MAJOR ARTICLE

The Number Needed to Vaccinate to Prevent Infant Pertussis Hospitalization and Death Through Parent Cocoon Immunization

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(See the Editorial Commentary by Healy and Baker, on pages 328–30.)

Background. Parental immunization has been recommended as a "cocoon" strategy to prevent serious pertussis outcomes in early infancy. We illustrate the high number needed to vaccinate (NNV) for this program based on recent epidemiologic data from the provinces of Québec and British Columbia (BC), Canada.

Methods. Surveillance trends were summarized for the period 1990–2010. Hospitalization, intensive care unit (ICU) admission, and mortality data were compiled from 2000 to 2009. The proportion of infant pertussis attributed to a parent was estimated at 35%, explored up to 55%. Adult vaccine efficacy (VE) was estimated at 85%. The NNV was calculated as [2 parents/(parent-attributable infant risk × parent VE)]. To capture at least 1 recent cyclical peak, NNV was derived for the period 2005–2009 and explored for peak/trough years.

Results. Substantial decline has occurred in pertussis incidence across all age groups including infants, reaching a 20-year nadir in 2010 in both provinces. For the period 2005–2009, the risk of infant hospitalization and ICU admission was 57 and 7, respectively, per 100 000 in Québec and 33 and 7, respectively, per 100 000 in BC. In both provinces the risk of infant pertussis-related death over that period was <0.5 per 100 000. The NNV for parental immunization was at least 1 million to prevent 1 infant death, approximately 100 000 for ICU admission, and >10 000 for hospitalization.

Conclusions. In the context of low pertussis incidence, the parental cocoon program is inefficient and resource intensive for the prevention of serious outcomes in early infancy. Regions contemplating the cocoon program should consider the NNV based on local epidemiology.

As found elsewhere, pertussis is endemic in Canada with cyclical peaks occurring every 3–5 years. After the introduction of whole-cell pertussis vaccine in Canada in 1943, overall pertussis incidence per 100 000 dropped by >90% from cyclical peaks of >150 in the mid-1930s to peaks of <10 in the mid-1980s (and an all-time low of 4 per 100 000 in 1988) [1–3].

The pediatric immunization schedule in Canada has long included a dose of pertussis-containing vaccine given at 2, 4, and 6 months, with booster doses at 18 months and 4–6 years of age [1–4]. Despite consistently high vaccine coverage, pertussis incidence in Canada increased through the 1990s and remained elevated in the early part of the new millennium [1–4]. In several provinces, dramatic peaks were accompanied by shifts in the age distribution toward preteens and teens [5, 6]. In the province of British Columbia (BC), the shift in age distribution was so dramatic that incidence among preteens and teens surpassed even that of infants and preschool children during large epidemics in 2000 and 2003 [5].

Infants, notably those <3 months, remain at highest risk of pertussis-related hospitalization, intensive care unit (ICU) admission, and death [5–8]. The prevention

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of these serious outcomes in a very young is a main goal of the pertussis immunization program [9]. Toward that goal, the whole-cell pertussis vaccine, recognized to be of suboptimal efficacy in Canada, was switched to a more efficacious and less reactogenic acellular version beginning in 1997–1998 [1–3, 8, 10, 11]. In 2004, most provinces also combined acellular pertussis vaccine with tetanus-diphtheria booster immunization for adolescents to address their high incidence [2, 4, 12, 13]; in the provinces of Québec and BC, this dose is administered at 14–15 years of age. Some provinces (ie, Québec), but not all (ie, BC), also implemented a single adult booster dose using the same combined tetanus-diphtheria-acellular pertussis (TdaP) vaccine. In Québec the adult TdaP program has been offered opportunistically since 2004 to those with tetanus booster indication, but the estimated annual coverage in adults 18–64 years remains low and stable at approximately 5% in 2010 [14].

Some protection against severe pertussis is afforded in the very young with a single dose of acellular pertussis vaccine [7, 15, 16]. However, current pediatric schedules recommend routine pertussis immunization beginning only at 8 weeks of age—narrowed to 6 weeks during outbreaks [1–4, 17]. Consequently, newborns <2–3 months of age remain most vulnerable and unprotected. To address this short interval of intense risk, the "cocoon" approach has been proposed in some countries such as the United States, Australia, and France as a further measure for the prevention of newborn pertussis [18–22]. For the cocoon approach, parents or other close contacts are vaccinated as soon as possible after the birth of their child to prevent pertussis infection and onward transmission to the newborn.

