

# Benefits, Risks and Costs of Immunization for Measles, Mumps and Rubella

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**Abstract:** For a single year, 1983, we compared the actual and estimated morbidity, mortality, and costs attributable to measles, mumps, and rubella with having or not having a childhood immunization program using the combined measles-mumps-rubella (MMR) vaccine. Without an immunization program, an estimated 3,325,000 cases of measles would occur as compared to 2,872 actual cases in 1983 with a program. Instead of an expected 1.5 million rubella cases annually, there were only 3,816 actual cases. Mumps cases were lowered from an expected 2.1 million to 32,850 actual cases. Comparable reductions in disease-associated complications,

sequelae, and deaths are gained with an immunization program. Without a vaccination program, disease costs would have been almost \$1.4 billion. Based on the actual incidence of disease in 1983, costs were estimated to be approximately \$14.5 million. Expenditures for immunization, including vaccine administration costs and the costs associated with vaccine reactions, totaled \$96 million. The resulting benefit-cost ratio for the MMR immunization program is approximately 14:1. The savings realized due to the use of combination rather than single antigen vaccine total nearly \$60 million. (*Am J Public Health* 1985; 75:739-744.)

## Introduction

Licensure of measles, mumps, and rubella vaccines has led to the vaccination of millions of children and dramatic reductions in the morbidity and mortality associated with these diseases.<sup>1-4</sup> Benefit-cost analyses have been used to evaluate the economic impact of these immunization programs. Most previous studies analyzing immunization against individual diseases with single antigen vaccine demonstrated benefit-cost ratios ranging between 5 and 12:1, depending on the techniques and assumptions used.<sup>5-9</sup> Since these studies, there has been greater experience and considerable success in controlling these diseases. Immunization is now usually accomplished with combination measles-mumps-rubella vaccine, MMR. The purpose of this study is to compare the relative benefits and costs for an MMR immunization program with the alternative of no immunization program, and with vaccination using individual measles, mumps, and rubella antigens.

## Methods

Our model assessed the morbidity, mortality, and costs attributable to measles, rubella, and mumps in 1983 with an immunization program, as compared to projected outcomes for a hypothetical situation in 1983 had there not been an immunization program. To estimate the number of cases of measles, mumps, or rubella that would have occurred in 1983 without a vaccination program, we made the following estimates and assumptions.

In the absence of a vaccination program, members of a birth cohort become infected at different ages based on the epidemiologic characteristics of the disease. Age-specific infection rates can be determined either from the seroprevalence of antibodies to the agent by age, or from historical surveys which determine the age at which infection occurred. For example, in the case of measles we know that prior to the initiation of vaccination programs 95 per cent of individuals in an unvaccinated population have evidence of infection by age 30.<sup>10,11</sup> We assume that the number of susceptible

persons entering the population annually was constant 3.5 million, the average of the annual number of births in the United States from 1976-81.<sup>12</sup> A steady-state condition is created where the annual input of susceptible individuals into the population is balanced by an approximately equal number of individuals leaving the study population having reached age 30 (95 per cent of whom would be immune to measles). Thus, in this steady-state, the number of individuals infected by measles annually would be equivalent to 95 per cent of 3.5 million, with an age distribution of cases proportional to the age-specific infection rates. Similar estimates can be made for rubella and mumps. This hypothetical situation is contrasted to the actual situation in 1983, the most recent year for which complete data are available, and one which we assume to be representative of morbidity, mortality, and immunization program costs.

