Future Savings from Measles Eradication in Industrialized Countries

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Estimates are made of monetary savings associated with measles eradication in seven industrialized countries. Three scenarios were studied: First, changing from the present two-dose measles-mumps-rubella (MMR) immunization schedule to one-dose of MMR; second, the use of an MMR and mumps-rubella schedule; or third, continuing the present schedule. Results show that the largest savings (US $623 million) would be achieved by changing to a one-dose MMR schedule with an assumption of a 3% discount rate and measles eradication in 2010. The smallest overall savings would result from option 3, by use of a 5% discount rate and the assumption that measles eradication occurs in 2020 ($10 million). These savings are less than previously estimated for the United States, partly because of the assumption that measles vaccines will continue to be delivered in response to possible bioterrorism threats.

In 2001 the World Health Organization and the United Nations Children’s Fund published a strategic plan for the control of measles in which it was suggested that a meeting of experts should be convened in 2005 to evaluate the possibility of global eradication of measles [1]. Eradication (i.e., the global elimination of the disease) can bring enormous benefits as cases will no longer occur and vaccination and surveillance efforts can be scaled down (and even completely ended). A recent study suggested that if measles were eliminated by 2010, the United States (USA) could save $500 million to $4.5 billion [2]. In this study, we estimated the cumulative savings that could be achieved by seven industrialized countries if measles is eradicated globally.

METHODS

We estimate the present value of future savings associated with global measles eradication by using three potential target dates: 2010, 2015, and 2020 in one North American country, Canada, and in six European countries, Denmark, Finland, The Netherlands, Spain, Sweden, and the United Kingdom (UK). All of these countries are considered to have eliminated measles [3–5] (i.e., indigenous transmission has been interrupted). This does not mean that no measles cases occur in these countries; however, cases that do occur are linked to importations [5]. All costs are presented in 2001 US dollars.

Vaccination strategies after measles global eradication. We present three alternative strategies to the two-dose measles-mumps-rubella (MMR) immunization program currently recommended in these seven countries. In all three scenarios, it is assumed that the first dose of MMR vaccine will remain part of the national immunization program because measles could be thought of as a potential bioterrorism agent and it is therefore unlikely that these countries would stop protecting their population against this potential threat.

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Furthermore, mumps and rubella vaccines would continue to be used, and since the measles component of MMR does not contribute to a large proportion of its price it seems likely that at least one dose of MMR would continue to be used.

In scenario 1, the second dose of MMR is not offered. Assuming that one dose of MMR would be sufficient to control mumps and rubella at current levels, the annual savings from this strategy will be the sum of the costs of treating measles cases that would occur if eradication is not achieved plus purchasing and delivering the second dose of MMR plus the costs associated with treating adverse events following immunization (AEFIs) associated with the second dose of MMR.

In scenario 2, the second dose of MMR is replaced by a mumps-rubella (MR) vaccine. The savings will be the sum of the costs of treating measles cases that would occur without eradication, the difference in price between MMR and MR vaccines, and the cost of measles-specific AEFIs after a second dose of MMR. In scenario 3, the second dose of MMR continues to be offered but no cases of measles occur. Thus, the savings only correspond to the costs of treating those cases that would occur without measles eradication. In the last two scenarios, we assume that the coverage of the second dose of vaccine will remain the same as current coverage. In all three scenarios, we assume that mumps and rubella will remain at current levels (i.e., the effective reproduction number of these two viruses will remain <1).

Costs of measles cases. The methodology developed for cost of an average measles case is described elsewhere [6]. In brief, measles cases are divided into two broad categories: those that do and those that do not seek medical attention. The former category is further divided into noncomplicated and complicated cases. We calculated the average costs per measles case and 95% confidence intervals (CI) and found them similar in the seven study countries. The future savings correspond to the average measles costs multiplied by the current annual incidence of measles multiplied by the population projections until 2100.

