

The effects of the scheme for BCG vaccination of schoolchildren in England and Wales and the consequences of discontinuing the scheme at various dates

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ABSTRACT The aims of this paper were to estimate the numbers of tuberculosis notifications in young white adults which will be prevented in the next 25 years by the schools BCG vaccination scheme, and to assess the numbers of additional notifications if the scheme were to be discontinued. Assuming that in the white ethnic group in England and Wales the decline in tuberculosis notification rates (8–10% per year for ages less than 45 years) and efficacy of BCG vaccination (75–80%) are maintained, it is estimated that the scheme for BCG vaccination of schoolchildren with its present coverage will prevent 217 notifications in those aged 15–29 years in 1993, 119 in 1998, and 69 in 2003. The epidemiological consequences of stopping the BCG in schools scheme, whenever this occurs, would be a substantial slowing of the rate of decline of tuberculosis notifications, confined almost entirely to the 15–29 years age group, for a period of about 15 years, after which the steeper decline would resume. If the scheme stopped at the end of 1991 the annual number of additional notifications would slowly increase to a maximum of just over 80 about 15 years later, and then decrease. For stopping at the end of 1996 the maximum annual number of additional notifications would be about 50.

The Medical Research Council (MRC) trial of tuberculosis vaccines, which began in 1950, showed that BCG vaccine, given at age 14 years in England and Wales, was highly effective in preventing tuberculosis for a period of at least 15 years.^{1,2} A national scheme for BCG vaccination in schools at about age 13 years was introduced in 1953. The scheme developed slowly, but by 1962 about 60 per cent of each cohort aged 13 years received the vaccine. This percentage rose to about 70 per cent by 1970, and has remained at about 75 per cent since 1977.³

The preventive benefits of this scheme have undoubtedly been considerable, though they have never been formally evaluated. However, soon after the scheme was introduced the first evidence appeared of the much steeper decreases in tuberculous infection and tuberculosis incidence which have taken place since about 1950.⁴ The absolute benefit from the scheme, in terms of the numbers of cases of tuberculosis prevented, will have risen during the first 10–15 years as the vaccination of successive annual cohorts aged 13 years gradually extended protection throughout the 15–29 year age group. But since then, the absolute benefit to this age group will have decreased steeply, in parallel with the declining incidence of the disease.

In a succession of monitoring studies, the efficacy of BCG vaccine in routine use in Britain has been examined in relation to technical changes in the vaccine^{5,6} and the decreasing risk of exposure to the disease.^{7–9} In another series of studies, the incidence of tuberculosis has been examined according to place of birth^{10–12} and ethnic group,¹³ and the secular trends in tuberculosis incidence in the white and other ethnic communities in England and Wales have also been investigated.^{14–16} The information from the two most recent of these studies^{9,16} allows the present position to be assessed, and forward projections to be made, with reasonable confidence.

The aims of the present paper are as follows: (1) to estimate the numbers of notifications of tuberculosis in young white adults aged 15–29 years that are now prevented, and will be prevented annually during the next 25 years in England and Wales, assuming the continuation of the BCG in schools scheme at its present level; (2) to assess the numbers of additional notifications that would be expected among young white adults each year, if the scheme were to be discontinued at certain specified dates.

The present and future usefulness of the scheme as a tuberculosis control measure in schoolchildren in England and Wales, taking into account the financial

implications of the scheme as well as the availability and efficacy of other methods of controlling the disease, will be considered in the light of these estimates in a separate report (in preparation).

These estimates are intentionally being made in relation to the white population only. The scheme for BCG vaccination at about age 13 years, when it was introduced in 1953, was an appropriate method for the control of tuberculosis in the population of England and Wales, which was then almost entirely white; it is the present and future usefulness of this scheme, as a mass vaccination programme for the white population, which is under consideration. The scheme has undoubtedly also been of benefit in recent years to children of other ethnic communities, who either entered the country as immigrants under the age of 13 years or were born in Britain, and who currently number about 7 per cent of the total population eligible for the scheme. But the problems posed by tuberculosis in the other ethnic groups now resident in England and Wales are different in their scale and in their nature from those in the white community, and a national policy which defers a first BCG vaccination until the age of 13 years is not regarded today as an adequate primary prevention policy for these other ethnic groups. The assessment of this and other tuberculosis control measures introduced for the other ethnic groups is outside the scope of the present report, but the position of these groups in relation to the future of the schools scheme will be considered further in the separate report referred to above.