The costs of disease include expenditures made for treatment of acute illness, complications and chronic sequelae, lost wages from missed work, and lifetime earnings lost due to retardation or death. The "benefits" of a vaccination program are savings in costs that would have been incurred to treat the disease and its complications had it not been prevented. Costs of immunization are the expenditures made for vaccine and its administration, treatment of vaccine-associated complications, and implementation of immunization programs. A benefit to cost (B/C) ratio is calculated by dividing the difference in costs of disease with and without an immunization program by the costs of the immunization program [i.e.,  $B/C = (\text{disease costs without an immunization program minus disease costs with an immunization program}) / \text{costs of the immunization program}$ ]. Expenditures counted as benefits or costs made in different years have been adjusted to their 1983 value using a discount rate of 10 per cent per annum. Wherever possible, documented figures for rates of illness, complications, and costs have been used. If published sources were not available, estimates were made with the assistance of experts in the epidemiology of vaccine-preventable diseases. In making estimates and assumptions, we tended to underestimate the benefits of the vaccines, thus providing a "lower bound" estimate of vaccine benefit. Most of our assumptions have been used in previous benefit-cost analyses and, to facilitate comparability, we have used similar figures where appropriate.

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**Measles, Rubella, and Mumps**

Specific estimates and assumptions were made in calculating disease incidence, frequency of complications, and costs, and are summarized in Appendix I. Cases predicted in the absence of a vaccination program were calculated according to the method described above. Cases having actually occurred in 1983 were calculated based on reported cases and the estimated reporting efficiency. Estimated incidence of complications was calculated using our estimated number of cases, and commonly accepted, published rates for complications. Complication rates were considered to be equal in both vaccinated and unvaccinated populations.

Direct costs included physician visits, hospitalization, supportive medical care, special schooling, and institutionalization. Indirect costs included wages lost from missed work, and lifetime earnings lost due to retardation or death. We calculated time lost from work, considering that in 1983 approximately 65 per cent of women between the ages of 20 and 40 were employed<sup>12</sup> and that, in those families where both parents were employed, one of the parents would be required to take time off from work to stay at home with a sick child.

**Costs of Immunization**

Costs for the immunization program included expenditures for public sector immunization programs, for private immunization, and for vaccine-related reactions requiring medical consultation. One-half of all children were assumed to receive their immunization from a private practitioner. Vaccine and program cost estimates were provided by the Immunization Division, Centers for Disease Control. Federal and state costs for immunization programs were estimated based on federal expenditures and grants to states. Costs for local health departments were assumed to be equal to one-half state and federal expenditures for immunizations.

**Results**

An MMR immunization program is associated with a considerable reduction in the morbidity and mortality associated with measles, rubella, and mumps in 1983 when compared to a situation without an MMR vaccination program (Table 1).

Cases of measles decreased from an expected 3,325,000 to 2,872 cases, while measles-related mortality was reduced from 366 deaths to less than one; the number of children handicapped by the neurological sequelae of measles decreased from 291 to less than one. Comparable impressive reductions are documented for rubella and mumps and their associated complications and mortality in Table 1.

Costs associated with measles, rubella, and mumps in 1983 totaled nearly \$14.5 million with a vaccination program, as contrasted to \$1.4 billion in the absence of a vaccination program (Table 2). Reduction in morbidity and mortality costs attributable to measles totaled almost \$670 million. For rubella, the comparable figure is almost \$380 million; for mumps it is almost \$340 million. The total reduction in morbidity and mortality costs amounts to almost \$1.3 billion.

The overall cost estimates for morbidity and mortality associated with measles, rubella, and mumps both in the absence and presence of a vaccination program, as well as the costs of the nationwide MMR immunization program in 1983, are summarized in Table 3. The estimated costs for both public and private MMR immunizations totaled about \$94 million. Costs related to adverse vaccine reactions were

