Excess tuberculosis risk during and following incarceration in Paraguay: a retrospective cohort study

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Summary

Background The increased risk of tuberculosis (TB) among people deprived of liberty (PDL) is due to individual and institution-level factors. We followed a cohort of PDL from 5 prisons in Paraguay to describe the risk of TB during incarceration and after they were released.

Methods We linked a 2013 national census of prisons with TB records from the TB Program from 2010 to 2021 to identify TB notifications among incarcerated and formerly incarcerated individuals. We used multivariable Cox regression models to quantify the risk of TB during and following incarceration and to identify risk factors associated with TB.

Findings Among 2996 individuals incarcerated, 451 (15.1%) were diagnosed with TB. Of these, 262 (58.1%) cases occurred during incarceration and 189 (41.9%) occurred in the community after release. In prison, the hazard ratio of developing TB was 1.97 (95% CI: 1.52–2.61) after six months of incarceration and increased to 2.78 (95% CI: 1.82–4.24) after 36 months compared with the first six months. The overall TB notification rate was 2940 per 100,000 person-years. This rate increased with the duration of incarceration from 1335 per 100,000 person-years in the first year to 8455 per 100,000 person-years after 8 years. Among former prisoners, the rate of TB decreased from 1717 in the first year after release to 593 per 100 000 person-years after 8 years of follow up.

Interpretation Our study shows the alarming risk of TB associated with prison environments in Paraguay, and how this risk persists for years following incarceration. Effective TB control measures to protect the health of people during and following incarceration are urgently needed.

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Keywords: Tuberculosis; Transmission; Prisons; Epidemiology; Paraguay

Introduction

Tuberculosis (TB) in prisons is an important public health concern, as the increasing burden in various regions of the world is hindering overall TB control. Recent estimates for the South American region show that the contribution of TB among people deprived of

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Research in context

Evidence before this study

It is well known that prisons are high-risk environments for tuberculosis (TB) transmission. TB prevalence within prisons far exceeds community rates, and with regular movement of incarcerated individuals between prisons and communities, this excess TB often spreads beyond prison walls. However, there is limited data on the incidence risk patterns following incarceration and release. We searched PubMed with the key terms: "tuberculosis", "incidence", "prison", and "release" or "community" for articles published in English before October, 2023. This search identified 254 articles. We identified only one article from Brazil that quantified the risk of TB during and after incarceration, showing that the risk of TB was 30 times higher in prisons than in the community and persisted several years after release among those who were previously deprived of liberty.

Added value of this study

This study, conducted from an initial cohort of 2996 people deprived of liberty from 5 prisons in Paraguay, allowed us to retrospectively observe how TB cases progressively developed over time during imprisonment and after release. We also measured how some factors such as overcrowding, time spent in prison, and re-incarceration affect the risk of developing TB within prison or after release. This study shows that the rate of developing TB increases considerably after each year spent in prison, from 1335 per 100,000 person-years in the first year to 8455 per 100,000 person-years after 8 years. Upon release, the incidence of TB decreases. However, even after 8 years of follow up in this group, their TB rates remain 10 times higher than community rates. This study also quantifies the relationship between a higher density of people deprived of liberty living per prison cells and an increased risk of developing TB.

Implications of all the available evidence

Our study shows the alarming risk of TB associated with prison environments in Paraguay, and how this risk persists for years following incarceration and release. These results call for urgent and effective TB control measures to protect the health of people during and following incarceration. Given the high contribution of TB in prisons to the overall TB burden in Paraguay, successful TB control interventions (including structural changes that reduce overcrowding) are likely to have a considerable impact on national TB burden indicators.

liberty (PDL) to the general TB burden more than doubled between 2011 and 2017.[1] This upward trend of TB in prisons, the increase in its population attributable fraction, and its role as an amplifier of TB epidemics in the community call for renewed attention to this public health problem[2,3]

The spread of TB in prisons presents a complex health problem that is magnified in the context of mass incarceration. In this setting, a continuous and dynamic process of social interaction between the prison population and the community exists. TB outbreaks in prisons have been associated with higher TB incidence in the community and vice versa. Another contributing factor to poor TB control in countries with high incarceration rates is the inconsistent follow-up of individuals infected with TB in prison who are released before completing treatment.[4,5] Limited data is available on the spillover effect and risk of TB among PDL once they are released from prison.

In 2020, the TB incidence rate in Paraguay was 48 cases per 100,000 inhabitants, but in prison settings it climbed higher than 3000 cases per 100,000 inhabitants.[6] In the last 10 years, the incarceration rate in Paraguay has doubled, reaching 200 PDL/100,000 population in 2020. Consequently, the increase in incarceration has been accompanied by a rapid increase in the proportion of TB cases nationally that occur in prison (7.1% in 2009 compared to 14.5% in 2018).[7] This has forced the National TB Control Program (NTP) to redirect its limited health resources on integral control strategies with an increasing focus on prison health.[3,8]

In order to better understand the impact of incarceration on the global TB burden, we must first characterise the excess TB burden among incarcerated and previously incarcerated individuals.[4,9] Therefore, we conducted a study to estimate the risk of TB in a cohort of PDL who were registered in a national prison census of Paraguay in 2013 and followed up until December 2021. In addition, we examined risk factors and the time course of TB during incarceration and following release from prison.

