%.⁴¹ We did not enrol children ≤ 10 years old because of the cultural challenges with venepuncture of small children in this population. Although child TB contacts in low^{12–14} and high¹⁶ prevalence countries have been studied, large-scale assessment of IGRAs in HIV-infected child TB contacts remains a priority.

In contacts of patients with TB and in contacts of controls, positive TST results were frequently associated with negative ELISpot responses, consistent with poor specificity of the TST in BCG-vaccinated populations with environmental mycobacterial exposure. These factors may be largely responsible for the poor level of agreement between ELISpot and TST results, particularly in HIV-negative persons, among whom the prevalence of positive TST results was uniformly high.

Targeting preventive therapy to TST-positive HIV-infected adults reduces the risk of active TB in these individuals in the short to medium term.³ Research into the long-term effects along with the impact on mortality conducted in large trials is required. Our findings suggest that ELISpot is a more accurate test than TST in HIV-infected persons recently infected with TB in a high-burden setting for both these infections. The increased accuracy of ELISpot testing compared with TST could improve targeting of preventive treatment to HIV-infected recent contacts of TB with LTBI which could further reduce the risk of active TB. The relevance of our findings for influencing TB control strategies was recently underscored by the demonstration that positive IGRA results in recent TB contacts are prognostic of development of active TB disease.^{42 43} Prospective trials of TB clinical outcomes in recent contacts given preventive treatment on the basis of IGRA results are now warranted to determine whether this strategy can improve TB control, especially in sub-Saharan Africa.

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Competing interests AL and KAM are inventors of patents relating to T cell-based diagnosis. The Lalvani ELISpot was commercialised by an Oxford University spin-out company (T-SPOT.TB, Oxford Immunotec, Abingdon, UK) in which Oxford University and AL have minority shares of equity and to which AL acted as non-executive director from 2003 to 2007. All other authors declare that they have no conflict of interest.

Ethics approval The study was approved by the ethics committees of the London School of Hygiene and Tropical Medicine, the Biomedical Research and Training Institute and the Medical Research Council of Zimbabwe.

Contributors AB, EC and AL designed the study. EC enrolled and clinically assessed the contacts and created the clinical and demographic database. JM and KC performed the ELISpot assays. KM read the ELISpot assay results. JM, YBC and AB unblinded and combined the clinical and ELISpot databases. The analysis was designed by AB, EC and AL, and the statistical analysis was done by YBC and KM. JM, AB, KM and AL wrote the paper. All researchers reviewed the final report.

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