Impact of Tuberculosis Control Measures and Crowding on the Incidence of Tuberculous Infection in Maryland Prisons

C. Raina MacIntyre, Newton Kendig, Leslie Kummer, Susan Birago, and Neil M. H. Graham

From The National Centre for Epidemiology and Population Health, Australian National University, Canberra, Australia; the Department of Epidemiology (School of Hygiene and Public Health), Johns Hopkins University; and the Department of Public Safety, Maryland Division of Correction, Baltimore, Maryland

Our aim was to determine the incidence of tuberculin skin test (TST) conversion in the Maryland state correctional system. We conducted a historical longitudinal cohort study. A sample of 1,289 inmates, incarcerated in 16 of 23 prisons, who had a negative TST and a second test within 24 months was selected. The incidence of recent conversion was 6.3 per 100 person-years. Risk factors for conversion included high prison-population density (relative risk [RR] = 2.4; 95% confidence interval [CI], 1.5–3.8) and incarceration in a higher-security institution (RR = 2.4; 95% CI, 1.4–4.3). Incarceration in an institution with higher levels of isoniazid prophylaxis (>65% of TST positives) reduced the risk of infection by 50% (RR = 0.5; 95% CI, 0.3–0.7). Crowding was strongly correlated with risk of conversion (r = 0.83; P < .001), while rates of isoniazid prophylaxis initiation were inversely correlated with risk of infection (r = −0.82; P < .001). In stepwise regression, higher prison-population density was the strongest predictor of increased infection. In a final model, inclusion of the rate of isoniazid prophylaxis initiation reduced the risk associated with crowding (RR = 1.4; P = .4). Annual screening programs for prisons can identify recent conversions that may not otherwise be detected.

In the United States the annual incidence of tuberculosis rose by 20% between 1985 and 1992 and has since declined by 8.7% [1, 2]. Outbreaks of tuberculosis in prisons have been well documented [3, 4], making these sites important targets for tuberculosis control. Screening of and prophylaxis for individuals at high risk is recommended by the Centers for Disease Control and Prevention (CDC) as a priority method of tuberculosis control [5].

Chemoprophylaxis with isoniazid has been shown to be up to 90% effective in preventing tuberculosis in both HIV-positive and HIV-negative persons with tuberculous infection, as long as they are compliant with therapy, and offers long-lasting benefits [6–9]. Although isoniazid has been associated with a risk of hepatitis in 1%–2% of cases, the risk is negligible in those aged <35 years [10, 11]. Risk-benefit studies of isoniazid prophylaxis have shown that—particularly if a patient is aged <35 years, and in many instances even in elderly patients—the benefits of isoniazid outweigh the risks [12].

The prevalence of tuberculous infection varies demographically in the United States. Studies have shown a point prevalence of 2.5% tuberculin skin test (TST) reactivity among U.S. Navy recruits in 1990, varying from 26% among Asian recruits to 5.2% among African-American recruits and 0.8% in white recruits [13]. The prevalence of tuberculous infection in prisons is higher than in the general population. Prevalence rates of up to 25% have been described in correctional institutions [14–18]. In HIV seronegative intravenous drug users in Baltimore the prevalence was 25% [19].

Infectious tuberculosis in prison inmates can be spread back into the community [14], as well as within the prisons, and should be an important target for tuberculosis control. The factors associated with the transmission of tuberculosis in prisons in the United States include the high prevalence of infection in the source population, HIV infection, overcrowding, and systematic rotation of prisoners. Stead [14] described conversion from negative to positive TST status among 12% of prisoners exposed to infectious tuberculosis.

While contact tracing around discrete outbreaks of tuberculosis in prisons has been well described and point prevalence of tuberculous infection in prisoners is easily studied, there are few data on the background incidence of new infection acquired within correctional facilities. The Maryland correctional system in March 1992 instituted systematic annual retesting of all inmates whose initial test was negative. This provides a unique opportunity to study the overall incidence of tuberculous infection, associated risk factors, and impact of control measures.

Methods

Study Population

The study population consisted of male inmates of the Maryland Division of Correction (MDOC). MDOC is a state prison...
system encompassing 23 prisons contained in four regions of Maryland, with an average daily population of 20,247 in 1994. Only one prison is solely for women, who comprise 5% of the MDOC inmate population. The study population was selected from Baltimore (region 1) and Jessup (region 2), the two regions that house 46% (9,308) of the MDOC population.