Methods

Study design

This was a retrospective longitudinal study following a cohort of PDL for the development of TB during and after incarceration. We linked three national data sources, including incarceration census data (2013), digital records of five prisons (2010–2021), both from the Ministry of Justice (MoJ) and TB case notification data from Paraguay's NTP (2010–2021) in the Ministry of Health (MoH).

Study setting

Our study focusses on five of Paraguay's 18 prisons: the National Penitentiary Tacumbú, the National Penitentiary Emboscada, the Regional Prison of Ciudad del Este (CDE), the Padre Juan Antonio de la Vega Penitentiary,

and the Esperanza Penitentiary. These prisons represent 30% of the overall prison population in the country and located near the country's most populated cities: Asunción (Paraguay's capital city) and CDE. All five prisons house only men. Further, these prisons register the movement of PDL within the national prison system including their entry, relocation, release, and re-incarceration data. Movement between prisons other than those included in the study is rare, especially due to their geographic location. In these cases, the PDL were censored at the time of relocation.

Data sources and linkage

Our study cohort included all PDL registered in the National Prison Census conducted from March 4 to March 15, 2013 (data provided by MoJ). The prison census provided the following variables for this study: name, surname, sex, date of birth, literacy, occupation, income level prior to entering the prison, cigarette or drug use, type of prison, reason for incarceration (with or without a sentence) and pavilion or prison sector.

The National TB registry (provided by MoH) is a compulsory report of all TB confirmed cases. For this study, data from 2010 to 2021 were analysed, and the variables collected were: names, surnames, national identity number, date of birth, date of diagnosis, date of death, and sociodemographic and clinical data. For all individuals diagnosed with TB in Paraguay, the national TB registry included information on patient incarceration status and the institution in which TB diagnosis occurred.

The five prisons selected for this study are the largest and oldest ones, which also have digital records with high quality data such as: dates of prison entry, relocation, release dates and re-incarceration through December 2021.

We conducted two analyses. First, we matched the 2013 prison census to the NTP registry. This enabled us to measure the percentage of TB cases among individuals included in the prison census up to 8 years after the census. However, the prison census was cross-sectional and did not include information on prison transfer or releases. Second, we conducted a sub-analysis in 5 prisons for which prison entry and release dates were available. We matched this dataset with the TB registry to identify individuals who were diagnosed with TB during and after incarceration. We used the second matched dataset to estimate hazard rates (Fig. 1).

We used a multi-stage approach to match these registries. First, our matching algorithm used individual identity numbers provided in both databases; however, some identity numbers were incomplete. Secondly, we used initials of the first name and first surname, date of birth, and sex. We confirmed all matches manually. The sensitivity of the analysis was measured by comparing people with TB registered in the NTP, according to the evaluation of "*incarceration*" variable (which provides the information on whether the TB patient was incarcerated at the time of diagnosis).

TB cases notified three years prior to the prison census (2010–2012) were excluded in order to appraise the effect of recent past TB episodes on the subsequent risk of TB. Individuals incarcerated prior to 2010 were excluded because of incomplete registration data.

Statistical analysis

We performed a survival analysis among PDL using notified TB (all forms) as the primary endpoint. Subsequently, we conducted survival analyses among two sub-populations: 1) PDL who remained incarcerated after 2013; 2) PDL who were released (and who had no TB episodes recorded while in prison), commencing observation-time at release. In the first group, the follow up period for each individual was determined from the date of their admission to prison until their release, death, or the end of the follow-up period (Dec 31, 2021). For the second group, follow-up time began at the time of their release until re-entry to prison or the end of the follow-up period. We performed all statistical analyses in R, version 3.5.0. We made right-censored survival analyses for the cohort of PDL and ex-PDL using the "survival" package.[10]

We calculated the TB notification rate and 95% confidence intervals for both PDL and former PDL over the study period as the number of new cases each year divided by the number of people at risk at the beginning of that year, repeating this model for each study year. We had mortality dates when death occurred in prison, but not if it happened after the release period if it was not associated with a TB episode.

