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Decrease in the incidence of culture-positive meningitis and cerebral tuberculomas in France from 1990 to 2007

T. V. BUI[1], V. MEYSSONNIER[1], P. Y. BOELLE[2], D. CHE[3], D. ANTOINE[3], V. JARLIER[1,4] AND J. ROBERT[1,4]*

[1] *EA 1541/ER5, Faculté de Médecine Pierre et Marie Curie-Paris 6, Site Pitié, UPMC, Paris, France*
[2] *UMR S 707, Faculté de Médecine Pierre et Marie Curie-Paris 6, UPMC, Paris, France*
[3] *Département des Maladies Infectieuses, Institut de Veille Sanitaire (InVS), Saint-Maurice, France*
[4] *Centre National de Référence des Mycobactéries et de la Résistance des Mycobactéries aux Antituberculeux (CNR-MyRMA), Hôpitaux Universitaires Pitié Salpêtrière-Charles Foix, AP-HP, Paris, France*

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SUMMARY

We evaluated the incidence rate of culture-positive central nervous system tuberculosis (CNS TB) in France in 2007 and its time trend between 1990 and 2007. We used a capture–recapture analysis by using data recorded in 2007 by the mandatory notification system and the national network of the National Reference Centre (NRC). The 2007 sensitivity of the NRC was 79·4%. The previous sensitivity for 2000 (75·6%) and that for 2007 yielded a pooled estimate of 77·4% (95% confidence interval 64·8–88·0), which was used to extrapolate the number of culture-positive CNS TB cases from those reported in four surveys (1990, 1995, 2000, 2007). The extrapolated number of culture-positive CNS TB cases fell from 90 to 35 between 1990 and 2007, and the extrapolated incidence rates fell from 1·6 to 0·55 cases/million ($P<0·001$). This favourable trend should be closely monitored following the change of the BCG vaccination policy in 2007.

Key words: Capture–recapture analysis, meningitis, *Mycobacterium tuberculosis*, trend, tuberculomas, tuberculous meningitis.

INTRODUCTION

Tuberculous involvement of the central nervous system (CNS), including meningitis (TBM) and cerebral tuberculomas (CTB), remains a serious health threat despite the availability of drugs effective against *Mycobacterium tuberculosis*. It is still the most severe form of the tuberculosis (TB) disease [1, 2]. Its incidence has increased in recent years in England and Wales and the USA and HIV co-infection has been identified as a major risk factor [3–5]. Confirming the clinical and biological suspicion of CNS TB has always been problematic. Indeed, definite diagnosis requires detection of tubercle bacilli in cerebrospinal fluid (CSF). Of cases suspected of TBM, the CSF is smear-positive in only 5–20%, and culture-positive in ~40% of cases [2, 6, 7]. Regarding CTB, smear-positive CSF is less common than in TBM but cerebral biopsy is of great interest for the diagnosis [8]. Therefore, the diagnosis of TBM or CTB is often only presumptive, and is based on a combination of clinical features, CSF findings, imaging findings, response to anti-tuberculous drug therapy, and sometimes isolation of *M. tuberculosis* in another clinical site [2].

* Author for correspondence: Dr J. Robert, Laboratoire de Bactériologie-Hygiène, Faculté de Médecine Pierre et Marie Curie (UPMC Paris 6), 91 Boulevard de l'hôpital, 75634 Paris Cedex 13, France.
(Email: jerome.robert@psl.aphp.fr)

France has a low incidence of TB (8·9/100 000 in 2007) [9], and the proportion of HIV co-infection in all TB cases has been stable at ~10% for more than 15 years [10]. The bacille Calmette Guérin (BCG) vaccination policy was modified in 2007, from systematic vaccination shortly after birth to vaccination of selected populations considered at risk. Because this change in vaccination policy may have an impact on the incidence of CNS TB, especially in childhood, it is of paramount importance to closely monitor its time trend before and after the policy change. Such surveillance is made complex because it is considered that more than half of TBM cases are culture negative, and therefore definite diagnosis is impossible in these cases [6]. In addition, the low number of cases combined with incompleteness of reporting to health authorities, and missing data regarding microscopy and culture results [9] underline the weaknesses of passive surveillance systems and may overlook small increases in incidence.