Data and assumptions

DATA FOR THE ASSESSMENT OF THE EFFECTS OF THE SCHOOLS BCG SCHEME

The data for the assessment of the present effects of the schools BCG scheme are set out in the upper section of table 1. The notification rates at ages 15–19 and 20–24

years in the two groups that had been tuberculin negative at age 13 years and were then either not vaccinated or BCG vaccinated, were estimated in the studies of the effectiveness of BCG vaccination in 1973, 1978 and 1983, and have been summarised.⁹ The percentage efficacies of BCG in these two age groups in 1983 are estimated directly from these figures.

These studies did not include the age group 25–29 years, and so no direct estimates are available for the notification rates in the unvaccinated and BCG vaccinated cohorts (nor for the efficacy of BCG) in this age group. Estimates of these rates at ages 25–29 years are however needed in 1983, both for the assessment of the effects of the scheme during a 15 year period following vaccination, and as a basis for forward projections. The estimates shown in table 1 were derived from the 1983 tuberculosis notification survey,¹³ as described in appendix 1.

The absolute effects of BCG vaccination are shown in the right hand section of table 1, where the differences between the notification rates in the tuberculin negative unvaccinated and the tuberculin negative BCG vaccinated group represent the estimated numbers of tuberculosis notifications prevented annually by 100 000 vaccinations.

THE BASIS FOR FUTURE PROJECTIONS

The principal finding of the 1983 BCG survey⁹ was that the efficacy of BCG, given at about age 13 years in England and Wales, had remained unchanged since its original use in the MRC vaccines trial.¹ It has therefore been assumed that the efficacies found in 1983, namely 80 per cent at age 15–19 years and 73 per cent at age 20–24 years, and the assumed value of 67 per cent at age 25–29 years (see appendix 1) will continue to apply in the future (lower section of table 1).

The recent assessment of trends in tuberculosis notification rates in the white ethnic population of

Table 1 Basic data for the assessment from the 1973, 1978 and 1983 surveys with the forward assumptions: white population of England and Wales.

Period during which the cohort was aged 13 years	Total eligible population of cohort when aged 15–19 yrs	Estimated annual tuberculosis notification rates per 100 000 population						Tuberculosis notifications prevented annually by 100 000 vaccinations when cohort aged		
		Negative unvaccinated at age 13 years when cohort aged			Negative BCG vaccinated at age 13 years when cohort aged			15–19 years	20–24 years	25–29 years
		15–19 years	20–24 years	25–29 years	15–19 years	20–24 years	25–29 years			
1967–71	2 970 000	22.88*	20.06	11.58	2.57	4.46	3.83	20.31	15.60	7.75
1972–76	3 448 000*	10.81	11.42	—	2.70	3.12	—	8.11	8.30	—
1977–81	3 666 000	7.59	—	—	1.53	—	—	6.06	—	—
<i>Forward assumptions</i>										
Percentage efficacy of BCG vaccination in 1983 and subsequently		—	—	—	80	73	67	—	—	—
Annual decrease in notification rate from 1983 (per cent)		9	9	9	9	9	9	—	—	—

*The corresponding figures in ⁹ are slightly in error

England and Wales¹⁶ showed that the rates in the age group 15–24 years have decreased since the early 1970s by about 8–10 per cent per year from causes other than the BCG in schools scheme and at ages 25–44 years by about 8–9 per cent. These were continuations of the steep decreases which began in about 1950. It has been assumed that the notification rate in the age group 15–29 years will continue to decrease by 9 per cent annually if the schools BCG scheme continues at its present level (lower section of table 1). An unchanging efficacy of BCG implies that the annual percentage decrease will be the same in vaccinated as in negative unvaccinated subjects.

Results

EFFECTS OF THE SCHOOLS BCG SCHEME

The impact of tuberculosis and the influence of vaccination on the individual and on the community may be expressed in several different ways. The next four subsections are different presentations of the data for 1973, 1978 and 1983, and of the forward assumptions summarised in table 1. Comparisons are also made with corresponding information derived from the MRC vaccines trial.²

The effect of BCG vaccination on the individual's risk of developing tuberculosis

Table 2 shows the risk to an individual tuberculin negative white young adult of developing notified tuberculosis in England and Wales between the ages of 15 and 30 years, according to whether he or she was BCG vaccinated or not at age 13 years. These are derived from the incidences in table 1 in the BCG vaccinated and the unvaccinated groups respectively, assigning the estimates to the central year of each 5 year cohort. For a tuberculin negative unvaccinated white child aged 13 years in 1984, the estimated risk of notified tuberculosis between age 15 and 30 years was 1 in 1700, and this was reduced by vaccination at age 13 years to 1 in 6500. By 1989, the estimated risk of notified tuberculosis in the 15 year period has