We used multivariate Cox regression to measure risk factors associated with TB. We included a set of pre-specified sociodemographic and behavioural variables from the prison census and those related to the prison environment, such as readmissions, type of prison, level of overcrowding in the cell room or total time in prison. We performed two main models: 1) considering only the initial incarceration (Fig. S1) and 2) considering all the episodes of incarceration, which is the one ultimately presented in the main text (Table 1). The life table showing cumulative risk for TB notification among PDL by months periods, and the Hazard Function of cumulative risk for TB notification is showed in supplemental material (Fig. S4). Furthermore, we obtained the number of people living in each cell or pavilion from the prison census, and the area of each cell or pavilion from an architectural study of the prisons carried out in 2018.[11] Therefore, overcrowding was defined as a density measure based on the number of occupants in a prison pavilion or cell and its area in square meters, divided in three categories: level 1 = Low: >7 m^2 per person; level 2 = High: 3.5–7 m^2 per person and level 3 = Very High: <3.5 m^2 per person. Total time in prison

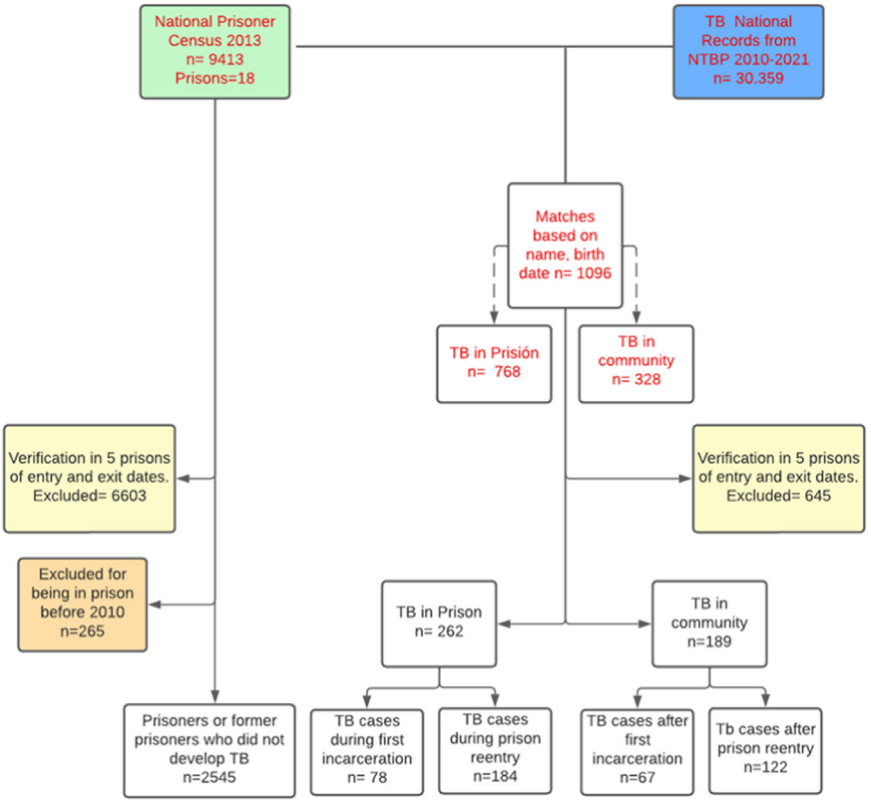

Fig. 1: **Flow diagram illustrating the process of linking databases and selecting individuals for survival analysis**. The 2013 National Census of Penitentiary Centers (green) was matched with the National Registry of TB Cases of the NTP, period 2010–2021 (blue). This analysis revealed 1096 cases of TB. PDL from prisons without documented records of entry and exit dates were subsequently excluded (yellow). These cases represent a total of 2996 PDL in five prisons. Out of these, 451 have developed TB and 2545 prisoners did not develop TB. PDL that had a prolonged duration of incarceration were excluded (orange).

is the sum of the time periods in all recorded admissions, is a calculated variable that we named duration of incarceration. Additionally, we compared the TB risk within prisons that house <200 prisoners (National Penitentiary Emboscada, Juan Antonio de la Vega Penitentiary and Esperanza Penitentiary) with larger prisons (Tacumbú and CDE), which host >1000 PDL.

Missing data was found in various behavioural variables of the census, but in all cases, it was less than 10% and its value has been inputted using a predictive mean matching algorithm that utilizes 3 nearest knots for continuous predictors (aregImpute function, Hmisc package in R). Overcrowding variable was the exception, as this analysis only considered data from the largest prisons and did not account for missing values in the other prisons.

Ethics statement

The study was approved by the ethics committee of the Central Laboratory of Public Health of the MoH of Paraguay (International Certification FWA N° FWAOOO20088) with code CEI-LCSP 91/010217. It was also authorised by the MoJ of Paraguay (reference number, MJ/GM/N°929/2021). Databases needed for matching were kept in password protected files. Once matching was completed, the resulting database was anonymised and data analysis conducted.

Role of the funding source

The funder had no role in data collection, analysis, interpretation, writing of the manuscript, or decision to submit the manuscript for publication.