The basic assumptions of the cocoon program are that a substantial proportion of newborn/infant pertussis is acquired from their closest contacts (notably parents, grandparents, or siblings) and can be indirectly prevented through effective close-contact immunization. To provide substantial benefit, however, the cocoon program also presupposes a high incidence of serious pertussis disease (notably ICU admission and death) in infants. As such, a recommendation for the cocoon program is crucially dependent upon the epidemiologic context in which it is being proposed. To date, however, no published reports or recommendations have taken that context into account to quantify the number of parents that would need to be vaccinated to prevent a single hospitalization or death in the newborn/infant. We assess the number needed to vaccinate (NNV) based on updated epidemiologic data in 2 of the largest provinces of Canada where pertussis trends have previously been described [5, 6]: Québec in eastern Canada (population ~7.4 million and birth cohort ~85 000) and BC on the western coast (population ~4.5 million and birth cohort ~40 000). Because most siblings are already included in the routine pediatric schedule, we focus here on the NNV for parental cocoon immunization.

METHODS

Pertussis Incidence Trends and Infant Risk

Pertussis is notifiable in Québec and BC. Cases are reported as confirmed (by laboratory testing or by epidemiologic link to a confirmed case) or clinical/probable (≥2 weeks of paroxysmal cough or cough ending in vomiting, apnea, or inspiratory whoop for which there is no other cause).

In Québec, hospital laboratories conduct pertussis testing. One of these laboratories (a tertiary pediatric hospital) uses polymerase chain reaction (PCR) as the only method of pertussis diagnosis, and the rest use culture only. In BC, the majority of pertussis testing is conducted at the BC Centre for Disease Control (BCCDC) Public Health Microbiology and Reference Laboratory; testing is also conducted at the Microbiology Laboratory of the BC Children's Hospital. In April 1998, PCR was routinely added to the laboratory assessment of all specimens submitted for pertussis testing at the BCCDC with specimens undergoing testing by both culture and PCR [5].

All pertussis reports (confirmed and clinical/probable) in Québec and BC between 1990 and 2010 were compiled. Trends in age-specific incidence were plotted for 1995–2010.

Mortality data were summarized for the period 2000–2010 using *International Classification of Diseases, Tenth Revision* (*ICD-10*) codes A370 (*Bordetella pertussis*) and A379 (pertussis/whooping cough). Acute care hospitalizations and ICU admissions with pertussis listed as the primary or first 2 secondary diagnoses were summarized for the period 2000–2009. *International Classification of Diseases, Ninth Revision* (*ICD-9*) codes 330/339 were used with the corresponding *ICD-10* A370/A379 conversions from 1 April 2006 in Québec and 1 April 2001 in BC. Pertussis-related deaths, hospitalizations, and ICU admissions were summarized with focus on newborn/infant risk using the birth cohort as denominator for a given year.

Proportion of Infants Infected by Parents and Parent Vaccine Effectiveness

A review of the published literature was conducted to summarize the proportion of confirmed infant pertussis acquired from a parent and to derive the parent-attributable infant risk. Original studies that specifically assessed and separately presented the source of infant infection and provided methodological details related to source ascertainment were included. Vaccine effectiveness (VE) in young adults was also estimated from the published literature to derive the vaccine-preventable fraction.

Number Needed to Vaccinate

The NNV for the cocoon program was derived as the inverse of the absolute risk reduction (ARR) for pertussis-related hospitalization, ICU admission, and death, multiplied by 2 parents. The ARR is the product of the parent-attributable infant risk and the parent VE in preventing that risk.

The NNV for parent immunization to prevent infant hospitalization/ICU admission or death was thus calculated as follows:

$$NNV = 2\,parents \times (1/ARR)$$

$$NNV = 2\,parents \times [1/(Parent\text{-}attributable\,Infant\,Risk \times Parent\,VE)]$$

Where *Parent-attributable Infant Risk* = *Infant Risk* × *Proportion of Infants Infected by Parents*.

To capture at least 1 cyclical peak and to reflect recent trends in pertussis risk, the NNV was calculated for the most recent period (2005–2009), including years with the highest (2009 in Québec; 2005 in BC) and lowest (2007) pertussis-related hospitalization rates. This was derived by province and infant age <12 months, <6 months, and <3 months.