The annual incidence of measles in the seven study countries is based on country-specific data over the last 5 years (of note, some countries report higher incidences than others, presumably as importations, and the effective reproduction number varies between countries) and was obtained from published data and local experts [7–13] (Leino T, incidence of measles in Finland, personal communication). It is assumed that these incidence rates will apply in the future, unless global eradication is achieved, after which the incidence of measles is assumed to be zero in each country. Uniform distributions are used to represent the uncertainty in the current annual incidence rates.

Vaccination costs. Savings associated with a change in vaccination will only occur for scenarios 1 and 2. The methodology and estimates of the present costs of current immunization programs and AEFI associated with the measles component in the seven study countries have been described [6]. The items of interest for the current analysis are the cost per vaccinee of the second MMR dose, including the price of the vaccine (and wastage) and the costs of its delivery (mothers missing work, visit to a physician) for scenario 1; the cost difference per vaccinee between the current price of MMR vaccine and the price of a potentially more widely used MR vaccine (and wastage) and the costs per vaccinee of measles-specific AEFIs for scenario 2.

The costs of AEFI per vaccinee associated with MMR are described later. The cost of immunization per vaccinee is multiplied by the expected number of children receiving a second dose of vaccine. This is calculated by multiplying the reported coverage of MMR for the second dose of MMR by the average projected population at the recommended age of vaccination (further methodology details will be published elsewhere).

In scenarios 1 and 2, we assume 10%–15% wastage for the second dose. Therefore, the savings associated with the vaccine itself would include the price of the vaccine plus an average of 12.5% for wastage. The price of the MMR vaccine used in scenario 1 was obtained from local experts and published data [14–16] (prices of MMR in The Netherlands and Finland are from van den Hof S, Salo H [personal communication] and for Sweden and Denmark from Gyldmark M [personal communication]). In scenario 2, it is assumed that the price of the measles component of MMR corresponds to 10%–40% of the total price of MMR.

Savings associated with MMR delivery will only occur in scenario 1 where the second dose of MMR is completely eliminated. The proportion of the delivery cost attributed to MMR depends on the vaccination schedule in the study country. One important assumption we make here is that the non-MMR immunization schedule will remain constant in the future in all study countries. In Denmark and Sweden, where the second dose of MMR is recommended alone, all delivery costs will be saved (health care provider and mothers missing work). Mothers are assumed to lose 3–5 work hours to bring their child for vaccination. However, if MMR is recommended at an age when other vaccines are also recommended, we assume (in the base case) that some delivery costs will remain, as these costs are assumed to vary by number of doses given.

In the UK, The Netherlands, and Canada, two other vaccines are currently given at the same time, therefore, one-third of the medical delivery costs are attributed to MMR. In Spain and Finland, one other vaccine is recommended at the same age; hence in these countries, half of the medical delivery costs will be saved (later we describe how we tested the sensitivity of our findings for the assumption of variable delivery costs). In these five countries, no savings are assumed to occur from mothers missing work to take their child for MMR vaccination since
they will need to take time off for the other vaccination(s). In scenarios 2 and 3, all delivery costs will continue to be incurred because mothers will still need to miss some work and there will be delivery costs associated with the MR (scenario 2) or MMR (scenario 3) vaccines.

The proportion of the yearly savings associated with AEFIs in the seven countries is about 0.30%. This value is consistent with data from a similar US study [2]. In addition, AEFIs associated with the MR component of MMR are likely not to be as important as the AEFIs associated with the measles component [17–19]. Thus, we assume that costs of AEFIs associated with MMR are the same as those associated with the measles component of MMR (scenario 1).

**Costs to society and the health care provider.** We estimated the present value of future savings for both the health care provider (HCP) and wider society perspectives. The proportion of the measles and vaccination costs associated with the HCP was based on the costs-sharing system used in each study country to establish the proportion of health care costs falling on the parent and/or insurer [20, 21]. Indirect costs associated with death and subsequent productivity losses were excluded and no attempt was made to put a monetary value on pain and suffering or measles-associated premature death.