The demographic features of inmates do not vary significantly between the four regions. In the entire population, 77% of inmates are African-American and 22% are white. The mean age of inmates is 33 years, the mean duration of incarceration is 74 months, and the mean turnover is 21%.

All 16 prisons in regions 1 and 2 were included. The facilities studied included the intake facility; a home detention unit; 5 prerelease units; 3 minimum, 2 medium, and 2 maximum security units; 1 combined medium and maximum security unit; and a solitary confinement unit.

**MDOC Tuberculosis Control Program**

Between 1991 and 1993 the MDOC tuberculosis program restructured its activities to include administration of isoniazid prophylaxis under direct observation, construction of tuberculosis isolation units, and mandatory annual skin testing for all inmates. Contact tracing is conducted for all cases of tuberculosis isolation units, and mandatory annual skin testing for all inmates. Contact tracing is conducted for all cases of tuberculosis, to have HIV infection, to have used intravenous drugs in the past year, or to have medical conditions predisposing to tuberculosis are recommended for isoniazid therapy, regardless of age. All inmates are offered HIV testing, which is voluntary. Special efforts are made to ensure that tuberculin-positive inmates agree to HIV testing.

**Study Design**

A historical cohort study of incidence of new infection acquired within the prison system was performed. Inmates undergo a TST on entry into the prison system, and since March 1992 annual retesting has been done for negative reactors during their birth month. Therefore, the interval between the first and second test may vary, which we accounted for by measuring person-years of incidence. If, however, an individual’s birthday falls within 3 months of the initial test, retesting is postponed until the following year. Complete 2-year follow-up data were available for inmates whose most recent birthday fell between August and December 1994 (inclusive).

A systematic sample consisting of all inmates born between 1 August and December (inclusive) of any year, regardless of when they entered the prison system, was selected. All inmates undergo annual screening or review for tuberculosis during their birth month; therefore, the inmates in our sample (n = 2,606) were due for review between 1 August and 31 December 1994. Those with a previously negative TST undergo retesting, and those with a previously positive TST are screened by clinical examination and chest radiography.

Prevalence of infection was calculated only for those (n = 1,977) who underwent an initial test between 1990 and 1994. A positive reaction was defined as one ≥10 mm. If HIV infection was present, a reaction of ≥5 mm warranted consideration for preventive therapy. A cohort of 1,289 individuals within this sample who had a negative initial skin test and a second test within 24 months was studied to determine the incidence of recent TST conversion.

The dates of retesting for this cohort ranged from February 1991 to December 1994, and all inmates had the initial and second test performed in the same institution, while serving the same sentence. The following factors were used to define newly acquired tuberculous infection: (1) an initial negative TST reaction (<5 mm) and no previously documented positive reactions and (2) a reaction with an increase in size (≥10 mm) to a second TST performed within 24 months of the initial test (a reaction of ≥5 mm in HIV-infected individuals warranted consideration for preventive therapy).

**Tuberculin Testing Procedure**

All inmates undergo tuberculin testing on admission to Maryland prisons, unless documented prior positive test results (most commonly from previous admissions) are available. Testing is performed and read by licensed nurses by means of the Mantoux method, with use of 0.1 mL of tuberculin containing 5 TU (Tubersol; Connaught Lab, Swiftwater, PA).

**Data Sources and Collection**

Tuberculin testing data were collected from MDOC testing logs. These data were merged with additional information from the correctional system database. If tuberculin testing data were incomplete, medical records were reviewed. Medical records were also reviewed for inmates with a positive TST or documented conversion. HIV testing results were matched to our database from the MDOC HIV testing records, and unique identifiers were then delinked. HIV testing is voluntary in the MDOC.

Estimates of population densities in each prison were made on the basis of total population and area of the prison. Estimates of population turnover for each prison were based on monthly admissions, discharges, and resident populations for the time period studied. Three binary variables were created, and 0–1 values were assigned to individuals according to which prison they were in. The cutoff points were selected as the median values for the variables being studied: isoniazid prophylaxis rates for infected individuals, >65% per prison; prison population turnover, >30%; and prison population density, >9
inmates per 1,000 square feet. The results of screening at the intake institution were significantly different from those at the other institutions, so screening data for all of 1994 at this institution were reviewed.