RESULTS

Pertussis Incidence Trends and Infant Risk

Asynchronous cyclical peaks in provincial pertussis incidence from 1990 to 2010 are shown in Figure 1. After dramatic epidemics in the mid-to-late 1990s and early millennium, the magnitude of provincial peaks has steadily and substantially decreased in both provinces. Peak incidence per 100 000 was recorded in Québec in 1998 (69) and in BC in 2000 (45). Although some cycling variation is still evident, neither province has experienced a significant provincial peak since 2003 with overall incidence in both provinces at or below 10 per 100 000 since 2005. In 2010, overall pertussis rates were the lowest in >20 years in both provinces (1.4 in Québec and 2.8 in BC).

The same pattern of steadily declining incidence is evident in all age categories, including infants shown for the period 1995–2010 in Figure 2*A* and 2*B* (Québec) and Figure 3*A* and 3*B* (BC). In Québec, infant pertussis rates per 100 000 have fallen from a high of 396 in 1998 to a high since 2005 of 116 (in 2009) and an all-time low of 20 in 2010. In BC, infant pertussis rates have fallen from a high of 242 per 100 000 in 1996 to consistently <60 since 2005 and an all-time low of 19 per 100 000 in 2010.

Since 2000, infants, especially those <3 months, have continued to experience the highest risk of pertussis-related hospitalization and ICU admission (Table 1). In Québec, the lowest infant hospitalization rate per 100 000 since 2000 was observed in 2007 (22) and the highest in 2009 (89), averaging 57 between 2005 and 2009. In BC, hospitalization rates among infants fell from a high of 70 per 100 000 in 2000 to a low of 14 in 2007, averaging 33 between 2005 and 2009. Although hospitalization data for 2010 are still incomplete, case notifications in both provinces suggest that hospitalization and ICU admission rates will be even lower for 2010.

Among all hospitalized infants in Québec since 2000, 10% were admitted to an ICU—14% aged <3 months and 5% aged 3–11 months. Among hospitalized infants in BC, 19% were admitted to an ICU—23% aged <3 months and 10% aged 3–11 months.

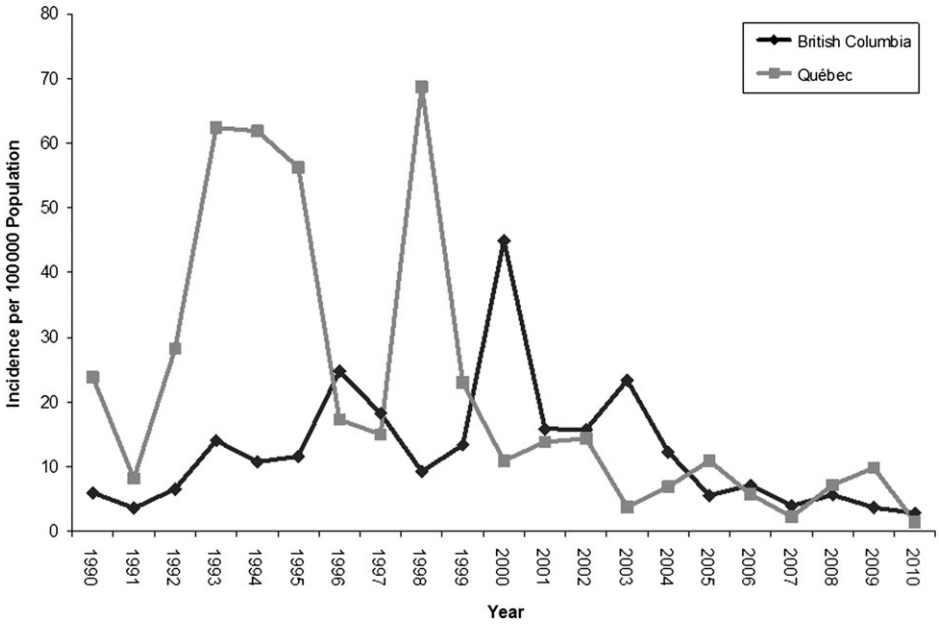

Figure 1. Overall incidence of pertussis in Québec and British Columbia per 100 000 population, 1990–2010.