**TABLE 1—Morbidity and Mortality with and without a Vaccination Program for 1983**

Disease	Without a Vaccination Program	With a Vaccination Program
<b>MEASLES</b>		
Cases of measles	3,325,000	2,872
Cases of measles encephalitis	1,164	1
Number with neurologic sequelae	291	<1
Deaths secondary to encephalitis	175	<1
Cases of SSPE	33	<1
Deaths (including SSPE)	366	<1
<b>RUBELLA</b>		
Cases of clinical rubella*	1,487,500	3,816
Cases of Thrombocytopenic Purpura	57	<1
Deaths secondary to TCP	2	<1
Cases of encephalitis	21	<1
Deaths secondary to encephalitis	4	<1
Cases of Congenital Rubella Syndrome (CRS)	2,000	40
Complications of Congenital Rubella Syndrome (CRS)		
Deaths secondary to CRS	400	8
Number of moderately deaf	376	7.5
Number of totally deaf	390	7.8
Number requiring heart surgery	560	11.2
Number with cataracts	320	6.4
Number with permanent blindness	22	<1
Number with moderate retardation	134	2.7
Number with severe retardation	160	3.2
<b>MUMPS</b>		
Cases of clinical mumps	1,890,000	32,850
Cases of meningitis	1,890	33
Cases of encephalitis	2,835	49
Deaths secondary to encephalitis	40	<1
Cases of hearing impairment		
Mild	85	1.5
Moderate	9	<1
Severe	1	<1
Cases of orchitis	33,075	575

\*The population at risk for complications of rubella were considered only to be those individuals who consulted a physician.

about \$2 million. The benefit-cost ratio for MMR immunization programs is 14.4:1. Using the same methodology, but assuming single antigen vaccine, the benefit-cost ratios for measles, rubella, and mumps were 11.9:1, 7.7:1, and 6.7:1, respectively (Table 3). The savings realized due to the use of combined versus single antigen vaccine total nearly \$60 million.

**Discussion**

This study demonstrates the tremendous reductions in morbidity, mortality, and financial expenditures realized as a result of the measles, rubella, and mumps immunization programs. With both measles and mumps, the greatest financial benefit is gained predominantly from savings associated with uncomplicated illness (the majority of which are indirect costs). The most significant cost factors associated with rubella are related to the long-term sequelae of congenital rubella.

The resulting benefit-cost ratio of over 14:1 is of such magnitude that even if particular assumptions and rates used in our calculations are thought to be incorrect, wide latitude exists for altering these estimates while still yielding a high benefit-cost ratio. We selectively altered a variety of our assumptions in an effort to test the sensitivity of our analyses. Altering the values for single variables had a negligible impact on the overall benefit-cost ratio. Increasing the actual number

**TABLE 2—Effect of Measles, Rubella, and Mumps Vaccination on Costs of Disease for 1983**

Cost Components	Without a Vaccination Program	With a Vaccination Program
<b>MEASLES</b>		
Direct	\$ 160,948,786	\$ 160,561
Indirect	\$ 508,963,070	\$ 439,622
<b>RUBELLA</b>		
Direct		
—acute	\$ 4,600,049	\$ 51,308
—CRS	\$ 121,002,219	\$ 2,420,044
Indirect		
—acute	\$ 166,984,895	\$ 218,376
—CRS	\$ 94,613,965	\$ 5,113,782
<b>MUMPS</b>		
Direct	\$ 6,720,494	\$ 157,871
Indirect	\$ 338,784,288	\$ 5,891,726
Subtotal	\$1,402,617,766	\$ 14,453,290
<b>IMMUNIZATION COSTS (MMR)</b>		
Vaccine and Program		\$ 94,149,998
Adverse Reactions		\$ 2,042,045
Totals	\$1,402,617,766	\$110,645,333

Benefit-cost ratio = 14.4:1

**TABLE 3—Summary of Benefits & Costs of Immunization for Measles, Rubella, and Mumps for 1983**

Vaccine	Disease Savings	Program Costs	Benefit:Cost Ratio
Measles	\$ 669,311,673	\$55,989,233	11.9:1
Rubella	\$ 379,397,618	\$49,248,749	7.7:1
Mumps	\$ 339,455,185	\$50,666,249	6.7:1
Combined (MMR)	\$1,388,164,476	\$96,192,043	14.4:1

of cases of measles, mumps, and rubella occurring with a vaccination program by a factor of four still produced a benefit-cost ratio of 13.9:1. Indirect costs comprise a large proportion of the expenditures associated with these diseases. Excluding indirect costs completely, the resulting benefit-cost ratio would be approximately 3.0:1.