Results

Sociodemographic characteristics of incarcerated individuals

In 2013, 9413 people were deprived of liberty in the Paraguayan penitentiary system, of which the five prisons included in this cohort study accounted for 2996 (31.8%) PDL. All were men and the mean age was 31.1 (SD 9.6) years. Of these, 417 (13.9%) were illiterate (four-fold more than the general population).[12] The most frequent crime reported was theft or

Variable	Categories	Total	TB	%	HR	95% CI, p-value
Age	More than 45	286	23	7.9	1	
	31–45	1070	131	12.2	1.59	(0.94–2.69, p = 0.086)
	18–30	1640	297	18.1	2.53	(1.51–4.23, p < 0.0001)
Illiterate	Yes	417	61	14.5	1	
	No	2579	390	15.1	1.11	(0.82–1.49, p = 0.50)
Worked	No	428	61	14.1	1	
	Yes	2568	390	15.2	1.12	(0.85–1.49, p = 0.41)
Wage	Minimun	717	105	14.6	1	
	More than Minimun	944	143	15.1	0.96	(0.73–1.27, p = 0.80)
	Less than Minimun	1335	203	15.2	1.00	(0.78–1.30, p = 0.97)
Addiction to substances	Yes	1203	169	14.1	1	
	No	1793	282	15.7	1.12	(0.91–1.38, p = 0.29)
Tobacco smoking	Yes	1410	199	14.1	1	
	No	1586	252	15.9	1.15	(0.94–1.41, p = 0.18)
Prision entries	1	1347	145	10.9	1	
	2	677	109	16.2	1.99	(1.52–2.61, p < 0.0001)
	3	405	79	19.4	2.58	(1.89–3.51, p < 0.0001)
	4 and more	567	118	20.6	3.36	(2.50–4.50, p < 0.0001)
Duration of incarceration	Less than 6 months	400	25	6.3	1	
	6–18 months	657	90	13.8	1.97	(1.26–3.08, p = 0.0034)
	19–36 months	503	100	19.9	2.81	(1.80–4.38, p < 0.0001)
	More than 36 months	1436	235	16.4	2.78	(1.82–4.24, p < 0.0001)
Prisons	Tacumbú	2209	345	15.6	1	
	Ciudad del Este	418	96	22.9	2.04	(1.50–2.76, p < 0.0001)
	Others[a]	369	10	2.7	–	
Crime	Others Crimes	274	26	9.6	1	
	Drug trafficking	372	43	11.7	1.42	(0.85–2.37, p = 0.19)
	Against persons	940	117	12.4	1.54	(0.98–2.41, p = 0.060)
	Against property	1410	265	18.8	1.87	(1.22–2.84, p = 0.0044)
Legal situation	Await sentencing	1940	275	14.2	–	
	Sentenced	1056	176	16.7	1.05	(0.84–1.31, p = 0.69)
Overcrowding[c]	Level 1	214	21	9.8	1	
	Level 2	367	41	11.2	1.48	(0.85–2.59, p = 0.18)
	Level 3	2046	379	18.5	2.06	(1.28–3.32, p = 0.0027)
	N/D[b]	369	10	2.7	–	

The variables used in this model were a-priori specified. [a]Other prisons: National Penitentiary Emboscada, Padre Juan Antonio de la Vega Penitentiary, and Esperanza Penitentiary. [b]Missing value from other prisons. [c]Overcrowding levels were defined as follows: 1 = Low:>7 m^2 per person; level 2 = High: 3.5–7 m^2 per person and level 3 = Very High: <3.5 m^2 per person.

Table 1: **Multivariable Cox regression of factors associated with developing TB among Paraguayan PDL included in the 2013 census of 5 selected prisons.**

robbery (47.1%; 1410/2996) and 51.3% (1539/2996) of PDL had a prior history of incarceration. Around two thirds of PDL (64.8%, 1940/2996) were pre-trial detainees who were awaiting their sentencing process in prison. All other individuals had a confirmed and definitive sentence.

TB hazard during and following incarceration

First, we matched the 2013 prison census with the 2010–2021 TB registry to identify TB cases among people incarcerated at the time of the census. During the 8 years following the census, 11.6% (1096/9413) developed TB. Of these, 70.1% (768/1096) were diagnosed with TB in prison and 29.9% (328/1096) were diagnosed in the community, according to the national TB registry.

To estimate the hazard of TB during and following incarceration, we focussed on five study prisons, for which we obtained information on timing of prison entry, release, and transfer. Within the 5 study prisons, the total follow-up time of the cohort was 15,341 person-years, with an overall median length of 8.2 years (IQR: 5.63–9.01). The median time of incarceration was 2.25 years (IQR: 0.75–4.58). Almost a third (31.1%); of the prison population is renewed each year. Once released from these prisons, the median out-of-prison cumulative follow-up was 4.30 years (IQR: 0.92–7.08). The overall notification rate was 2940 TB cases per 100,000

person-years. We observed that 15.1% (451/2996) developed TB during the total years of follow-up. Of these TB episodes, 58.1% (262/451) occurred while incarcerated and 29.7% (78/262) of them during the initial incarceration. Over two fifths (41.9%, 189/451) of the TB cases registered occurred outside the prison, with 35.4% (67/189) of them happening after their first incarceration.