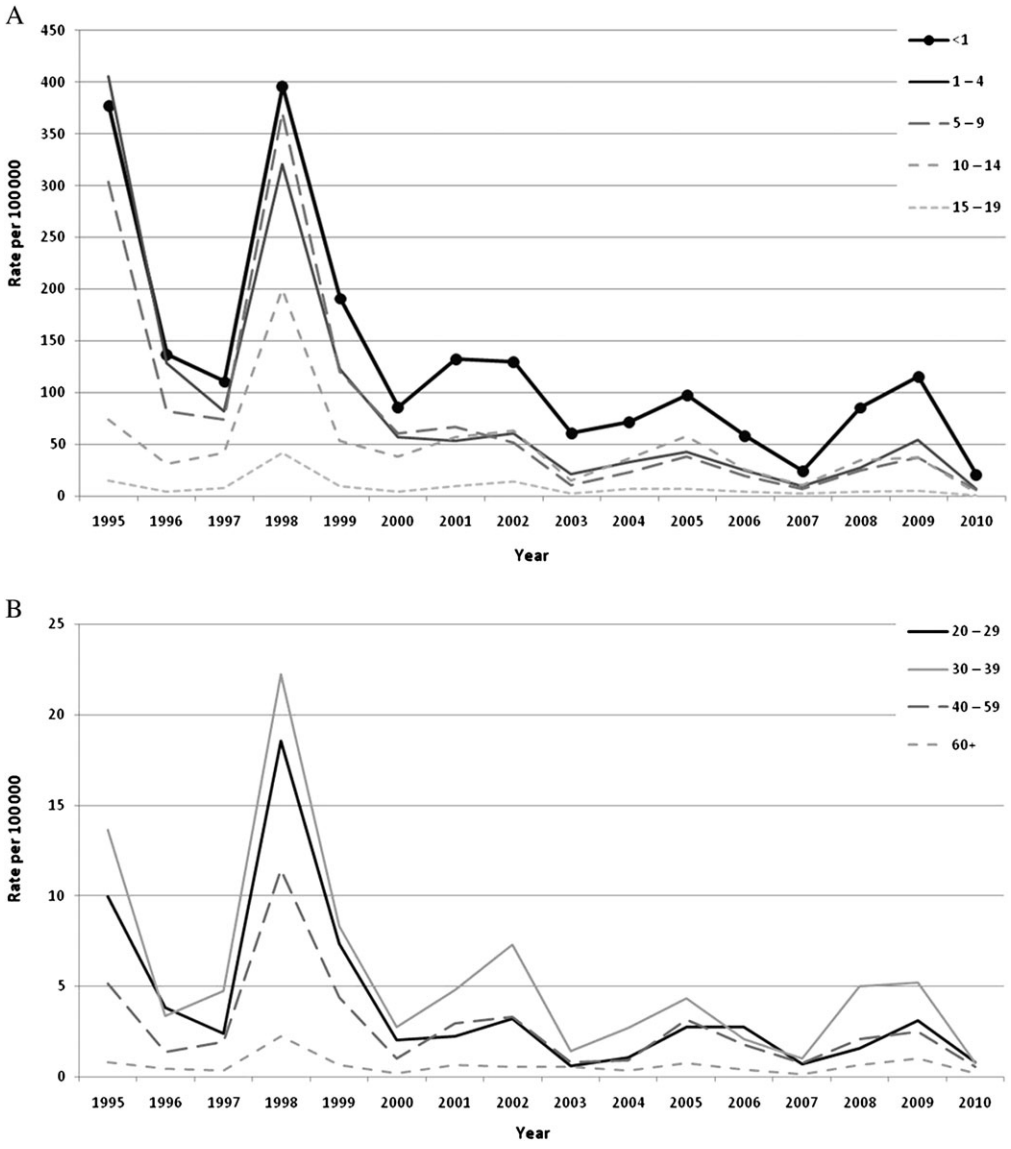

Figure 2. Annual incidence of pertussis per 100 000 in Québec by (*A*) pediatric age categories <20 years and (*B*) adult age categories ≥20 years, 1995–2010.

Since 2000, there were 2 infant pertussis deaths recorded in each province (all <3 months), including 2 in Québec and 1 in BC since 2005. On that basis, the infant pertussis-related mortality risk was <0.5 per 100 000 in both provinces for the period 2005–2009.

Beyond 5 years of age, serious outcomes due to pertussis were rare (data not shown).