Table 2 *Estimated risk of developing notified tuberculosis between the age of 15 years and the age of 30 years for an individual white adult in England and Wales.*

Aged 13 years in	Tuberculin negative	
	Not vaccinated at age 13 years	BCG vaccinated at age 13 years
1950	1:52	1:238
1969	1:370	1:1800
1974	1:680	1:2400
1979	1:1000	1:4000
1984*	1:1700	1:6500
1989*	1:2700	1:10 000
1994*	1:4300	1:17 000
1999*	1:6900	1:26 000

*Projected

decreased to 1 in 2700 for an unvaccinated white child, and this would be reduced by vaccination at age 13 years to 1 in 10 000. By 1994, the corresponding risks have become 1 in 4300 and 1 in 17 000 respectively. These figures contrast sharply with the findings in the MRC vaccines trial² in urban and suburban areas in England, corresponding to the cohort that was aged 13 years in about 1950. The risk of developing tuberculosis within 15 years for a tuberculin negative unvaccinated subject in that trial was 1 in 52, compared with 1 in 238 in those who were BCG vaccinated.

The number of tuberculosis notifications prevented by 100 000 BCG vaccinations

Table 3 presents estimates of the numbers of tuberculosis notifications prevented, between 15 and 30 years of age, by 100 000 BCG vaccinations of white children at about age 13 years. These are derived from the differences in table 1 between the incidences in the unvaccinated and the BCG vaccinated groups, assigning the estimates to the central year of each 5 year cohort. In comparison with an estimate of 1495 notifications prevented in a 15 year period by 100 000 BCG vaccinations in 1950, derived from the MRC vaccines trial,² the figure for 100 000 vaccinations in 1984 was 45 notifications prevented; for 1989 it is 28 and for 1994 only 17.

Table 3 *Estimates of the number of tuberculosis notifications prevented between the age of 15 years and the age of 30 years by the vaccination of 100 000 white schoolchildren at age 13 years in England and Wales.*

Vaccinated at age 13 year in:	Notifications prevented in the 15 year period	Vaccinations to prevent one notification in the 15 year period
1950	1495	67
1969	218	460
1974	106	940
1979	71	1400
1984*	45	2200
1989*	28	3600
1994*	17	5800
1999*	11	9300

*Projected

The final column of table 3 presents the same information in inverse form, namely as the number of vaccinations required to prevent one notification during the 15 year period. From a figure of 67 vaccinations in the MRC vaccines trial, the estimate for 1984 was 2200; by 1989 it is estimated that it will require 3600 and by 1994, 5800 BCG vaccinations of white schoolchildren to prevent one tuberculosis notification during the 15 year period.

Total numbers of notifications prevented in England and Wales

Table 4 gives estimates of the total numbers of tuberculosis notifications prevented throughout

Table 4 *Estimated numbers of tuberculosis notifications prevented by the schools BCG scheme, if continued, in white adults aged 15–19, 20–24 and 25–29 years in selected calendar years in England and Wales.*

BCG vaccinations	No. ($\times 10^6$)	Number of notifications prevented in the year								
		1973	1978	1983	1988	1993	1998	2003	2008	2013
1967–71	2.210	449	345	171						
1972–76	2.548		207	211	123					
1977–81	2.892			175	150	87				
1982–86	2.55				97	83	48			
1987–91	2.00					47	40	24		
1992–96	2.10						31	26	16	
1997–2001	2.1							19	16	9
2001–06	2.1								12	10
2007–11	2.1									8
Total prevented, 15–29 years:			557	370	217	119	69	44	27	

England and Wales in white adults aged 15–19 years in 1973, 15–19 and 20–24 years in 1978 and 15–19, 20–24 and 25–29 years in 1983, with forward projections at five year intervals to the year 2013, assuming the continuation of the schools BCG scheme with its present coverage of 75 per cent. These estimates result from the application of the differences between the projected notification rates in the unvaccinated and BCG vaccinated groups from table 1 to the numbers of vaccinations shown in table 4. The numbers of vaccinations were estimated directly from the DHSS returns³ for 1967 to 1981; they have been taken as 75 per cent of the estimated white population aged 13 years from 1982 to 1996; and as a constant 2.1 million in each 5 year period thereafter.