**Present value of future savings after global eradication of measles.** For each country, we estimated the future savings associated with measles global eradication from 2010, 2015, and 2020 until 2100. In all cases, we calculated future savings by using discount rates of 3% and 5%. We used Organization for Economic Co-operation and Development estimates of population size and assumed that the populations will remain constant from 2050 until 2100 [22].

**Uncertainty analysis.** Several parameters could not be accurately quantified from the literature or from country-specific health or statistical web sites. To represent this uncertainty, each parameter was assigned a distribution over which the values were likely to lie [6]. The model was then run 10,000 times, and on each occasion a random sample of input parameter values was drawn from the distributions by use of Latin hypercube sampling. The average of the distribution of these 10,000 estimates and the 2.5th and 97.5th percentiles represent the average cost of measles with corresponding 95% CI. These iterations were run by using @Risk version 4 [23] with Microsoft Excel software. We also used this method to identify factors with the largest impact on total cumulative savings.

**RESULTS**

**Future savings.** Table 1 presents the 2001 population and the average and 95% CI of the cumulative savings after measles eradication for the seven study countries with measles global eradication in 2010, 2015, and 2020. Clearly the earlier eradication is achieved, or the lower the future discount rate, the greater the cumulative benefits derived from measles eradication. The largest savings occur with scenario 1, which ends the second dose. Under this scenario, countries that now recommend MMR vaccine alone (Sweden, Denmark) and the country with the largest population (UK) would obtain the largest savings. (Table 2 shows savings per capita.) Thus, the most optimistic situation is scenario 1 with measles eradication achieved by 2010 and a discount rate of 3%, giving a cumulative savings for all seven countries of $623 million (95% CI, $569–$678 million). The equivalent value with a 5% discount rate is $350 million (95% CI, $320–$381 million). If eradication is not achieved until 2020, the cumulative savings for all countries is estimated at $445 million (3% discount rate; 95% CI, $407–$484 million).

With scenario 2, the total savings for the seven study countries drop to $205 million (95% CI, $102–$310 million) for eradication in 2010 and a discount rate of 3%. With a 5% discount rate, this value would be $115 million (95% CI, $57–$175 million). This represents about one-third of the savings incurred from scenario 1.

With scenario 3, the total savings for the seven countries is estimated at only $29 million (95% CI, $10–$53 million) for eradication in 2010 with a 3% discount rate. These savings are 10 times lower than those for scenario 1. This is to be expected given that the only savings are those associated with the (currently rare) measles cases that would be prevented by global eradication. The largest savings occur in The Netherlands and Spain, which have a higher incidence of measles than in the other five countries.

Figure 1A–1C shows the cumulative savings for scenarios 1–3 in the seven study countries for measles eradication in 2010 and a discount rate of 3%. Clearly, scenario 3 would lead to very small savings for these countries from 2010 to 2100. The discounted savings accumulate until they plateau about 2100. After this date, the marginal increase in savings is small and is not shown.

**Health care provider costs.** In scenario 1, the proportion of savings to the health care provider is 88%, 22%, 91%, 83%, 83%, 50%, and 92% for Canada, Denmark, Finland, The Netherlands, Spain, Sweden, and the UK, respectively. In all of these countries, MMR vaccine and its delivery costs are covered by public services [15, 16]. The largest difference occurs in Denmark and in Sweden where MMR is currently recommended alone. The savings would include mothers not having to miss work. In the other countries, there would be no such savings as mothers would still need to miss work to get their child vaccinated with the other vaccine(s) currently recommended on the same schedule as the second MMR dose.

With scenario 2, the health care provider component represents over 82% of the total savings in all study countries and reaches 99% in Finland, Sweden, and the UK. With this sce-
Table 1. Present value of future measles savings (shown as million US$) and 95% confidence intervals in Canada and six European countries for global eradication of measles by 2010, 2015, and 2020 by three alternative scenarios.