Data Analysis

Univariate analysis was performed with Epi-Info version 5 (CDC) [20], with use of $\chi^2$, Taylor series 95% confidence intervals (CIs) for relative risks, and Cornfield 95% CIs for odds ratios. Multiple regression was performed with EGRET software [21]. Poisson regression was used to analyze risk factors for TST conversion. The most significant increases in likelihood were used to select the best multivariate models.

We computed Pearson’s moment correlation coefficients ($r$ values). We excluded the intake institution in the correlation studies because of the unusually high conversion rates therein. We also excluded the solitary confinement unit, in which no inmate-intermingling occurs and, therefore, degree of crowding is not a relevant factor.

A sensitivity analysis for incidence of TST conversion was performed to allow for the boosting effect, assuming a maximum of 30% of all positive reactions in recent converters were due to boosting. This figure was based on the highest incidence of boosting noted in the literature [22].

Institutional Approval

The study was approved by the Committee for Human Research of the School of Hygiene and Public Health at Johns Hopkins University (Baltimore). This committee includes a prisoner advocate.

Results

Demographics and Tuberculosis Case Rates

In 1992, the incidence of active tuberculosis in Maryland prisons was 58 cases per 100,000 inmates, >5-fold the incidence rate in the state of Maryland. However, the annual number of cases in the MDOC has decreased from 11 in 1992 to 4 (20 per 100,000) in 1994.

The sample comprised 28% of the inmates of the two regions studied (2,606 of 9,308) and 13% of the total MDOC inmate population (2,606 of 20,247). The total number of inmates eligible for screening between August and December 1994 was 2,606. Of these, 82% (2,143 of 2,606) had at least one TST done. The remainder (463, or 18%) were excluded because no TST was done. The reasons for this were transfer to another institution (347 of 463; 75%), release or leave (107 of 463; 23%), and refusal (9 of 463; 2%). Over 90% (1,977 of 2,143) were tested after 1990, and only 1.5% (32 of 2,143) were tested before 1980.

Prevalence of Infection

The prevalence of infection was 18% (358 of 1,977). There was no significant difference in prevalence of infection between region 1 (17.5%; 104 of 594) and region 2 (18%; 254 of 1,383) ($P = .7$). There was a higher prevalence of infection in inmates aged >35 years (33%; 212 of 651) than in those aged <35 years (11%; 146 of 1,326) (OR = 3.9; 95% CI, 3.0–5.0). The strongest risk factor associated with prevalence was an age >35 years. Prevalence was also associated with a duration of incarceration >10 years (OR = 2.0; 95% CI, 1.6–2.6).

Prevalence increased significantly with duration of incarceration, from 13% for inmates incarcerated for ≤12 months to 31% for those incarcerated >10 years ($P < .001$) (figure 1). Prison population density and rate of isoniazid prophylaxis were not associated with prevalence. Among African-American inmates the prevalence was 18.8% (287 of 1,523), and among

Prevalence increased significantly with duration of incarceration, from 13% for inmates incarcerated for ≤12 months to 31% for those incarcerated >10 years ($P < .001$) (figure 1). Prison population density and rate of isoniazid prophylaxis were not associated with prevalence. Among African-American inmates the prevalence was 18.8% (287 of 1,523), and among

Within this sample of 2,143, 1,708 had a negative initial TST. Of these, 86% (1,466 of 1,708) underwent a second test, and 1,289 of these 1,466 (88%) had the second TST performed within 24 months. The remainder were transferred to other prisons or discharged, and they were excluded.

Of the 2,143 inmates, 72% (1,532) were housed in region 2 and 28% (611) in region 1. The mean age of inmates was 33 years (median, 32 years), and the mean duration of incarceration was 72 months (median, 42 months; range, <1 month to 437 months); most (77%; 1,651) were African-American, and 22% (473) were white. Most inmates (99.5%; 2,134) were born in the United States, and 70% (1,492) were born in the state of Maryland. Most inmates (1,393; 65%) resided in Baltimore before incarceration. The remainder included 7.7% (164) from Prince George’s County, Maryland; 3.9% (83) from Baltimore County; 16.8% (361) from other counties in Maryland; and 6.6% (142) from other states.
Table 1. Incidence of recent tuberculin skin test (TST) conversion per institution type in Maryland.