Therefore, we conducted a retrospective study to assess the epidemiological situation of TBM and CTB in France in 2007, the year of the change in BCG vaccination policy. We focused only on definite cases, i.e. culture-positive cases. We did not include culture-negative CNS TB because its definition may vary by centre or with time. Our objectives were (i) to estimate the incidence and to describe demographic, BCG history and other characteristics of culture-positive CNS TB in 2007, (ii) to assess the completeness of the surveillance system, and (iii) to evaluate the time trend in culture-positive CNS TB before the change in vaccination policy by using results of the present survey and of surveys conducted since 1990. The results will serve as a starting point to evaluate the new BCG vaccination policy.

MATERIAL AND METHODS

Case ascertainment

A case was defined as a patient residing in France from whom a CSF sample taken between 1 January 2007 and 31 December 2007 was found to be culture-positive with *M. tuberculosis* complex. In addition, we recorded all cases with a brain biopsy sample yielding *M. tuberculosis* complex by culture to ensure we captured all CNS TB cases.

Data sources

In France, TB surveillance is performed by two different systems. The first is based on the mandatory notification of TB (MNTB) coordinated by the National Institute of Health [Institut de Veille Sanitaire (InVS)]. Each patient with confirmed TB, i.e. culture-positive, or with suspected TB, i.e. culture-negative, and treated with at least two anti-TB drugs for at least 1 month have to be reported to county health authorities.

The second system is based on a national network of all laboratories performing the culture of *M. tuberculosis*, and is coordinated by the National Reference Centre (NRC) for Mycobacteria and Resistance of Mycobacteria to Anti-tuberculosis Drugs [11]. Regular surveys (1990, 1995, 2000, 2007) aimed at the surveillance of CNS TB are regularly performed and for each culture-positive case, laboratories have to complete a standardized questionnaire including age, sex, country of birth, BCG vaccination status, HIV status, clinical features, CSF, cerebral biopsy, imaging findings, and outcome [12–14].

Capture–recapture (CR) analysis

The CR method was applied only to culture-positives cases of CNS TB reported in 2007 by cross-tabulation of data from the two sources (MNTB, NRC) in order to determine common cases (i.e. cases reported to both sources, n_{11}), and cases reported to only the first (MNTB, n_{12}) or only to the second (NRC, n_{21}) source. The number of unreported cases, i.e. cases unknown by the two sources (missing cases, n_{22}) was estimated by using the nearly unbiased formula $(n_{12} \times n_{21})/(n_{11}+1)$ [15]. The estimated total number of cases $(n_{11}+n_{12}+n_{21}+n_{22})$ was used to estimate the completeness (sensitivity) of both systems. The latter was computed as follows: (number of cases reported to the source × 100)/(estimated total number of cases), which is derived from CR analysis. In order to evaluate the dependence of the sources, we calculated the relative odds ratio (OR) that, if a case is reported in one source it is also reported to the other: $\mathrm{OR} = (n_{11} \times n_{22})/(n_{12} \times n_{21})$ [16, 17].

Because both sources record anonymized data, we had to return to the original patients' data files to enable cross-recognition of each case. Consent was obtained from the National Commission for Information Technology and Civil Liberties in 2010.