<table>
<thead>
<tr>
<th>Scenario, a</th>
<th>Population (in 2001 in millions)</th>
<th>Discount at 3%</th>
<th>Discount at 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>165.5</td>
<td>623 (569–678)</td>
<td>527 (481–573)</td>
</tr>
<tr>
<td>Canada</td>
<td>31.0</td>
<td>48 (40–56)</td>
<td>41 (34–48)</td>
</tr>
<tr>
<td>Denmark</td>
<td>5.3</td>
<td>95 (75–115)</td>
<td>79 (63–97)</td>
</tr>
<tr>
<td>Finland</td>
<td>5.2</td>
<td>10 (10–13)</td>
<td>10 (8–11)</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>16.0</td>
<td>80 (68–94)</td>
<td>68 (58–80)</td>
</tr>
<tr>
<td>Spain</td>
<td>39.6</td>
<td>78 (58–100)</td>
<td>66 (48–84)</td>
</tr>
<tr>
<td>Sweden</td>
<td>9.0</td>
<td>178 (158–198)</td>
<td>152 (135–170)</td>
</tr>
<tr>
<td>UK</td>
<td>59.4</td>
<td>133 (115–152)</td>
<td>111 (96–127)</td>
</tr>
</tbody>
</table>

Sensitivity analysis

In scenario 1, the factor with the largest effect on the cumulative savings (by far) was the number of hours mothers had to miss work to have their child vaccinated. Other factors with less impact were the coverage of the second dose of MMR in Spain, the UK, Canada, and Denmark; the incidence rate of measles in The Netherlands and Spain; and the current wastage for the second dose of MMR. If there had been no savings associated with the cost of delivery of MMR in countries where it is recommended with other vaccines (i.e., delivery costs are fixed), our savings estimates would have been reduced by 10%. In scenario 2, the factor with the single largest impact was the proportion of the price of MMR attributable to the measles component. In scenario 3, the incidence rate of measles in Spain and The Netherlands and the number of hours missed by parents to care for a measles case with upper respiratory tract infection symptoms were the factors with the largest impact on total cumulative savings.

DISCUSSION

Transmission of measles has been interrupted in all but two countries in the Americas and in many Western European countries. However, measles will still incur costs to all countries worldwide unless it is globally eradicated. In this study, we estimated potential future savings for six European and one North American country under three alternative immunization scenarios following global measles eradication. Our estimates of savings are $1.3–$728 million depending on the year of global
Table 2. Present value of future measles savings per capita (US$) in Canada, Denmark, Finland, The Netherlands, Spain, Sweden, and the United Kingdom (UK) for global eradication of measles by 2010 and 2020 by three alternative scenarios.

<table>
<thead>
<tr>
<th>Country</th>
<th>Eradication at 2010, 3% discount rate</th>
<th>Eradication at 2020, 5% discount rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scenario 1</td>
<td>Scenario 2</td>
</tr>
<tr>
<td>All</td>
<td>3.76</td>
<td>1.24</td>
</tr>
<tr>
<td>Canada</td>
<td>1.55</td>
<td>0.65</td>
</tr>
<tr>
<td>Denmark</td>
<td>17.72</td>
<td>1.57</td>
</tr>
<tr>
<td>Finland</td>
<td>2.22</td>
<td>0.82</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>5.01</td>
<td>2.54</td>
</tr>
<tr>
<td>Spain</td>
<td>1.98</td>
<td>1.06</td>
</tr>
<tr>
<td>Sweden</td>
<td>19.78</td>
<td>5.22</td>
</tr>
<tr>
<td>UK</td>
<td>2.24</td>
<td>0.72</td>
</tr>
</tbody>
</table>

NOTE. The scenarios are as follows (all assume there are no longer measles cases): (1) second dose of measles-mumps-rubella (MMR) vaccine is no longer offered; (2) the second dose of MMR is replaced by a mumps-rubella vaccine; and (3) the vaccination program is not changed.

eradication, the alternative immunization scenario, the discounting rate, and uncertainty in the economic and epidemiologic parameters used.