The overall TB notification rate in prison increased with duration of incarceration, from 1335 per 100,000 person-years (95% CI: 1073–1664) in the first year to 8455 per 100,000 person-years (95% CI: 6651–10,752) after 8 years in prison. During the first incarceration, the notification rate in the first incarceration year was 549 per 100,000 person-years (95% CI: 351–865) and increased to 6459 per 100,000 person-years (95% CI: 4556–9160) after 8 years in prison. The TB notification rate among released PDL decreased immediately and steadily through time, from 1717 (95% CI: 1396–2115) in the first year to 593 per 100,000 person-years after (95% CI: 267–1326) 8 years of follow up. Among those who were incarcerated only once, the notification rate after release decreased immediately from 1196 (95% CI 848–1692) in the first year to 439 per 100,000 person-years (95% CI 153–1268) after 8 years of release (Fig. 2).

Factors associated with TB risk

The risk of TB during incarceration was greater among younger PDL, as those aged 18–30 years old had a higher risk of TB (HR: 2.53; 95% CI: 1.51–4.23, $p < 0.0001$) compared to incarcerated individuals older than 45 years. TB rate was also greater for subsequent incarcerations. Individuals in their second incarceration had almost a two-fold risk of TB (HR: 1.99 (95% CI: 1.52–2.61, $p < 0.0001$), as compared to those during their first incarceration. The risk increased with each new admission and reached a HR of 3.36 (95% CI: 2.50–4.50, $p < 0.0001$) after the fourth readmission, compared to the initial one (Table 1). However, the shape of the time course of risk during incarceration did not differ substantially when considering only the first incarceration. In this group, there was a 2.36 (95% CI: 0.89–6.31, $p = 0.086$) increased hazard for developing TB after 6 months of entry, reaching 4.55 (95% CI 1.82–11.35, $p < 0.0001$) after 36 months in prison (Fig. S1).

The two largest prisons reported 97.8% (441/451) of the TB cases in this study. Individuals incarcerated in the prison of CDE had the highest rate of TB–twice that of the Tacumbú prison (HR: 2.04; 95% CI: 1.50–2.76, $p < 0.0001$). Individuals charged with or convicted of property crimes, mainly due to theft and robbery, had a higher risk of TB (1.87, 95% CI 1.22–2.84, $p = 0.0044$) compared to drug trafficking or crimes against person. This was independent of the type of prison, but poorly associated with the time of the sentence. The rate of TB also increased with the density of cell. When compared to individuals residing in cells with >7 m^2 per person, those residing cells 3.5–7 m^2/person had a HR of 1.48 (95% CI 0.85–2.59, $p = 0.17$) and those with <3.5 m^2 per person had HR of 2.06 (95% CI 1.28–3.32, $p = 0.0027$). Fig. 3 illustrates how almost all of the TB prison population of the larger prisons (CDE and Tacumbú) were living in the overcrowding level 3 (87.0% and 81.5%, respectively).

Discussion

By linking Paraguay's prison census with the National TB registry, we report a previously undocumented burden of TB among currently and formerly incarcerated individuals. We found that a substantial proportion (15.1%) of those incarcerated or who had been recently incarcerated experienced TB. This study shows that the risk of TB in PDL remains elevated several years after incarceration. The TB rates among PDL seen in this study are amongst the highest for any at-risk population

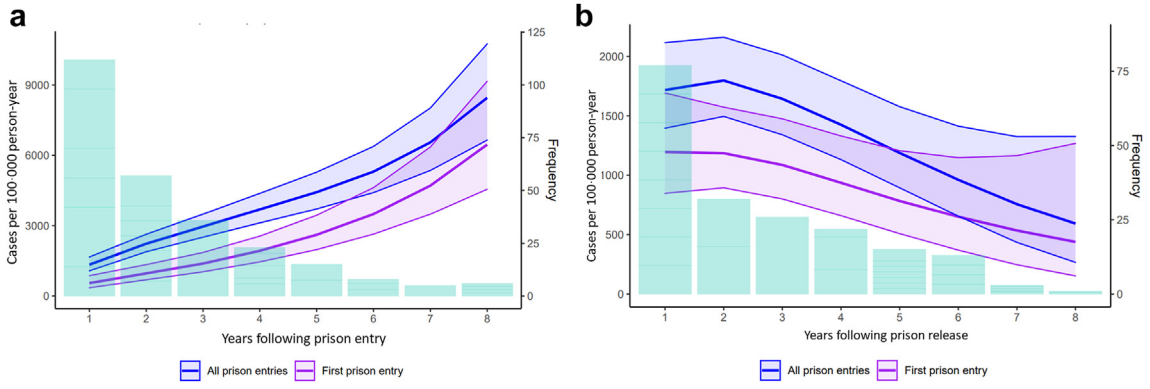

Fig. 2: **Modeled TB notification rate among a) PDL and b) people formerly deprived of liberty.** Blue lines indicate notification risk among all incarcerated individuals, purple lines indicate notification risk among individuals during their first incarceration. Blue bars indicate the number of notified TB cases by year.