Trend analysis

The NRC performed three other surveys on culture-positive TBM in 1990, 1995, and 2000 by using the

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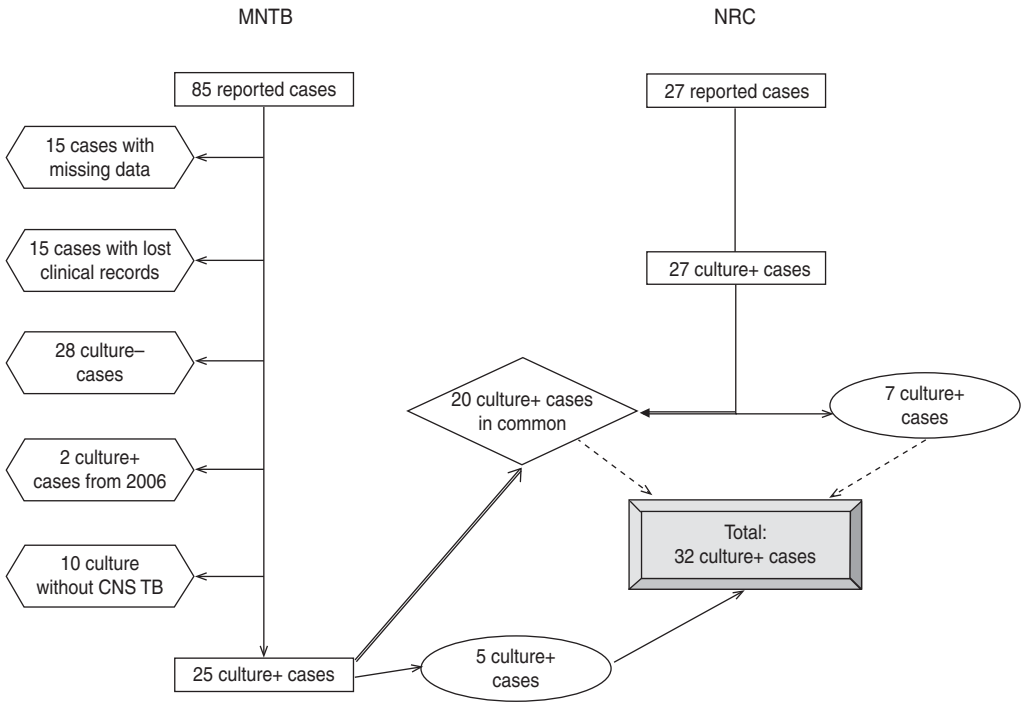

Fig. 1. Flow chart of the cases of central nervous system tuberculosis reported to the National Institute of Health through the mandatory notification system (MNTB) or to the National Reference Center (NRC). Culture+, culture positive; culture–, culture negative.

same network of laboratories and the same methodology. The results of these surveys have been published elsewhere [12–14]. The CR analysis performed on cases reported in the 2000 survey found a sensitivity of 75·6% (95% CI 68·9–81·6) for the NRC. We derived a pooled (average) sensitivity estimate for the NRC from the 2000 and 2007 CR analyses using the DerSimonian–Laird random-effect method, and the Freeman–Tukey-type arcsine square-root transformation to stabilize variance [18, 19]. The pooled sensitivity was applied thereafter to the results reported by the NRC network in the four surveys, making the assumption that sensitivity remained stable over the entire study period. Finally, Poisson regression of incidence *vs.* time was applied to the raw NRC data to test for a linear time trend.

Statistical analysis was performed by using EpiData (www.epidata.dk) and the R META package [20]. Incidence rates were calculated by using population estimates from the French National Census for the corresponding years (wdelword_www.insee.fr).

RESULTS

In 2007, 85 cases of CNS TB were notified to the MNTB system. Of these, 60 were finally excluded because of missing data in the mandatory notification system preventing any file analysis ($n=15$), lost clinical and bacteriological records ($n=5$), culture-negative CSF ($n=28$), CSF samples drawn in 2006 ($n=2$), and finally lack of CNS TB ($n=10$), including six TB cases without CNS involvement, and four meningitis unrelated to TB.

The NRC laboratory network recorded 27 culture-positive cases of CNS TB in 2007. After case identification, 20 cases common to both systems were identified, five were reported only to the MNTB system and were unknown by the NRC network, and seven cases were registered only with the NRC and not the MNTB system. Finally, a total of 32 culture-positive cases of CNS TB were identified in 2007 (Fig 1).