While immunization is associated with significant reductions in all disease-related complications, this effect is not necessarily equal and proportional in all cases. The ratio of congenital rubella syndrome (CRS) to rubella cases differs with and without a vaccination program, 40:3816 (or 1:95) compared to 2000:1,487,500 (or 1:744). The higher ratio of CRS cases to overall rubella cases with a vaccination program reflects the altered age-distribution of cases when there is an immunization program. With an immunization program, a greater proportion of the infections occur in young adults, and thus there is a proportionate increase in the number of infections in pregnant women although the absolute number of cases is markedly reduced.

In our calculations, we did not make allowances for the possibility that pregnant women contracting rubella might choose to terminate their pregnancy. This would alter the costs which largely can be attributed to CRS. However, even if as many as 90 per cent of those at risk had abortions, without any cost attributed to the procedures and care, the overall benefit-cost ratio would still be almost 12.5:1. Of course, this calculation as with the others in this analysis does not consider the intangible losses of grief and suffering.

The model also allows us to compare the benefit-cost ratios for separate immunizations with single antigen vaccines (M + M + R) with that of combined vaccine using our same model. We assumed that public program costs remained unchanged. The calculated benefit-cost ratio for combined vaccine substantially exceeds the benefit-cost ratios for the individual components. The savings using combined vaccine are primarily generated as a result of reduced physician visits, more efficient administration, less expensive vaccine costs, and a lower overall number of adverse vaccine reactions. Other advantages not given economic credits in this study include more uniform coverage, with a reduction in the number of both missed and reimmunized individuals, and reduced administrative and personnel requirements.

While this study demonstrates the added benefit realized from the use of combination as opposed to single antigen vaccine, the benefits of combination vaccine have been underestimated in our model. We did not consider that there was any decrease in public expenditures for immunization with combination vaccine. Yet, we know that in 1983 approximately 10 per cent of vaccine used in public immunization programs was single antigen; if only combination vaccine was used, there would have been an additional savings of \$320,000 in vaccine costs, as well as additional savings from fewer physician visits and other administrative costs.

Combined measles, mumps, and rubella vaccine (MMR) has been available in the United States since 1971. Seroconversion rates and reaction rates are not significantly different from those occurring when the antigens were administered separately at different times.<sup>26-32</sup> Despite the fact that there are no valid scientific reasons for using the three single antigen products in persons likely to be susceptible to multiple components, these individual antigens continue to be used in some settings, requiring the patient to make multiple visits before protection against the three diseases is assured.

Vaccination policy for rubella control varies from country to country. In the United States, the goal has been to interrupt or curtail transmission by universal vaccination of infants and young children.<sup>33</sup> This allows administration of rubella vaccine with measles and mumps simultaneously in a single vaccine for infants, resulting in marked economic savings compared to use of the single antigens. Other countries such as the United Kingdom vaccinate females approaching puberty. This means that separate visits are needed for measles vaccine in infancy and rubella vaccine in 11-12 year old girls. While many factors must be considered in determining vaccination policies for rubella control including accessibility of target populations, vaccine safety and efficacy, and coverage rates, the savings afforded through use of combined vaccines should be considered in those countries embarking on or continuing rubella control programs.

Although not directly comparable due to differences in the models used, our results parallel and are supported by earlier studies.<sup>5-9,24</sup> While individually all these programs show impressive benefits, there is substantial financial advantage to the use of combined vaccine (MMR). Our study clearly demonstrates the extraordinary benefits of a combined measles, rubella, and mumps immunization program in reducing both the burden of illness and its resulting costs.