<table>
<thead>
<tr>
<th>Type of unit</th>
<th>No. of units</th>
<th>No. of conversions</th>
<th>No. of person-years</th>
<th>No. of conversions per 100 person-years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home detention</td>
<td>1</td>
<td>0</td>
<td>7.3</td>
<td>0</td>
</tr>
<tr>
<td>Prerelease</td>
<td>5</td>
<td>1</td>
<td>195</td>
<td>0.5</td>
</tr>
<tr>
<td>Minimum security</td>
<td>3</td>
<td>9</td>
<td>131</td>
<td>6.9</td>
</tr>
<tr>
<td>Medium security</td>
<td>2</td>
<td>28</td>
<td>319</td>
<td>8.8</td>
</tr>
<tr>
<td>Medium and maximum</td>
<td>1</td>
<td>9</td>
<td>139</td>
<td>6.5</td>
</tr>
<tr>
<td>Home detention</td>
<td>1</td>
<td>0</td>
<td>7.3</td>
<td>0</td>
</tr>
<tr>
<td>Maximum security</td>
<td>2</td>
<td>18</td>
<td>276</td>
<td>6.5</td>
</tr>
<tr>
<td>Solitary confinement</td>
<td>1</td>
<td>0</td>
<td>44</td>
<td>0</td>
</tr>
<tr>
<td>Intake</td>
<td>1</td>
<td>5</td>
<td>9.4</td>
<td>53</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>70</td>
<td>1,119</td>
<td>6.3</td>
</tr>
</tbody>
</table>

white inmates it was 15.6% (71 of 454) (OR = 1.3; 95% CI, 0.9–1.7).

Incidence of Conversion

For 70 of 1,289 inmates, the TST converted from positive to negative within 24 months. The incidence of recent conversion was 6.3 per 100 person-years. To be certain that boosting did not significantly influence the estimated incidence of TST conversion, we performed a sensitivity analysis, assuming that 30% of positive reactions in recent converters were due to boosting. Even with adjustment for this high hypothetical rate of boosting, the rate of conversion was 5.0 per 100 person-years.

The mean reaction size among recent converters was 15 mm. There were significant differences in conversion rates between regions and between prisons. Region 1 had a significantly higher conversion rate (8.5 per 100 person-years) than did region 2 (5.4 per 100 person-years) (RR = 1.6; 95% CI, 1.1–2.5). Six prison facilities had no conversions; these were the solitary confinement unit, the home detention unit, and four prerelease units. The remaining prerelease unit had only one conversion.

Table 1 shows the wide variation in rates of recent conversion by institution type. Because of the extremely high rate of conversion in the intake facility, we reviewed screening data for all of 1994 for that institution to determine if we had inadvertently sampled a period of unusually high incidence. In fact, all the conversions in the intake facility for 1994 occurred in just 1 month (September 1994), yielding unusually high rates in our sample. These conversions were all associated with exposure to a single infectious case of tuberculosis in the intake institution. The incidence of conversion at the intake institution for all of 1994 was nine per 100 person-years, which was not significantly higher than the overall rate (RR = 2.0; 95% CI, 0.9–4.8). Table 2 shows risk factors for conversion, determined in univariate analysis. In stepwise Poisson regression using all variables in table 2, prison population density was the most significant variable (RR = 2.22; P < .001), followed by a rate of isoniazid prophylaxis initiation of >65% (RR = 0.44; P = .01), medium and maximum security level (RR = 2.35; P = .01), and race (RR = 2.15; P = .03). In all multivariate Poisson regression models tested, rate of isoniazid prophylaxis initiation and population density were consistently the most significant variables when only one or the other was included. However, when these two variables were included together, rate of isoniazid prophylaxis reduced the risk associated with crowding.

Table 3 shows three multivariate models (A, B, and C) including variables that were significant in stepwise testing and illustrates the effect of isoniazid prophylaxis initiation rates on crowding. In model A, prison population density is the most significant variable, and in model B rate of isoniazid prophylaxis is the most significant variable. When both were included in model C, both ceased to be significant, while race and security level remained significant.