Characteristics of CNS TB cases

A majority (37·5%) of the 32 identified patients were aged $\geqslant 60$ years, four (12·5%) were aged <20 years, including only one of $\leqslant 5$ years. Fifteen patients (46·9%) were male, and three (9·4%) were HIV positive (Table 1). Of all patients, 16 (50·0%) were French-born, and 15 (46·9%) foreign-born (Table 1). The place of birth of the latter patients is unknown. Foreign-born

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Table 1. *Characteristics of the 32 culture-positive cases of central nervous system TB reported in France in 2007 to the mandatory notification system or to the National Reference Centre*

Characteristic	*n* (%)
Sex	
Female	17 (53·1)
Male	15 (46·9)
Age (years)	
Median	48·5
<20	4 (12·5)
20–39	10 (31·3)
40–59	6 (18·8)
⩾60	12 (37·5)
Country of birth	
France	16 (50·0)
Europe	1 (3·1)
North Africa	4 (12·5)
Other Africa	8 (25·0)
Asia	2 (6·3)
Unknown	1 (3·1)
HIV status	
Positive	3 (9·4)
Negative	28 (87·5)
Unknown	1 (3·1)
Cerebral localization of TB	
Cerebrospinal fluid	29 (90·6)
Tuberculoma	3 (9·4)
Extraneural TB site	
No	8 (25·0)
Yes	21 (65·6)
Unknown	3 (9·4)
Extra-cerebral TB manifestations ($n=21$)	
Pulmonary	13 (61·9)
Extra-pulmonary	3 (14·3)
Both	2 (9·5)
Disseminated	3 (14·3)
Outcome	
Full recovery	10 (31·3)
Sequelae	9 (28·1)
Death	12 (37·5)
Unknown	1 (3·1)

TB, Tuberculosis.

patients were younger than French-born patients (41 years *vs.* 52 years, $P=0·05$). A total of 29 patients (90·6%) had meningitis with culture-positive CSF, and three had intracranial tuberculoma diagnosed by cerebral biopsy. Of all patients, 21 (65·6%) had extra-cerebral manifestations of TB disease, including 13 with pulmonary TB, and three with disseminated TB. Overall, 12 patients (37·5%) died, including eight that were aged ⩾60 years, 10 (31·3%) recovered without sequelae, nine (28·1%) had neurological sequelae, and the outcome was unknown for the last patient.

CNS TB incidence and sensitivity of the two systems in 2007

When combining the 32 culture-positive CNS TB cases registered by both systems, the 2007 incidence was 0·50/million inhabitants (95% CI 0·38–0·62). By using the CR method, it was calculated that two cases had not been reported to either of the two systems:

$$\frac{\binom{\text{7 cases known}}{\text{only by NRC}} \times \binom{\text{5 cases known}}{\text{only by MNTB}}}{\text{20 cases known by both systems} + 1} = 1.7 \text{ cases.}$$

Thus, the total estimated number of culture-positive cases was 34 (32 reported + 2 unknown). Hence, the incidence of culture-positive CNS TB corrected for the two missing cases was 0·53/million (95% CI 0·41–0·65). The sensitivity (exhaustivity) was 73·5% (95% CI 56·9–86·3) for the MNTB system, 79·4% (95% CI 63·5–90·5) for the NRC system, and 94·1% (95% CI 81·9–99·0) for both systems combined (Table 2).

The relative odds ratio of being in one source if reported to the other source was $(20\times2)/(5\times7)=1·14$, showing a moderate positive dependence [16, 17].

Seventeen-year trend in CNS TB in France

Numbers and incidence rates of culture-positive CNS TB reported in France to the NRC according to the year of the survey are given in Table 2 [12–14]. There was a clear decrease in the number (from 70 to 27 cases) and in the incidence rates (1·2 to 0·43 cases/million) reported to the NRC ($P<0·001$). However, the proportion of reported CNS TB, which decreased slightly from 1995 to 2000 (0·67% to 0·56%), remained stable in 2007 (0·56%).