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## APPENDIX

## Assumptions Used in MMR Benefit-cost Calculations

Variable	Rate	Number	Cost	Duration	Discounted Total	References*
<b>General Costs</b>						
Physician visit			\$25			17
Hospitalization						
regular			\$375			18
ICU			\$750			
Telephone consultation			\$10			
Time lost for follow-up MD visit		1 hour				
Lost wages from missed work (per day)			\$40			12
Lifetime lost earnings (death)					\$62,200	34
<b>Measles</b>						
Infection rate in unvaccinated population	95%					
—cases in absence of vaccination program		3325000				
Reported cases in 1983 (provisional)		1436				22
Actual cases (assumes 50% reporting efficiency)		2872				
MD visits:						
—without immunization program	20%					
—with an immunization program	50%					
Hospitalization rate	1.5%					13
—median hospital stay		4 days				13
—follow-up MD visits		2				
Measles Encephalitis:						
—rate per measles cases	.35/1000					1
—days in hospital						
ICU		3				
regular		7				
—number without sequelae	60%					14
follow-up MD visits		4				
follow-up testing			\$100			
—number with neurologic sequelae	25%					
—case fatality rate	15%					
SSPE (occurs on average 7 years post-measles infection; death is assumed to occur over 1 year)	1/100000		\$15,000		\$8,000	15, 16
Lost Time/Earnings						
Uncomplicated measles		3.5 days				20
Hospitalized cases		4.5 days				
Measles encephalitis cases		7 days				
Measles encephalitis brain damage					\$62,200	34
<b>Rubella</b>						
Infection rate in unvaccinated population	85%					21
—number with clinical illness	50%					7
—number <15 years old	90%					
—cases in absence of vaccination program		1487500				
Reported cases in 1983 (provisional)		954				25
Actual cases (assumes 25% reporting efficiency)		3816				
MD visits: (of those with clinical illness)						
—without an immunization program:						
<15 y/o	10%					
15+ y/o	25%					7
—with an immunization program	50%					
Thrombocytopenic Purpura						7
—rate per clinical rubella cases	1/3000					
—days in hospital		10				
—follow-up MD visits		2				
—case fatality rate	4%					
Encephalitis						7
—rate per clinical rubella cases	1/8000					
—days in hospital:						
ICU		3				
regular		7				
—follow-up MD visits		2				
—follow-up testing			\$100			
—case fatality rate	20%					
CRS cases: —without an immunization program		2000				7,000
with an immunization program		40				25,000
—days of acute hospital care: ICU		5				7
regular		5				7
—case fatality rate	20%					7
Long-term CRS survivors: complications						7
—moderate deafness requiring special school	23.5%		\$10,000/yr	10 yrs	\$71,445	
—total deafness requiring special school	24.5%		\$10,000/yr	20 yrs	\$95,134	
—congenital heart defects requiring surgery	35%		\$10,000			
—cataracts requiring surgery	20%		\$2,000			
(15% failure rate resulting in blindness)						