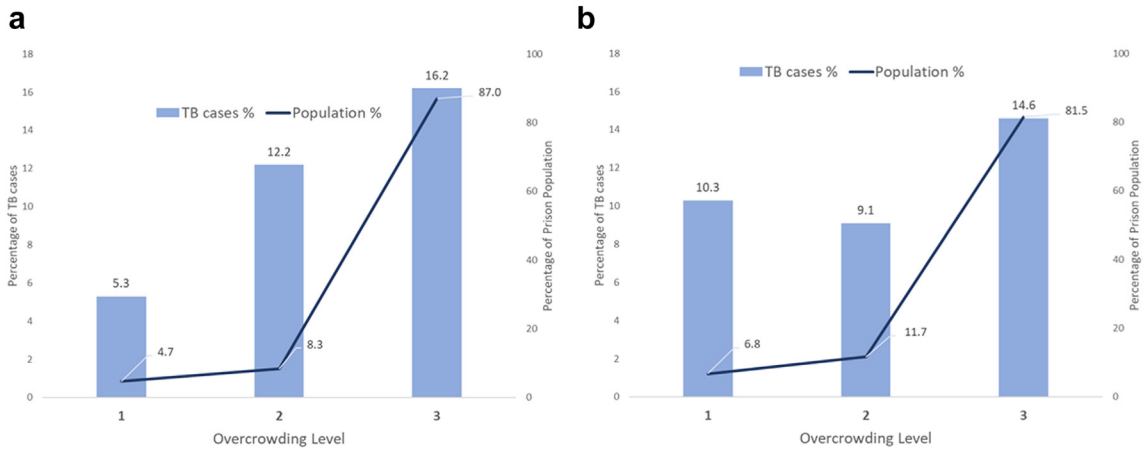

***Fig. 3*: Percentage of TB cases according to the level of overcrowding and the distribution of prison population inside the two largest prisons in the study: a) CDE prison and b) Tacumbú prison.** Bars correspond to the percentage of TB cases among PDL according to the rate of overcrowding of their cell rooms. Blue line corresponds to percentage of TB prison population in each level. A) Regional Prison of Ciudad del Este and b) National Penitentiary of Tacumbú. Overcrowding level are 1 = Low: >7 m^2 per prisoner; 2 = High: 3.5–7 m^2 per prisoner; 3 = Very High: <3.5 m^2 per person.

recorded. The detailed data on incarceration entries and exits provided us a unique opportunity to follow this population that is notoriously difficult to track after leaving prison. Our findings highlight a previously undocumented population health consequence of incarceration in Paraguay and underscores the urgency of new programs to protect the health of incarcerated and formerly incarcerated individuals.

In this study, we found that the risk of developing TB increases rapidly following prison admission; this risk was more than 100 times the TB risk in the community. The high TB rates found after eight years following incarceration indicate that when the conditions of incarceration remain unchanged (overcrowding, smoking, malnutrition, etc.) the risk of developing TB accumulates over time. This high risk can be attributable to the gradual progression of new TB infections acquired in prisons and/or of pre-existing infections. In both of these cases, risk is likely to be exacerbated by the presence of risk factors favouring TB progression. Similarly, when PDL are released, the risk of developing TB is much higher than in the general population at more than 30 times in the first two years after release. Although this risk decreases gradually, it remains 10 times higher than the risk of TB in the general population over 8 years of follow-up. This expected increase in the TB risk occurring while deprived of liberty and the decrease in risk after release confirms that prisons are environments which contribute to the propagation of TB. In this context, well known individual determinants of TB, such as smoking, drug abuse or poverty, are insignificant factors in enhancing the TB risk in the already high-risk, high transmission environment of prisons. The poor conditions of Paraguayan prisons, mostly driven by overcrowding, poor ventilation, limited access to healthcare and high exposure periods, may overshadow the progress that may be made in TB control in the community.[7,13]

The elevated risk of TB that is associated with incarceration also undermines TB control more broadly, as individuals infected with *M. tuberculosis* within prisons may transmit the bacteria beyond prison walls. We have found genomic evidence that *M. tuberculosis* genomic clusters span prisons and into the general population in Paraguay's major urban centres, indicating close transmission linkages between prisons and the community, with similar evidence of infection spillover in Central West Brazil[14,15]