Impact of Isoniazid Prophylaxis and Crowding on Tuberculous Infection

Prison population density and rates of isoniazid prophylaxis were strongly associated with risk of tuberculous infection and varied between institutions. These variables were examined further to determine if tuberculous infection rates in each institution were correlated with the level of crowding and the level of isoniazid prophylaxis initiation per institution. These data are shown in figures 2 and 3, where each point on the graph represents an individual institution.

Figure 2 shows that prison population density was strongly correlated with conversion rates per institution (r = 0.83; 95% CI, 0.56–0.94; P < .001): conversion rates increased as population density increased. There was also a significant inverse correlation between isoniazid prophylaxis initiation rates and recent TST conversion rates per institution. As isoniazid rates increased, conversion rates decreased (r = −0.82; 95% CI, −0.94 to −0.54; P < .01).

HIV Infection

Overall, 36% (774) of the 2,143 analyzed inmates were tested for HIV. The prevalence of infection was 9% (70 of 774). The prevalence of HIV infection in those aged <35 years was 7%, and in those aged ≥35 years, 12% (OR = 0.55; 95% CI, 0.32–0.92; P = .02). The mean age of HIV-positive inmates was 36 years, and that of HIV-negative inmates was 33 years (P < .001). In the cohort tested for recent conversion, 398 of the 1,289 underwent an HIV test, of whom 38 (9.5%) tested positive.
Table 2. Incidence of recent TST conversion in Maryland prisons: univariate analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of conversions</th>
<th>Person-years</th>
<th>Incidence per 100 person-years</th>
<th>RR</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>African-American race</td>
<td>61</td>
<td>858</td>
<td>7.1</td>
<td>2.1</td>
<td>1.1–4.1</td>
<td>&lt;.05*</td>
</tr>
<tr>
<td>Age &lt;35 y</td>
<td>44</td>
<td>804</td>
<td>5.5</td>
<td>0.7</td>
<td>0.4–1.1</td>
<td>.08</td>
</tr>
<tr>
<td>Prison population density &gt;9/1,000 sq ft</td>
<td>40</td>
<td>399</td>
<td>10.0</td>
<td>2.4</td>
<td>1.5–3.8</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Isoniazid &gt;65%</td>
<td>22</td>
<td>561</td>
<td>3.9</td>
<td>0.5</td>
<td>0.3–0.7</td>
<td>&lt;.01*</td>
</tr>
<tr>
<td>Region 1 facility</td>
<td>27</td>
<td>316</td>
<td>8.5</td>
<td>1.6</td>
<td>1.0–2.5</td>
<td>&lt;.05*</td>
</tr>
<tr>
<td>Pre-release unit</td>
<td>1</td>
<td>195</td>
<td>0.5</td>
<td>0.1</td>
<td>0.01–0.5</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Medium and maximum security level</td>
<td>56</td>
<td>704</td>
<td>8.0</td>
<td>2.4</td>
<td>1.4–4.3</td>
<td>&lt;.01*</td>
</tr>
<tr>
<td>Duration of incarceration &gt;10 y</td>
<td>10</td>
<td>178</td>
<td>5.6</td>
<td>0.9</td>
<td>0.5–1.7</td>
<td>.7</td>
</tr>
<tr>
<td>Turnover &gt;30%</td>
<td>14</td>
<td>213</td>
<td>6.6</td>
<td>1.1</td>
<td>0.6–2.0</td>
<td>.68</td>
</tr>
<tr>
<td>Total</td>
<td>70</td>
<td>1,119</td>
<td>6.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Statistically significant.

Two of the 38 in the HIV-positive group converted (5.7 per 100 person-years) vs. 48 of the 360 in the HIV-negative group (14.0 per 100 person-years). This difference was large but did not reach statistical significance (RR = 0.41; 95% CI, 0.1–1.60; Yates-corrected P = .26). The TST reaction sizes of the two HIV-positive individuals who converted increased from zero to 12 mm and 16 mm, respectively. The mean TST reaction size in converters was not significantly different between HIV-positive persons (14 mm) and HIV-negative persons (14.3 mm) (P = .6).