Table 5 *Primary and secondary effects of stopping the schools BCG scheme at various times; estimated numbers of tuberculosis notifications at ages 15–29 years among white adults who had been resident in England and Wales at age 13 years.*

	1983	1988	1993	1998	2003	2008	2013
Total notifications if scheme continues	446	288	165	90	52	33	21
Primary additional notifications resulting from stopping scheme at end of:							
1986		0	47	71	69	44	27
1991		0	0	31	45	44	27
1996		0	0	0	19	28	27
Secondary additional notifications* resulting from stopping scheme at end of:							
1986		0	14	47	60	51	32
1991		0	0	9	31	38	32
1996		0	0	0	6	19	24
Total notifications including primary and secondary effects of stopping at end of:							
1986		288	226	208	181	128	80
1991		288	165	130	128	115	80
1996		288	165	90	77	80	72

*Some of the secondary additional notifications will be outside the age range 15–29 years

It is estimated that in total 557 notifications were prevented at ages 15–29 years throughout England and Wales in 1983 (namely 175 at age 15–19 years, 211 at age 20–24 years and 171 at age 25–29 years) as a result of the 7.65 million BCG vaccinations of white schoolchildren during the previous 15 years. This total of notifications prevented is substantially greater than the estimated total occurring in 1983 among white adults aged 15–29 years who had been resident in England and Wales at age 13 years, namely 446 (table 5). However, the absolute benefits—if the scheme is continued—will diminish steeply. In 1988 an estimated 370 notifications will be prevented, in 1993, 217 and in 1998, 119.

Total notifications expected in England and Wales

The first section of table 5 shows the total numbers of notifications expected in various years among white adults aged 15–29 years who had been resident in England and Wales at age 13 years, assuming that the scheme continues with its present coverage of 75 per cent. These are derived from the projected notification rates for the negative unvaccinated and the vaccinated groups from table 1, supplemented with similar projections for the notification rates among those who had been tuberculin positive, or were otherwise ineligible for the scheme at age 13 years, as found in the 1983 BCG survey.⁹

EFFECTS OF STOPPING THE SCHOOLS BCG SCHEME

Expected numbers of primary additional notifications

The primary effect of stopping the scheme would be to leave unvaccinated in each subsequent year a group of children who would otherwise have been protected against tuberculosis. The numbers of additional notifications expected at ages 15–29 years throughout England and Wales in certain specified years, as a result of infections from existing sources of those who would have been vaccinated if the scheme had continued, are shown for various dates of stopping in the second section of table 5. These figures are derived directly from table 4, by adding the estimated numbers prevented, subsequent to each date for the cessation of vaccination. The estimates therefore allow for changes in the size of the eligible population. These expected additional notifications represent the *primary* effect of stopping the scheme.

If the scheme had stopped at the end of 1986, the expected annual numbers of primary additional notifications would have risen gradually to about 70 by 1998, remained at this level until about 2003, and then decreased. The rise to a plateau 10–15 years after stopping the scheme is attributable to the gradual increase in the proportion of the 15–29 year age group that would have been left unvaccinated, and the

subsequent decrease to the continuation of the 9 per cent annual decrease in the incidence of the disease.

If the scheme were to be stopped at the end of 1991, the subsequent time trend of the primary effect would be similar, but with a maximum of about 45 additional notifications a year, reached after 10–15 years. For stopping at the end of 1996, the maximum number of primary additional notifications expected throughout England and Wales in a year would be about 30.

Expected numbers of secondary additional notifications

There would, however, be a *secondary* effect of stopping. The primary additional notifications represent new sources of infection in the community, and would themselves lead to further notifications of tuberculosis or chains of notifications, not necessarily confined to the 15–29 year age group. The expected continuation of decreases in the notification rates in all age groups implies that each primary additional notification must on average give rise eventually to a *total* of secondary additional notifications that is less than one. A method of estimating the numbers of secondary additional notifications and their timing is described in appendix 2. The resulting figures are shown in the third section of table 5. For stopping in 1986 the expected annual secondaries would have risen gradually to a maximum of about 60 by 2003, 15 years after stopping, and would then have gradually decreased. The corresponding maxima for stopping in 1991 and 1996 would be about 40 and 25 annual secondaries respectively, about 15 years after stopping. These are estimates of the numbers of annual secondaries over the entire age range, not only at ages 15–29 years, and as explained in appendix 2, they are likely to be overestimates.

Expected total notifications

The final section of table 5 shows the total notifications expected if the scheme is discontinued, allowing for both the primary and the secondary effects of stopping. If the scheme had stopped at the end of 1986, it is estimated that the total notifications would have decreased from 288 at ages 15–29 years in 1988 to 181 in 2003, 15 years later, some of the 181 being secondary additional notifications outside the age group 15–29 years. This compares with a total of 52 expected at ages 15–29 years in 2003 if the scheme continues. If the scheme were to be stopped at the end of 1991, the total notifications would be expected to decrease from 165 at ages 15–29 in 1993 to 115 in 2008; 33 would be expected in 2008 if the scheme continued. For stopping at the end of 1996, the expected decrease would be from 90 in 1998 to 72 in 2013, compared with 21 expected in 2013 if the scheme continued.