Environmental and structural changes in these institutions may have a considerable impact on TB control. However, reducing overcrowding will not be sufficient to substantially reduce the TB burden in Paraguay's prisons (in the least crowded prison cells, 5.3–10.3% of individuals developed TB). Our findings are in line with those from Brazil, where the risk factors associated with prison environments, increase TB incidence more than the risk factors associated with the individual factors of this high risk population. Thus, targeted structural interventions within prisons could have a substantial effect on the broader TB epidemic. More importantly, reducing our reliance on incarceration and significantly reducing prison populations will decrease the population put at increased risk of TB.[16]

Although the overall incidence rate of TB in prisons is not dramatically increasing, the recent upward trends in general rates of incarceration will result in a considerable number of TB cases in prisons that would otherwise not exist. This observation correlates with the

increase in overall TB incidence rate reported for Paraguay. The proportion of PDL with a definitive sentence for a crime was only 26.2% at the time of the census, the remaining ones were pre-trial detainees, awaiting the judicial process for a trial. In Latin America, Paraguay has one of the highest proportions of pre-trial detainees among all PDL.[14,17] Reforms in the penal system must include decarceration as well as expediting a definite sentence. Although this problem seems to be primarily judicial, the impact on the public health is considerable.

We found that almost a third (31.1%) of the population in prisons is renewed each year. This population cycles between prison and the general community leading to substantial transmission spillover. We found that 3/4 of TB cases among former PDL occurred in the first 3 years after being released, suggesting that screening at the time of prison exit (and periodically after that) may be efficient targeted interventions.[16,18] When former PDL are reintegrated within a community with lower TB risk, exit screening may improve the identification of TB cases to allow for preventive interventions among persons at high-risk of subsequently developing TB, and thus reducing the spread of the disease. Furthermore, due to the high risk of TB among former PDL, primary care screening algorithms may consider persons with a recent history of incarceration.

We found that re-admission into prison is related to the type of crime (robbery/theft) with a short sentence (less than 3 years on average) that mostly occurs to younger prisoners. This is the most frequent profile of PDL readmitted into prison. A key question is whether the TB risk in this population is higher in the community before first entering prison. This could be done by comparing pre-existing high-risk attributes – such as poverty, illiteracy, drug abuse, HIV and others–among persons first entering prison and persons that have not been incarcerated. The evident increase in TB risk occurs upon incarceration. This phenomenon has already been described before for several contagious diseases.[16,19,20]

In Latin America the collaboration between authorities that are responsible for public health and those that govern prisons is insufficient. This is also why it is hard to find documented evidence of TB history or incarceration history among TB cases that occur in the community, which makes this analysis unique in the region.[16] Renewed joint efforts between these two sectors are needed to improve overall TB control, but particularly to address TB in prisons.

Our study has some limitations. First, utilizing cross-sectional data has certain limitations. The sociodemographic characteristics of the PDL were collected through census questionnaires and might not be accurately captured by the discrimination and stigma that the PDL population is subjected to. Second, our study cohort includes five of the 18 prisons in the Paraguayan penal system, including two of the largest prisons with the highest TB rates in the country. Larger prisons hold more prisoners with higher overcrowding, and these large-prisons were overrepresented in this study. Additionally, if any of the prisoners included in this study had readmissions to prisons other than those selected, this event could not be recorded for analysis, potentially underestimating the total time a PDL was in prison. Third, the TB episodes are based on TB notification from the NTP, and it is well known that the surveillance system misses a proportion of the real TB cases. Thus, although this study finds very high TB rates, the real prison attributable rate may be even higher. Lastly, deaths from non-TB related causes that occurred after release could not be registered, leading to an overestimation of the total follow up time and an underestimation of the TB burden in this subset of individuals.

Our data show that prisons are a high risk setting for the development of TB, and that the risk continues after release. There is a critical need to develop new TB control strategies to achieve the WHO global targets for 2035 and we believe that implementing and strengthening TB control interventions in prisons cannot be neglected to achieve these goals. Specific interventions within prisons are likely to have a valuable impact on reducing the tuberculosis epidemic. However, these interventions should not solely focus on biomedical approaches such as active diagnosis, mass screening, and secondary IPT.[16,18] In addition, it is important to consider architectural reforms aimed at improving the living conditions within penitentiary centres and legal reforms including decarceration, reducing reliance on incarceration, and preventing the imprisonment of individuals who have not been sentenced. These measures should be implemented with a strong focus on upholding human rights principles.[21]

Contributors

GS and AGB conceived the study and contributed to interpretation of the results. GS did statistical analyses and drafted the first manuscript. GES, SA, CP, LM, JRA, KSW, JC, AGB, and GS contributed to critical revision of the manuscript. GS attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. GS and AGB have accessed and verified the underlying data. All authors had access to the data and accepted responsibility for the decision to submit for publication.