Proportion of Infants Infected by Parents and Parent VE

Studies that were included in estimating the proportion of infant pertussis likely attributable to parents are listed in Table 2 [7, 23–28]. Other studies were additionally reviewed but ultimately excluded because details related to ascertainment of the primary source as parents were incomplete or noninterpretable [29–32] or not separately presented for infants [33, 34].

For 41%–73% of infected infants, the source of infection was not found. When a source of infection was found, 20%–60% of infant infections were attributed to parents, more often the mother (range 38%–50%) than the father (range, 10%–17%). However, when considering all infant cases by study, parents were the possible source of infection among 8%–42% of infant pertussis (Table 2). The most recent literature from the Netherlands [23] concluded that 35%–55% of infant cases could be prevented through parent immunization. Overall, based on our review, parental contribution to infant pertussis infection is unlikely to exceed 50%–60% and is probably <40% (Table 2).

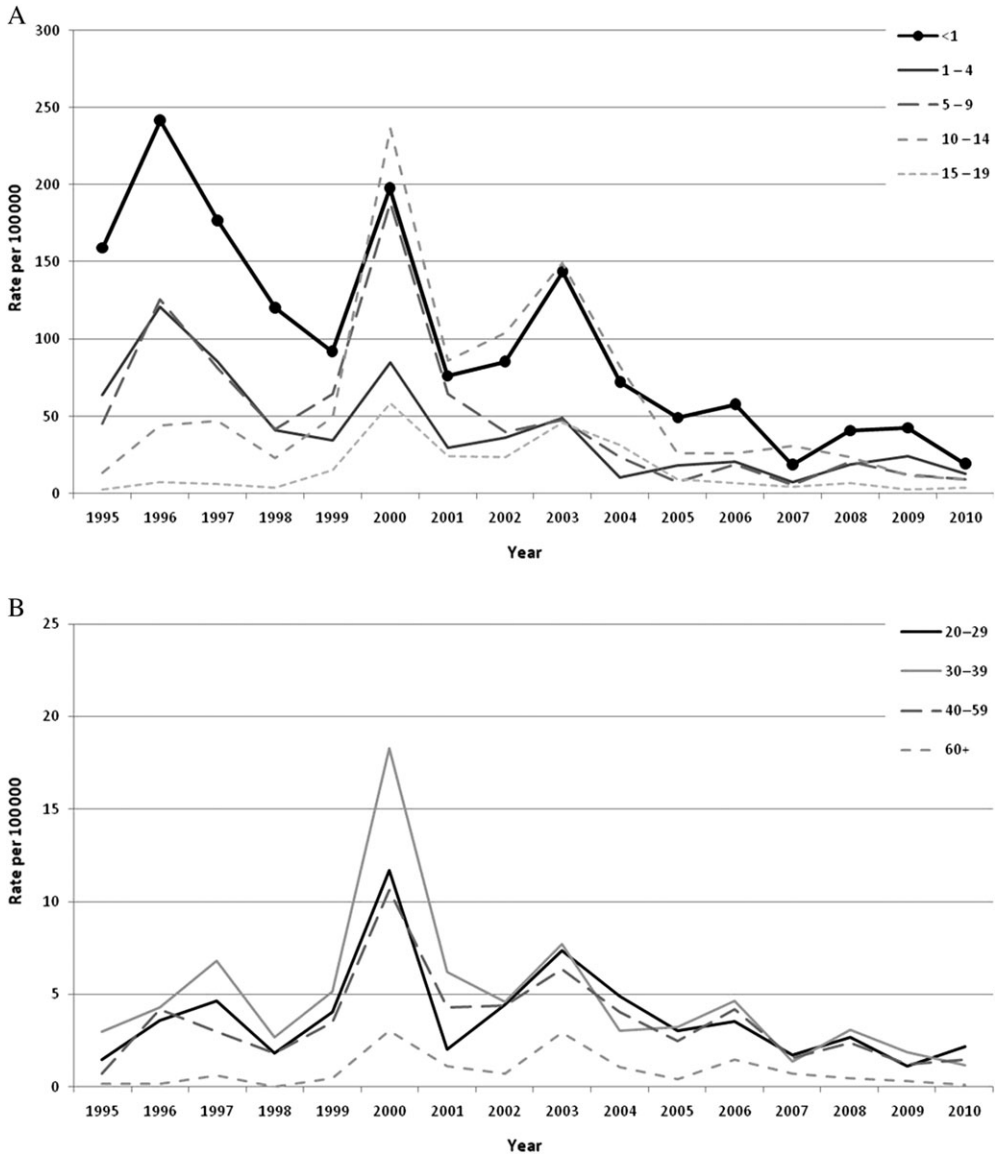

Figure 3. Annual incidence of pertussis per 100 000 in British Columbia by (*A*) pediatric age categories <20 years and (*B*) adult age categories ≥ 20 years, 1995–2010.