Individual risk of developing tuberculosis

The risks to a tuberculin negative white individual aged 13 years of developing tuberculosis between 15 and 30 years of age, given in table 2, are those which would apply if the BCG in schools scheme continues. If it is stopped, the risks for an unvaccinated tuberculin negative white individual aged 13 years would be greater than those in the table, because of exposure to the new sources of infection represented by the primary additional notifications. The extent to which the risk to an unvaccinated individual is enhanced at different intervals after stopping the scheme may be estimated approximately from table 5. Thus, if the scheme had stopped at the end of 1986, a total of $165 + 47 = 212$ notifications would have been expected in 1993 from existing sources of infection (that is, from sources other than those represented by the primary additional notifications). An additional 14 (secondary) notifications would have been expected from the new sources of infection, represented by the primary additional notifications. The ratio $(212 + 14) / 212 = 1.07$ thus provides an estimate of the increased risk to an unvaccinated individual in 1993 (that is, when the first wholly unvaccinated five year cohort was aged 15–19 years), above the level which would have applied if the scheme had continued. The corresponding ratios when the cohort was aged 20–24 and 25–29 years would have been 1.3 and 1.5 respectively. The same ratios would apply following each future date of stopping. On this basis, if the scheme had stopped at the end of 1986, the estimated risk to a white adult of developing tuberculosis between ages 15 and 30 years for the first wholly unvaccinated five year cohort, that is, for those aged 13 years in 1987–91 (central year 1989), would have been 1 in 2200 compared with 1 in 2700 if vaccination had continued (table 2).

Moreover, the figure of 1 in 2200 may be regarded as an overestimate because it assumes that all the secondary additional notifications would have been in the age group 15–29 years. For the later wholly unvaccinated cohorts, the risks would have been less than for the first 5 year cohort, because the total notification rate at ages 15–29 years would have continued to decrease after the scheme had stopped.

If the scheme were to be discontinued at the end of 1991, an unvaccinated tuberculin negative white individual aged 13 years in 1992–96 would face a maximum risk of developing tuberculosis between ages 15 and 30 years of 1 in 3400, compared with 1 in 4300 if the scheme had continued. The corresponding figure for an individual aged 13 years in 1997–2001, the scheme having stopped at the end of 1996, would be 1 in 5400, compared with 1 in 6900 if the scheme had continued. The risk of developing tuberculosis, for an unvaccinated tuberculin-negative white 13 year old,

has become very small in England and Wales, and would not be greatly increased if the schools BCG scheme were stopped.

Discussion

THE ESTIMATED EFFECTS OF THE SCHEME

Although the estimates of notifications prevented by the schools BCG scheme are clearly not as exact as the detail of their derivation might suggest, there are several reasons why their orders of magnitude, and the pattern they indicate, must be broadly correct.

The two principal groups of eligible subjects at age 13 years, both numerically and in terms of numbers of subsequent cases of tuberculosis, are those who were BCG vaccinated and those tuberculin negative but not vaccinated. The surveys of the efficacy of BCG vaccine⁷⁻⁹ have in essence estimated the sizes of these two main population groups and have divided the known total of notifications between them, the relative notification rates indicating the efficacy of the vaccine. The similarity of the efficacy estimates, in three cohorts born 19, 24 and 29 years later, to those in the controlled MRC trial of BCG vaccine,^{1 2} under greatly different conditions of exposure to infection, provides good confirmation of the present high efficacy of the vaccine and a considerable assurance that this will continue at a similar level in the future. This implies that the notification rates among the unvaccinated and the BCG vaccinated subjects can each be expected to follow the same future calendar trend as the total notification rate; it is the absolute difference between these two rates that provides the estimates of the notifications prevented by the scheme.

There can also be little doubt that the substantial decrease in the notification rates among young white adults, which has taken place throughout the last 30 years,¹⁶ will also continue in the future if the BCG scheme continues. For these reasons, the estimates of the effects of the scheme in tables 2, 3 and 4 may all be regarded as of the right order of magnitude.