The pooled estimate of the sensitivity of the NRC network derived from the 2000 (sensitivity, 75·6%) and 2007 (sensitivity, 79·4%) CR analysis was 77·4% (95% CI 64·8–88·0). This pooled sensitivity, estimating the average underreporting, was used to correct the number of cases reported in each survey (number reported/pooled sensitivity). Consequently, incidence rates of CNS TB were 'corrected' for underreporting (Table 2). There was a 62% decrease in the number of corrected CNS TB cases from 1990 to 2007 (from 90 cases to 35 cases, respectively) and the corrected

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Table 2. *Number and incidence rates of culture-positive central nervous system tuberculosis (CNS TB) reported to the National Reference Centre and estimated after capture–recapture analysis in France according to years of survey*

Culture-positive TB	1990	1995	2000	2007
Total number reported (all sites)	n.d.	7119	5569	4802
Reported CNS TB (reference)	[13]	[14]	[12]	This study
Number	70	48	31	27
Proportion (% total cases)	–	0·67%	0·56%	0·56%
Incidence (per million) (95% CI)	1·2 (0·95–1·52)	0·81 (0·70–0·90)	0·52 (0·39–0·64)	0·43 (0·31–0·55)
Estimated CNS TB*				
Number (95% CI)	90 (80–108)	62 (55–74)	40 (35–48)	35 (31–42)
Incidence (per million) (95% CI)	1·6 (1·37–1·86)	1·0 (0·93–1·25)	0·67 (0·58–0·79)	0·55 (0·49–0·66)

CI, Confidence interval; n.d., no data.
* Pooled sensitivity of the National Reference Center: 0·774 (95% CI 0·6484–0·8801).

incidence rates fell from 1·6 to 0·55 cases/million inhabitants during the same period.

DISCUSSION

CNS TB, including meningitis is the least frequent but the most severe form of TB. We showed that in France in 2007, CNS TB represented <1% of all culture-positive TB cases and that its incidence was around 0·50/million inhabitants (Table 2). The reported number of TBM in children aged ⩽5 years is very low (only one case in 2007). We showed that CNS TB remains an unreported disease in almost a quarter of cases. By combining the results of two CR surveys, we were able to correct for underreporting and therefore to model the downward trend in CNS TB from 1990 to 2007, the year of the change in BCG vaccination policy.

Only one patient aged ⩽5 years was reported in the present 2007 study, a figure identical to the 2000 report, and lower than in 1995, where two cases were reported [12, 14]. Consequently, the incidence of culture-positive CNS TB in this population was around 1 case/60 million general population in 2000 and 2007. This result definitely puts France in the low-incidence category of countries that fulfil the requirements of IUATLD for discontinuation BCG vaccination, i.e. <1 case/10 million general population over the previous 5 years [21]. In addition, we showed that, overall, there was a major decrease in CNS TB in France during the study period. Indeed, we estimated the decrease to be 62% over 17 years. This decrease parallels the incidence rates of total TB cases reported to the MNTB between 1993 and 2007 [9]. Of note, the proportion of culture-positive CNS TB in all culture-positive TB cases did not vary significantly in the last three surveys. This suggests that the decrease in CNS TB incidence is likely to be related to the overall decrease of TB in France. Of interest, such a decrease was not observed in the UK or the USA, the latter even noticing an increase in extrapulmonary TB, including TBM [4, 5], highlighting differences in the epidemiology of TB in countries with established market economies.

In France, the favorable epidemiology of TB led to the change of policy regarding BCG vaccination in 2007. The policy is now to replace systematic vaccination of all children by vaccination of targeted 'at-risk' populations. Close monitoring of CNS TB will be necessary to evaluate the impact of the new policy, and our study aimed to be a starting point for the surveillance of culture-positive CNS TB. However, the system to be used in the years following the new policy should focus on children aged ⩽5 years and has to be sensitive because of the extreme rarity of CNS TB in children and the difficulty of an accurate and definite diagnosis of CNS TB in this population [2, 6, 7]. Consequently, it will be necessary to establish a sensitive surveillance system over many consecutive years before drawing any conclusions. In addition, the system will have to address culture-positive and culture-negative TBM, in order to delineate the upper and the lower bounds of incidence. In the present study as in the 2000 survey, there were no children in the culture-negative cases reported to the MNTB ([12], data not shown). Information was lacking in the other two surveys preventing any trend assessment.