Discussion

It has been shown that the rate of active tuberculosis in prisons is nearly 4 times higher than in the general community [23]. Braun et al. showed by phage typing that intramural transmission of tuberculosis in prisons does occur [16], and Stead [14] showed that active tuberculosis may go undetected in prison. A study of New York state prisons identified 171 cases of active tuberculosis between 1990 and 1991 [24]. The occurrence of significant transmission of tuberculosis in prisons is also supported by the strong association we found between duration of incarceration and prevalence, with rates as high as 31% after 10 years. The relationship of active tuberculosis to number of admissions and increasing duration of incarceration has been described previously [15].

With this background, high conversion rates would be expected in prisons. Our study found a TST conversion rate of 6.3 per 100 person-years. A contact study in a correctional facility in California demonstrated a conversion rate in exposed employees of 6.4 per 100 person-years [4]. Another study reported an initial TST positivity rate of 23%, with a 71% rate of subsequent conversion in initially negative reactors, among 107 inmates residing in the same tier as an infectious inmate.

Figure 2. Pearson’s moment correlation between prison population density and TST conversion rates per institution in Maryland (r = 0.83; 95% CI, 0.56–0.94; P < .001). Each point represents one institution.
Inmates have access to the community and live in less crowded facilities in which a staff member developed active tuberculosis with incidence but not prevalence. This suggests that anergy may have contributed to the occurrence of false-negative TST reactions on initial testing. We compared the groups with prevalent and incident infection to test the hypothesis that if anergy at the time of entry into the prison system and test failure were largely responsible for “conversions” (that is, the inmates who converted from negative to positive but actually infected but anergic at the time of the first test), then the demographics and risk factors for the two groups would be similar.

In contrast with those with prevalent infection, there was no significant difference in the incidence of infection by age group, implying that the risk of negative reactors acquiring infection remains uniformly high, regardless of age. In addition, conversion rates were significantly higher in prisons in region 1 than in those in region 2, but prevalence of infection was the same. Duration of incarceration was associated with prevalence (assumption).

The biological plausibility of our findings is supported by the fact that the solitary confinement unit (where no prisoner interaction takes place) and the home detention unit (where inmates have access to the community and live in less crowded conditions) had no conversions. In addition, the prerelease units (where conditions are less crowded) had minimal TST conversion.

Institutions at greater risk for tuberculosis transmission included the intake institution and the maximum and medium security institutions, which have crowded conditions, daily prisoner intermingling, and no community access. The intake institution had the highest case rate of active tuberculosis and the highest staff TST conversion rates, and it was the only facility in which a staff member developed active tuberculosis (unpublished data, N. Kendig). Inmates with active tuberculosis diagnosed in the intake institution are likely to have acquired their disease outside the prison system, but uninfected inmates in the same institution are still at high risk of exposure during the initial holding period.

The association of conversion with institution type, independent of levels of crowding and preventive therapy, may reflect different inmate mix in different institutions. The independent association of race is consistent with the findings of Stead et al. [27].

The inverse correlation between use of isoniazid prophylaxis and incidence of tuberculous infection in institutions could indicate that a prison with high prophylaxis rates is more likely to have a more disciplined and systematic approach to tuberculosis control and, therefore, fewer conversions. The wide variation in isoniazid prophylaxis rates between prisons may indicate underutilization in some institutions. A study of preventive therapy in older contacts of infectious tuberculosis found that only 30% of infected contacts who were deserving of preventive therapy actually received it [28].

Another study found that for 59% of all patients with tuberculosis reported to the Oregon health division, previous opportunities for prevention had been missed [29]. Mehta et al. found a decline in the rate of preventive therapy for infected contacts in Tennessee, dropping from 67% in 1979 to 37% in 1985 [30]. With regard to tuberculosis screening, when effective intervention is available, it is essential that adequate resources are made available to the correctional system to ensure uniformly high initiation and completion of isoniazid prophylaxis.

The incidence of TST conversion in our study is subject to certain caveats. For example, transient anergy or observer error may have contributed to the occurrence of false-negative TST reactions on initial testing. We compared the groups with prevalent and incident infection to test the hypothesis that if anergy at the time of entry into the prison system and test failure were largely responsible for “conversions” (that is, the inmates who converted from negative to positive were actually infected but anergic at the time of the first test), then the demographics and risk factors for the two groups would be similar.