THE ESTIMATED CONSEQUENCES OF STOPPING THE SCHEME

Primary consequences—The consequences of stopping the schools BCG scheme can be evaluated by distinguishing between the primary and secondary effects of stopping, and assessing each separately. If the scheme is stopped, the proportion of the population aged 15-29 years that is unvaccinated (at present 25 per cent) would gradually increase to 100 per cent. When exposed to the existing sources of tuberculous infection in the whole community, an increasing proportion would therefore be expected to develop tuberculosis according to the notification rates for the unvaccinated, instead of those for the

vaccinated. The additional notifications expected for this reason represent the primary effects of stopping the scheme. For any date of stopping, the estimated numbers of notifications which would have been prevented thereafter by continuing the scheme (table 4) also represent the estimated numbers of primary additional notifications if it is stopped (table 5). The primary consequences of stopping the scheme are thus as reliably estimated as the effects of continuing.

Secondary consequences—The primary additional notifications would all be in the age group 15-29 years, and would all arise from the existing sources of infection in the community. They would also represent new sources of infection, which would be expected to give rise to further tuberculosis notifications or chains of notifications according to the same pattern as the existing sources are expected to do. These generations of notifications, all linked to an initial infection from one of the primary additional notifications, represent the secondary effects of stopping. These secondary additional notifications could be in individuals of any age, and would influence the decline in notification rate over a longer calendar period than the primary additional notifications.

The estimation of the numbers of secondary additional notifications, and their timing, is not as straightforward as for the primary effects. The continuing decrease, in all age groups, in notification rates from the existing sources of infection implies that the total number of secondary additional notifications from the new sources, over the entire age range, must be less than the number of primary additional notifications in young adults which gave rise to them. Estimates of the total number and its time scale, however, depend additionally on knowing the average time interval between each notification and the notification of the individual who infected him or her, as explained in appendix 2. Although evidence on the duration of this average interval is limited, there is good reason to believe that it is not less than 2 years (see appendix 2), and this figure has been used for the estimates in table 5. If the average interval between linked notifications is greater than this, the total number of secondary notifications would be smaller and spread over a longer period of time. The figures in table 5 may thus be regarded as maximum estimates of the size and rapidity of the secondary effects of stopping.

Effect on the downward trend in notification rate—The primary additional notifications would influence the decline in notification rate in young adults only until the entire 15-29 year age group had become unvaccinated, and the major effects of the secondary additional notifications derived from them would occur over the same period. There would thus be only a temporary disturbance to the current steep

downward trend in the tuberculosis notification rate at ages 15–29 years, and that trend would be expected to resume about 15–20 years after stopping. During these 15–20 years, additional notifications would be expected to occur—at their peak—in relatively substantial numbers (table 5). However, whenever the scheme was stopped, there would still be a downward tendency in the total annual notifications at ages 15–29 years (apart from a static or slightly increasing total between 7 and 12 years after stopping—see the final two lines of table 5). This decrease would not be as rapid as the 9 per cent expected annually if the scheme had continued. Thus the reduction in expected total annual notifications from 288 to 181 in the 15 years after stopping in 1986 (table 5) represents an average decrease of about 3 per cent per year. The expected decrease to 80 during the following 10 years represents the resumption of a decrease of about 8 per cent per year. The reductions following any future stopping date would be expected to follow a similar pattern.

The total consequences of stopping the BCG scheme, at any future date, would thus seem to be reliably estimated and summarised as a temporary slowing of the decline in the notification rate in young white adults from a figure of 9 per cent annually to about 3 per cent annually, for a period of about 15 years. Thereafter a steeper rate of decline would be expected to resume in this age group.

This detailed analysis has shown that if the BCG in schools scheme were to be stopped, the consequences would be limited in time and would not be epidemiologically disastrous. It is important to appreciate that this is so because tuberculosis in England and Wales is essentially an endemic disease which is decreasing steeply for reasons unconnected with the efficacy of BCG or its application in the schools scheme. The additional notifications expected after stopping, both primary and secondary, would lead to only a temporary disturbance in the basic epidemiological trend which preceded the introduction of the scheme, and has continued during it (table 1), namely a steeply decreasing tuberculosis incidence in *unvaccinated* young adults. The situation is quite different from that of an infectious disease with a different basic epidemiology. The effect of abandoning (or of a substantial reduction in) measles vaccination in this country, for example, could be analysed, and the numbers of primary additional cases estimated, in the same way as for tuberculosis. But for measles, the secondary additional cases would not be a decreasing series, and the disease would be expected to revert rapidly to the basic epidemiological pattern in England and Wales before vaccination was introduced, with major epidemics every other year.