**Assumptions Used in MMR Benefit-cost Calculations (continued)**

Variable	Rate	Number	Cost	Duration	Discounted Total	References*
—blindness requiring special school/equipment	1.4%		\$20,000/yr	20 yrs	\$190,268	
—moderate retardation requiring special school	8.4%		\$10,000/yr	20 yrs	\$71,445	19, 33
—severe retardation requiring institutional care	10%		\$20,000/yr	40 yrs	\$215,576	19, 33
Lost Time/Earnings						
Uncomplicated rubella illness		2.8 days				7
Thrombocytopenic Purpura		3.5 days				
Encephalitis cases		3.5 days				
CRS complications						7
—moderate deafness		200 hrs/yr		5 yrs		
—total deafness		200 hrs/yr		5 yrs		
—congenital heart defects		30 hrs				
—cataracts		10 hrs				
—blindness		24 hrs/yr		5 yrs		
—moderate retardation		24 hrs/yr		5 yrs		
—severe retardation		24 hrs/yr		5 yrs		
Lifetime disability among CRS survivors	67%		\$62,200			7, 33, CDC
<b>Mumps</b>						
Infection rate in unvaccinated population	90%					8
—number with clinical illness	60%					8
—cases in absence of vaccination program		1890000				
Reported cases in 1983 (provisional)		3285				22
Actual cases (assumes 10% reporting efficiency)		32850				
MD visits: (of those with clinical illness)						
—without an immunization program	5%					
—with an immunization program	10%					
Meningitis						4
—rate per case of clinically apparent mumps	1/1000					
—number hospitalized	25%					
—days in hospital		1				
—follow-up MD visits		2				
—case fatality rate	0%					
Encephalitis						4
—rate per case of clinically apparent mumps	1.5/1000					4
—number hospitalized	50%					8
—days in hospital		5				
—follow-up MD visits		2				
—follow-up testing			\$100			
—case fatality rate	1.4%					4
Hearing Impairment Cases	1/20000					4, 8
—number with minor hearing impairment	90%		\$350			
—number with moderate hearing impairment	9%		\$2,500			8
—number with total hearing impairment	1%		\$10,000	20 yrs	\$95,134	8
Orchitis (occurs in males >15 y/o)						4, 8
—assumes half of all mumps cases are in males						
—14% of males are >15 y/o						
—rate in males >15 y/o	25%					8
—MD visits		1				
—number hospitalized	1%					
—hospital days		2				
Lost Time/Earnings						
Uncomplicated mumps		4 days				8
Encephalitis						
—not hospitalized		3.5 days				
—hospitalized		5 days				
Meningitis		2.5 days				
Hearing Impairment						8
—moderate hearing loss		200 hours		5 yrs		
—total hearing loss		200 hours				
Orchitis						8
—not hospitalized		5 days				
—hospitalized		6 days				
Lost income due to disability						
—moderate hearing loss					\$31,100	34
—total hearing loss					\$62,200	34
<b>IMMUNIZATION PROGRAM</b>						
<b>Private Costs</b>						
—office visit for immunization					\$15.00	
—vaccine costs: measles vaccine					\$4.26	CDC
rubella vaccine					\$4.76	CDC
mumps vaccine					\$5.57	CDC
MMR vaccine					\$11.30	CDC
<b>Public Program Costs**</b>						
—federal and state expenditures for immunization total \$27.5 million each						
—local costs are equal to half of total federal and state expenditures						
—measles: federal share (1/3 of immunization budget)					\$9,166,667	

**Assumptions Used in MMR Benefit-cost Calculations (continued)**

Variable	Rate	Number	Cost	Duration	Discounted Total	References*
state share (1/6 of immunization budget)					\$4,583,333	
local health department share					\$6,875,000	
—rubella: federal share (1/6 of immunization budget)					\$4,583,333	
state share (1/6 of immunization budget)					\$4,583,333	
local health department share					\$4,583,333	
—mumps: federal share (1/6 of immunization budget)					\$4,583,333	
state share (1/6 of immunization budget)					\$4,583,333	
local health department share					\$4,583,333	
<b>Adverse Vaccine Reactions</b>						
—assumes 3,500,000 individuals all receive immunizations						
—for all adverse vaccine reactions, it is assumed that half require only a telephone consultation and half require a physician visit.						
—both measles and MMR vaccine have associated with them a post-vaccination encephalitis which occurs only once per million doses; costs, both direct and indirect, are the same as for measles encephalitis						CDC
—measles: 7.5% have some reaction,						23
25% severe enough to require consultation					\$1,148,438	23
—post-vaccination encephalitis				3.5	\$510,795	
—rubella: 6% have some reaction,						23
25% severe enough to require consultation					\$918,750	23
—mumps: 6% have some reaction,						23
25% severe enough to require consultation					\$918,750	23
—MMR: 10% have some reaction,						23
25% severe enough to require consultation					\$1,531,250	23
—post-vaccination encephalitis				3.5	\$510,795	

\*Where no reference is listed, published references were unavailable or inadequate, estimates were made with the assistance of experts in epidemiology of vaccine-preventable diseases. Estimated lost earnings due to death or disability are derived from reference number 35, adjusted to a 1983 base year by adding 10% per year for inflation.

\*\*Public program costs were assumed to be identical regardless whether single antigen or combined antigen vaccine was administered.

NOTE: CDC used as reference refers to data provided by Immunization Division, Centers for Disease Control, 1984.

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