The two systems implemented for the surveillance of TB in France display sensitivities just <80%.

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The use of CR analysis allowed us to correct for underreporting and resulted in a sensitivity of 94·1% when both systems are combined. Such a combined sensitivity was estimated to be 92·7% in 2000 [12]. We used the results of these two CR analyses to estimate a pooled (mean) sensitivity over the years. This approach allowed us to model more accurately the decrease in CNS TB in France. Surveys with CR analyses performed on a regular basis may be a tool to closely monitor changes over time and to evaluate the accuracy of surveillance systems over the years. To our knowledge, this method has seldom been applied [22]. However, the CR method is cumbersome and therefore difficult to implement every year.

There are three limitations that need to be acknowledged and addressed regarding the present study. First, as emphasized earlier, we focused only on culture-positive cases, i.e. definite cases. Therefore, even if a rare event, definite cases diagnosed at autopsy will be missed. In addition, the present study overlooked culture-negative, possible cases, which represent a large part of CNS TB [2, 6, 7]. Consequently, the real number of cases is likely to be higher than the one reported here. By contrast, the choice of focusing on definite cases has the advantage of dealing only with 'true' cases, which is of importance in CR methodology. Second, the use of CR analysis assumes that some prerequisites are met. The most important issue is that of dependence of the sources, i.e. the probability of being captured by one source depends on not being captured by the second source. When using only two sources, it is acknowledged that there is no simple way to evaluate dependency other than qualitatively [23]. In France, it is assumed that clinicians inform the MNTB when they diagnose or treat a case. On the contrary, the NRC survey relies exclusively on microbiologists who extract data on culture-positive cases once a year from their laboratory information system, regardless of the MNTB notification. In addition, the simple odds ratio method [16, 17] used found a moderate positive dependency. Therefore, we feel confident that the dependency of the two sources is low and slightly positive, hence slightly underestimating the total number of cases. Consequently, our result is likely to represent the lower boundary of the estimates. Finally, by using a similar pooled sensitivity for the four studies, we assumed that the NRC sensitivity remained stable over time, an assumption reinforced by the 2000 and 2007 surveys that found similar sensitivities. Nevertheless, it is likely that the sensitivity increased over time for both sources by outreach programmes performed for more than 10 years. Indeed, the first evaluation of the sensitivity of the MNTB system performed in 1992–1993, revealed a sensitivity of 48% (InVS, unpublished data), which is far lower than the sensitivities found in the 2000 and 2007 surveys. Consequently, it is likely that we underestimated the corrected number of CNS TB cases in the first study, and therefore underestimated the decrease in CNS TB over time.

In conclusion, we report a large decrease in the incidence rate of culture-positive CNS TB in France since 1990. This favourable trend was observed before the change of BCG vaccination policy, and reinforces the decision to stop universal BCG vaccination. However, the new policy warrants a close monitoring of CNS TB in the coming years, especially in the vulnerable populations that are targeted by the new vaccination policy. It will therefore be of interest to improve the sensitivity of the surveillance systems but also the diagnosis process of this challenging disease.

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DECLARATION OF INTEREST

None.