DURATION OF PROTECTION FROM BCG VACCINATION

It has been assumed throughout this paper that the preventive efficacy of BCG lasts for 15 years, and (tacitly) for no longer. If this is so, the benefits of continuing the scheme will be confined to the age group 15–29 years. The effects of stopping it will also be confined to this age group, except for the occurrence of a diminishing number of secondary additional notifications outside this age group and after more than 15 years. It is however more likely that some protection from BCG will continue in England and Wales for more than 15 years after vaccination, and that the benefits of vaccination in the scheme have also extended to those who are now aged more than 30 years. In these circumstances, primary and secondary effects of stopping the scheme will also occur at ages above 30 years. The size of these effects will be small, because they will not begin to occur until the first wholly unvaccinated cohort reaches the age of 30 years, that is, more than 15 years after the scheme is discontinued. Consequently they have not been explored further in this paper.

TUBERCULOSIS AND ACQUIRED IMMUNODEFICIENCY SYNDROME (AIDS)

Patients with AIDS following human immunodeficiency virus (HIV) infection have an increased susceptibility to tuberculosis.¹⁷ There is understandable concern that the expected increase in the number of AIDS patients in England and Wales will also lead to increased numbers of tuberculosis notifications, and that this may seriously disturb the current downward trend of the disease. In particular, the forward projections in this paper might be affected.

The effects on the incidence of tuberculosis of an increase in the proportion of the population with AIDS are epidemiologically analogous to the consequences of an increase in the proportion of the population left unvaccinated after stopping the BCG scheme. The primary effect would be additional cases of tuberculosis among those whose susceptibility to the disease had been increased by AIDS. These cases would arise partly from the breakdown of quiescent tuberculosis infections which had preceded the development of AIDS (endogenous reactivation) and partly from fresh tuberculous infections following the development of AIDS (exogenous infection). These primary additional cases would represent potential new sources of infection in the community, and the further cases of tuberculosis to which they gave rise would represent the secondary effect.

The numbers of primary additional cases would depend on the proportion of the population that develops AIDS, the proportion of these who have had

a past, or experience a fresh, tuberculous infection, and the (at present unknown) extent to which susceptibility either to breakdown of quiescent tuberculous infection or to fresh tuberculous infection is increased by AIDS. The increases with time in the proportion of the population with AIDS will be offset to some extent by the expected continuation of the substantial annual decreases in the proportion of the population infected with tuberculosis. The number of primary additional cases of tuberculosis will therefore not rise as rapidly as the proportion of the population with AIDS, and the totals will not necessarily become large.

The current steep downward trend in the incidence of tuberculosis in the general population not suffering from AIDS reflects a similar downward trend in the number of sources of tuberculous infection. This trend will be disturbed by an increase in primary additional cases of tuberculosis with AIDS, to the extent that these additional cases represent new sources of infection for the general population. It should be possible for the infectivity of cases of tuberculosis in patients with AIDS to be controlled with chemotherapy, and their life expectancy and therefore duration of infectivity is also limited by their susceptibility to other infections. It is not at present possible to assess the combined effects of all these factors on the risk of tuberculosis infection in the community. There could be circumstances in which the downward trend in the risk of tuberculous infection (and hence the projections in this paper) would be seriously disturbed, but this is by no means an inevitable outcome.

NATIONAL SURVEY OF TUBERCULOSIS NOTIFICATIONS—1988

A national survey of tuberculosis notifications in England and Wales in 1988 is being undertaken by the MRC Cardiothoracic Epidemiology Group,¹⁸ on the same lines as the two previous surveys.^{12 13} One of the main reasons for the survey is to assess the secular trends in tuberculosis incidence in the various ethnic groups since 1983. The estimates in the present report are based on the assumption that the tuberculosis incidence in white adults aged 15–29 years, who were resident in England and Wales at age 13 years, has continued to decrease by 9 per cent annually since 1983. On this assumption, our estimate of the numbers of tuberculosis notifications in England and Wales in this population group in 1988, based on the data available up to 1983, is 288 (table 5). A comparison with the number actually recorded in the 1988 survey will indicate whether our future estimates of the notifications prevented by the scheme, if it continues, and of the additional notifications if it is discontinued, should both be regarded as too large or both as too

small. However, the new information will not radically alter the pattern of the effects of continuing the scheme, nor the pattern of the consequences of stopping the scheme, that have been presented above, unless the survey reveals large departures from the expected trends in several age groups.

As indicated in the introduction, the present and future usefulness of the BCG in schools scheme as a tuberculosis control measure, in the light of these estimates, will be considered in a separate report (in preparation).