In contrast with those with prevalent infection, there was no significant difference in the incidence of infection by age group, implying that the risk of negative reactors acquiring infection remains uniformly high, regardless of age. In addition, conversion rates were significantly higher in prisons in region 1 than in those in region 2, but prevalence of infection was the same. Duration of incarceration was associated with prevalence (as expected), but not with incidence.

This makes intuitive sense, since the risk of an uninfected inmate acquiring tuberculous infection would not depend on duration of incarceration but on the risk of exposure at any given time. Furthermore, risk factors such as rate of isoniazid prophylaxis initiation and population density were associated with incidence but not prevalence. This suggests that anergy and test failure probably made only a minimal contribution to the results.

Boosting cannot be excluded, since two-step testing was not used, but several factors suggest its contribution was also minimal. Boosting is associated with larger initial TST reactions, previous BCG vaccination, birth in a foreign country, and older age [31]. Our group had initially negative (0 mm)
TST reactions, a mean age of 33 years, and minimal prior vaccination with BCG, since >99% were born in the United States. In largely unvaccinated North American populations with and without HIV infection, no more than 3%–5% of reactions of >10 mm can be attributed to boosting [31, 32].

Boosting is also associated with past exposure to atypical mycobacteria, and Thompson et al. showed that residents of Pennsylvania had significantly lower rates of boosting than did residents of southeastern and western states [33]. Maryland, which is adjacent to Pennsylvania, is not known to have a high prevalence of environmental mycobacterial exposure (personal communication, G. Comstock).

Higher rates of boosting (up to 30%) in Southeast Asian refugees, who have a higher level of BCG vaccination and exposure to environmental mycobacteria [22], have been described, but there are very few Southeast Asian refugees in Maryland prisons. Nevertheless, if we assumed 30% of positive reactions in recent converters were due to boosting, the adjusted conversion rate would still be 5.0 per 100 person-years, so it is unlikely to have had a major impact on the estimated incidence in this study.

The fact that lower conversion rates were described for HIV-positive inmates than for HIV-negative inmates may suggest that the cutoff point used is not sensitive enough to detect all cases of tuberculous infection in the HIV-positive group. One study found a significantly lower rate of TST reactions of >5 mm in HIV-positive inmates than in HIV-negative inmates of correctional and drug treatment facilities [34]. In the MDOC, where HIV testing is voluntary, only 30%–40% consent to testing, and HIV seroprevalence is higher among inmates who initially refuse testing [35].

Anonymous serosurveys conducted in the MDOC since 1985 show a 7%–8.5% HIV seroprevalence among male inmates [35]. This is lower than the 21% HIV seroprevalence reported in a survey of prisons in 25 states [34]. Studies have described HIV seroprevalence of 49%–56% in prison inmates with active tuberculosis [16, 34]. For this reason, the MDOC uses a 5-mm cutoff point for all inmates, to define infection and guide decisions to treat. The rationale for this is that the potential sequelae of missing a diagnosis of tuberculous infection in an HIV-positive inmate because of a higher cutoff point are more serious than those of increasing the false-positivity rate in non-HIV-infected inmates.

The annual screening program at the MDOC identified and treated individuals with infection that might otherwise have gone undetected. The occurrence of undetected transmission of tuberculosis in prisons has been described before [14, 17] and may be due to high rates of population turnover in prisons. For this reason, contact screening alone, in response to discrete outbreaks, may not be adequate for control of tuberculosis.

Increasing incarceration rates and longer inmate sentences mean that crowding in prisons is not readily amenable to change. Instead, a practical approach would be to maintain annual screening and to target the most crowded institutions for increased support and resources in tuberculosis control.

Acknowledgments

The authors are grateful to Tom Stough, of the Maryland Division of Correction (MDOC), for merging the database with the MDOC database; to Dr. Diane Matuszak and Dr. Ebenezer Israel, of the Maryland Department of Health & Mental Hygiene, Division of Tuberculosis Control, for providing data from the state tuberculosis registry; to Dr. Aileen Plant, of Australian National University, and Dr. George Comstock, of Johns Hopkins University, for their comments and suggestions; and to Dr. Connie Benson, of Rush Presbyterian–St. Luke's Hospital (Chicago), for her evaluation of the manuscript.

References