REFERENCES

1. **Farinha NJ, *et al.*** Tuberculosis of the central nervous system in children: a 20-year survey. *Journal of Infection* 2000; **41**: 61–68.
2. **Hosoğlu S, *et al.*** Tuberculous meningitis in adults: an eleven-year review. *International Journal of Tuberculosis and Lung Disease* 1998; **2**: 553–557.
3. **Berenguer,** *et al*. Tuberculous Meningitis in patients infected with the human immunodeficiency virus. *New England Journal of Medicine* 1992; **326**: 668–672.
4. **Kruijshaar ME, Abubakar I.** Increase in extrapulmonary tuberculosis in England and Wales 1999–2006. *Thorax* 2009; **64**: 1090–1095.
5. **Peto HM, *et al.*** Epidemiology of extrapulmonary tuberculosis in the United States, 1993–2006. *Clinical Infectious Diseases* 2009; **49**: 1350–1357.
6. **Bhigjee AI, *et al.*** Diagnosis of tuberculous meningitis: clinical and laboratory parameters. *International Journal of Infectious Diseases* 2007; **11**: 348–354.

7. **Kusum S, *et al.*** Multiplex PCR for rapid diagnosis of tuberculous meningitis. *Journal of Neurology* 2011; **258**: 1781–1787.
8. **Thwaites G, *et al.*** British Infection Society guidelines for the diagnosis and treatment of tuberculosis of the central nervous system in adults and children. *Journal of Infection* 2009; **59**: 167–187.
9. **Antoine D, Che D.** Tuberculosis cases reported in France in 2007 [in French]. *Bulletin épidémiologique hebdomadaire* 2009; **12–13**: 106–109.
10. **Khuê PM, *et al.*** A 10-year prospective surveillance of Mycobacterium tuberculosis drug resistance in France 1995–2004. *European Respiratory Journal* 2007; **30**: 937–944.
11. **Robert J, *et al.*** Multidrug-resistant tuberculosis: eight years of surveillance in France. *European Respiratory Journal* 2003; **22**: 833–837.
12. **Cailhol J, *et al.*** Incidence of tuberculous meningitis in France, 2000: a capture-recapture analysis. *International Journal of Tuberculosis and Lung Disease* 2005; **9**: 803–808.
13. **Schwoebel V, Hubert B, Grosset J.** Tuberculous meningitis in France in 1990: characteristics and impact of BCG vaccination. *Tubercle and Lung Disease* 1994; **75**: 44–48.
14. **Truffot-Pernot C, *et al.*** A survey on tuberculous meningitis in France in 1995 [in French]. *Bulletin épidémiologique hebdomadaire* 1998; **12**: 49–50.
15. **Hook EB, Regal RR.** Capture-recapture methods in epidemiology: methods and limitations. *Epidemiologic Reviews* 1995; **17**: 243–264.
16. **Hook EB, Regal RR.** The value of capture-recapture methods even for apparent exhaustive surveys. The need for adjustment for source of ascertainment intersection in attempted complete prevalence studies. *American Journal of Epidemiology* 1992; **135**: 1060–1067.
17. **Brittain S, Böhning D.** Estimators in capture–recapture studies with two sources. *Advances in Statistical Analysis* 2008; **93**: 23–47.
18. **Freeman MF, Tukey JW.** Transformations related to the angular and the square root. *Annals of Mathematical Statistics* 1950; **21**: 607–611.
19. **Fleiss JL.** The statistical basis of meta-analysis. *Statistical Methods in Medical Research* 1993; **2**: 121–145.
20. **R Development Core Team.** R META package (http://cran.r-project.org). Accessed 31 may 2013.
21. **Anon.** Criteria for discontinuation of vaccination programmes using Bacille Calmette-Guerin (BCG) in countries with a low prevalence of tuberculosis. A statement of the International Union Against Tuberculosis and Lung Disease. *International Journal of Tuberculosis and Lung Disease* 1994; **75**: 179–180.
22. **Nardone A, *et al.*** Repeat capture-recapture studies as part of the evaluation of the surveillance of Legionnaires' disease in France. *Epidemiology and Infection* 2003; **131**: 647–654.
23. **Gallay A, *et al.*** The capture–recapture methods applied to epidemiology: principles, limitations, and applications [in French]. *Revue d'épidémiologie et de santé publique* 2002; **50**: 219–232.