Appendix 1

ESTIMATION OF TUBERCULOSIS NOTIFICATION RATES AT AGES 25–29 YEARS IN 1983 IN COHORTS BCG VACCINATED OR NOT VACCINATED AT AGE 13 YEARS

Satisfactory totals are available for the population in the relevant tuberculin negative unvaccinated and BCG vaccinated cohorts separately, and for the number of tuberculosis notifications at ages 25–29 years in these two cohorts combined. A value for the efficacy of BCG was assumed, and this allowed the separate notification rates at ages 25–29 years to be calculated, giving the results shown in table 1. The following details of the method include previously unpublished figures for the white ethnic group from working tables used in the preparation of references 9 and 13.

- (1) Population estimates for these two cohorts when aged 15–19 and 20–24 years were obtained.⁹ For age 25–29 years the latter estimates were each reduced by the all causes mortality for the same cohort in England and Wales between ages 20–24 and 25–29 years (0.34 per cent). No adjustment was made for emigration. (Tuberculin negative unvaccinated 438 000, BCG vaccinated 2 196 000.)
- (2) The number of notifications at ages 25–29 years in whites who had been resident in England and Wales at age 13 years was determined in the 1983 tuberculosis notification survey¹³ for the first 6 months of the year only. This was scaled up to a total of 161.4 for the whole year, using the ratio of the OPCS total of corrected notifications at ages 25–34 years for the whole of 1983 to that in the first two quarters of the year.
- (3) The cohort that was tuberculin positive at age 13 years in 1967–71 showed a steep decrease in notification rate between age 15–19 years in 1973 and age 20–24 years in 1978,⁹ as did the cohort that was ineligible for the scheme, namely those tuberculin positive, or BCG vaccinated, prior to age 13 years (rates not tabulated). It was assumed that equally steep proportionate decreases in rate would have occurred in these cohorts by age 25–29 years, which led to an estimate of 26.7 notifications in 1983 in these two cohorts combined. This leaves an estimated 134.7 notifications at ages 25–29 years in the tuberculin negative unvaccinated and BCG vaccinated cohorts combined.

(4) In the cohort aged 13 years in 1967–71, the efficacy of BCG was 89 per cent at age 15–19 years and 78 per cent at age 20–24 years.⁹ There was a similar decrease with interval since vaccination up to 15 years in the MRC vaccines trial.¹ An efficacy of 67 per cent was assumed at ages 25–29 years in 1983, leading to the rates shown in table 1.

Appendix 2

ESTIMATION OF THE NUMBER OF SECONDARY ADDITIONAL NOTIFICATIONS AND THEIR TIMING

(1) Let the average interval between the notification of any individual and the notification of the patient who infected that individual be z years. If the notification rate is decreasing by a proportion d (> 0) each year, the expected total number of secondary notifications (T) arising eventually from any one primary notification is given by:

$$T = (1-d)^z < 1$$

(2) Suppose that on average one notified patient infects y individuals, of whom x develop notified tuberculosis after an average interval of z years. These x notifications will be expected to lead to a second generation of x^2 notifications on average z years later, these to a third generation of x^3 notifications z years later, and so on. The total number of secondary notifications expected to arise from one primary notification is thus:

$$T = x + x^2 + x^3 + \dots,$$

and because $x < T < 1$, the sum of this series is

$$T = x/(1-x)$$

(3) The expected average interval (Z) between each primary notification and *all* the secondary notifications arising from it is given by:

$$Z = \frac{x.z + x^2.2z + x^3.3z + \dots}{x + x^2 + x^3 + \dots} = z/(1-x)$$

(4) Thus for any given value of d , information on the value of z will enable estimates of T , x and Z to be made. We do not know of any direct information on the average interval between two linked notifications. Unpublished information from the MRC vaccines trial indicates that in the total of 249 initially tuberculin negative individuals aged 14 years who were left unvaccinated in 1950–52 and who developed tuberculosis within the next 20 years,² the average interval between infection and the first signs of tuberculosis was about 1.6 years. Bearing in mind that the infecting patient may infect before notification, but that the infected individual may not be notified until some time after the first signs of disease, the average interval between linked notifications is likely to exceed 1.6 years, but it is uncertain by how much. We suggest that 2 years may represent a minimum value for this average interval.

(5) With $d = 0.09$, and taking $z = 2.0$, the estimates are:

$T = 0.828$ secondary notifications resulting from each primary additional notification

$x = 0.453$, the size of the first generation of secondary notifications

$Z = 3.7$ years, the average interval to all the secondary notifications

It should be noted that if the true value of z is greater than 2 years, T and x will be smaller, and Z will be greater. The above figures may thus be regarded as maximum estimates of the size and rapidity of the secondary effects.

(6) The expected numbers of secondary additional notifications have been estimated as 82.8% of the primary additional notifications 3.7 years previously, and are shown in the third section of table 5.

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