Data sharing statement

Certain restrictions apply regarding the accessibility of these data. As such, the data are not publicly available. However, data may be obtained by reasonable request to the corresponding author, subject to institutional permission.

Declaration of interests

All authors report no potential conflicts.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lana.2023.100668.

References

1 Walter KS, Martinez L, Arakaki-Sanchez D, et al. The escalating tuberculosis crisis in central and South American prisons. *Lancet*. 2021;397(10284):1591–1596.
2 Cords O, Martinez L, Warren JL, et al. Incidence and prevalence of tuberculosis in incarcerated populations: a systematic review and meta-analysis. *Lancet Public Health*. 2021;6(5):e300–e308.
3 Baussano I, Williams BG, Nunn P, Beggiato M, Fedeli U, Scano F. Tuberculosis incidence in prisons: a systematic review. *PLoS Med*. 2010;7(12):e1000381.
4 Sacchi FPC, Praca RM, Tatara MB, et al. Prisons as reservoir for community transmission of tuberculosis, Brazil. *Emerg Infect Dis*. 2015;21(3):452–455.
5 Warren JL, Grandjean L, Moore DAJ, et al. Investigating spillover of multidrug-resistant tuberculosis from a prison: a spatial and molecular epidemiological analysis. *BMC Med*. 2018;16(1):122.
6 World Health Organization. *Global tuberculosis report*. 2021.
7 Sequera VG, Aguirre S, Estigarribia G, et al. Increased incarceration rates drive growing tuberculosis burden in prisons and jeopardize overall tuberculosis control in Paraguay. *Sci Rep*. 2020;10(1):21247.
8 Basu S, Stuckler D, McKee M. Addressing institutional amplifiers in the dynamics and control of tuberculosis epidemics. *Am J Trop Med Hyg*. 2011;84(1):30–37.
9 Binswanger IA, Stern MF, Deyo RA, et al. Release from prison — a high risk of death for former inmates. *N Engl J Med*. 2007;356(2):157–165.
10 Therneau TM, Lumley T, Atkinson E, Crowson C. *Survival analysis*; 2022. https://cran.r-project.org/web/packages/survival/survival.pdf.
11 Mecanismo Nacional de Prevención de la Tortura. Pabellón la bronca. In: MNP & FADA, ed. *Índice de ocupación de instituciones de privación de libertad de la República del Paraguay*. Asunción: goiriz imagen y cia. S.A; 2018:31–80. http://www.mnp.gov.py/index.php/repository/informes-de-monitoreo-y-seguimiento/albergue-sanitario/func-startdown/192/. Accessed December 24, 2023.
12 UNESCO Institute for Statistics (UIS), UIS.Stat Bulk Data Download Service. Literacy rate, adult total (% of people ages 15 and above) - Paraguay. https://data.worldbank.org/indicator/SE.ADT.LITR.ZS?locations=PY; 2020. Accessed October 24, 2022.
13 Reyes H, Coninx R. Pitfalls of tuberculosis programmes in prisons. *BMJ*. 1997;315(7120):1447–1450.
14 Sanabria GE, Sequera G, Aguirre S, et al. Phylogeography and transmission of Mycobacterium tuberculosis spanning prisons and surrounding communities in Paraguay. *Nat Commun*. 2023;14(1):303.
15 Walter KS, Pereira dos Santos PC, Gonçalves TO, et al. The role of prisons in disseminating tuberculosis in Brazil: a genomic epidemiology study. *Lancet Reg Health Am*. 2022;9:100186.
16 Mabud TS, de Lourdes Delgado Alves M, Ko AI, et al. Evaluating strategies for control of tuberculosis in prisons and prevention of spillover into communities: an observational and modeling study from Brazil. *PLoS Med*. 2019;16(1):e1002737.
17 Institute for Crime & Justice Policy Research. World prison brief report. Available from: https://www.prisonstudies.org/country/paraguay; 2022.
18 Paião DSG, Lemos EF, da Silva Santos Carbone A, et al. Impact of mass-screening on tuberculosis incidence in a prospective cohort of Brazilian prisoners. *BMC Infect Dis*. 2016;16(1):533.
19 Reinhart E, Chen DL. Incarceration and its disseminations: COVID-19 pandemic lessons from Chicago's cook county jail. *Health Aff*. 2020;39(8):1412–1418.
20 Reinhart E, Chen DL. Carceral-community epidemiology, structural racism, and COVID-19 disparities. *Proc Natl Acad Sci U S A*. 2021;118(21):e2026577118.
21 Sequera G, Estigarribia G, Walter KS, Lopez R, Andrews J, Croda J. Tuberculosis in prisons: a growing global health concern. In: *The challenge of tuberculosis in the 21st century*. Sheffield, United Kingdom: European Respiratory Society; 2023:251–266.