If the current two-dose MMR immunization strategy remains unchanged after global measles eradication, the cumulative savings for Canada, Denmark, Finland, The Netherlands, Spain, Sweden, and the UK are estimated to be at most $53 million (eradication by 2010, 3% discount rate, 95th percentile). This is not surprising given that measles has been (or is nearly) eliminated in all of these countries and the only savings from this strategy arise from the cessation of measles cases, which are already rare. Nevertheless, this scenario is possible given the current fears of bioterrorism and because it may be necessary to deliver two doses of MR vaccines to ensure continued elimination of these viruses. In such a case, the monetary benefits of global eradication to countries that have already eliminated measles would be negligible.

If the current two-dose MMR immunization were replaced by an MMR-MR vaccination schedule, the total cumulative savings to all seven countries would be on average $69–$205 million. In 1998, it was estimated that replacing the two-dose MMR schedule by a two-dose MR schedule in the USA would lead to savings of $1 billion if measles were eradicated by 2010. This calculation used a 3% discount rate (discounting from 1997) [2]. This is considerably more than our estimates. Part of the difference is due to the large US population (275.1 million [22]) compared with 165.5 million in our study population. However, the equivalent savings per capita are $4.00 for the US population and $1.24 for the study countries. This difference can be explained by country and methodology differences. The methodology aspect with the largest impact on savings is that we assume that the first dose of MMR would remain unchanged, whereas in the US study it was assumed that MMR would be replaced by an MR vaccine. This leads to an extra cumulative saving of almost $0.5 billion since each dose of MR was assumed in the US study to cost $5.10 less than MMR [2].

A few other differences also lead to larger estimates for the US study. Whereas the proportion of MMR costs attributable to the measles component was similar in the US study and in our study (26% and 10%–40%, respectively), the price of MMR itself in six of the seven study countries (with the exception of Sweden) was at least $7 less than the US estimate. Furthermore, Miller et al. [2] assumed that the coverage of the second dose of vaccine would improve from the current (1997 data) 64%–95% without taking into consideration the extra costs associated with improving coverage. This leads to optimistic savings estimates. Finally, the US study estimated much larger average costs per measles case ($1188) than was apparent from our work [6].

If the current two-dose MMR immunization was replaced by a single MMR vaccination schedule, we estimate the savings, on average, to be $209–$623 million depending on the year of eradication and the discounting rate used ($1.26–$3.76 per capita), assuming that the incidence of mumps and rubella would not increase (i.e., they would remain eliminated via the one-dose program). The US study estimated that the overall savings for a similar scenario would be $2.4–$4.6 billion (2001 US$) with discount rates of 5% and 3%, respectively ($8.43–$16.15 per capita) [2]. Again, the largest difference can be attributed to our assumption that the first dose of MMR would continue to be delivered rather than be replaced by MR vaccine.

In addition to this and the country and methodology differences mentioned, the assumptions made about vaccine delivery costs varied. In the US study, it was assumed that the second dose of MMR was always offered with at least one other vaccine and that half of the indirect costs (parents missing on average 2 h of work, average worker salary data) would be
Figure 1. Present value of cumulative savings (US$, millions) until 2100 after measles global eradication in 2010 by three scenarios in Canada (cross), Denmark (circle), Finland (line), The Netherlands (triangle), Sweden (square), Spain (diamond), and UK (x). All scenarios assume there are no measles cases. Scenario 1, second dose of measles-mumps-rubella (MMR) vaccine is no longer offered; scenario 2, second dose of MMR is replaced by a mumps-rubella vaccine; scenario 3, vaccination program is not changed.

We demonstrate that savings for industrialized countries
from measles eradication may be considerable but might be significantly smaller than previously thought [2]. Considerable country-specific differences cause a large variation in potential savings within each nation.

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