We thus estimated NNV based on a parent-attributable infant risk of 35% and explored this up to 55%.

There are limited direct VE data for a single dose of acellular pertussis vaccine in adults. The only randomized placebo-controlled clinical trial that directly assessed efficacy in adults found a point estimate of 92% for a single dose of monovalent tricomponent acellular pertussis vaccine, but cases were not numerous and the confidence interval was wide (32%–99%) [35]. However, a single dose of vaccine in adolescents/adults increased pertussis antibody levels in excess of those observed among Swedish infants given 3 doses of a 5-component acellular pertussis vaccine and in whom VE was 85% [12, 36]. In adolescents, VE for a single dose of TdaP varied from 65.6%–85.4% in 2 observational field studies [37, 38]. For the current analysis, we thus assumed parental VE of 85%.

Number Needed to Vaccinate

For the period 2005–2009, the NNV to prevent infant hospitalization, assuming parents account for 35% of infant illness, exceeded 10 000 in Québec and 20 000 in BC (Table 3). Assuming parents account for as much as 55% of infant illness, the NNV would still exceed 5000 in both provinces. During the most recent cyclical peak, NNVs would exceed 4500 and during the trough 2007 year, NNVs would be 20 000 or more, in both provinces.

The NNV to prevent infant ICU admission is even higher (Table 3). In both provinces for the period 2005–2009,

Table 1. Risk of Pertussis Hospitalizations per 100 000 by Age

	Year									
Age	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Québec, 2000–2009										
0–<3 months[a]	35	34	42	21	14	22	29	15	49	50
3–<6 months[a]	18	27	26	10	6	15	18	6	20	25
6–<9 months[a]	3	10	4	3	5	2	4	0	4	6
9–<12 months[a]	1	1	4	1	2	6	2	0	1	8
<12 months[a]	57	72	76	35	27	45	53	22	74	89
1–4 years	6	3	6	1	4	4	3	1	1	4
British Columbia, 2000–2009										
0–<3 months[a]	56	44	23	42	30	39	31	9	14	20
3–<6 months[a]	12	12	15	12	7	10	7	2	7	7
6–<9 months[a]	2	0	5	0	2	10	2	2	7	0
9–<12 months[a]	0	2	0	0	0	0	0	0	0	0
<12 months[a]	70	59	43	54	40	59	41	14	27	27
1–4 years	0	0	0	0	0	0	0	0	0	0

[a] Used in number needed to vaccinate calculation with denominator the birth cohort for the specified year.

approximately 100 000 parents would need to be vaccinated to prevent 1 infant ICU admission if they account for 35% of infant illness and more than 60 000 if they account for as high as 55%. During the most recent cyclical peak, NNVs to prevent ICU admission would still be 25 000 or more in both provinces. During the trough 2007 year, NNVs would be 200 000 or more in Québec and in BC would be incalculably high.

The parental NNV to prevent hospitalization or ICU admission in infants <6 months or <3 months is even higher (Table 3). For the period 2005–2009, the parental NNV to prevent one infant pertussis-related death would exceed 1 million at 35% parental attribution and at 55% would still approach that magnitude.

DISCUSSION

The main objective of the parental pertussis cocoon program is to prevent serious infant pertussis disease. As such, its utility is predicated on a high absolute rate of severe morbidity and mortality to be prevented in newborns and substantial parental contribution to that. Despite broad recommendation and promotion of cocoon immunization [17–21], ours is the first publication to assess the number of parents that would need to be vaccinated to prevent infant hospitalization or death through the cocoon approach.

We highlight a very high NNV for the pertussis cocoon program. This should not be unexpected given the low incidence of severe pertussis illness in recent years in Québec and BC. After the introduction of more effective acellular pertussis immunization for children in Canada in 1997–1998 and adolescents in 2004 as well as sequential large epidemics in the mid-to-late 1990s and early millennium, there has been substantial decline in pertussis rates across all age groups including infants, in both provinces. As incidence rates become lower, the resources required to achieve further reduction in disease rates become far greater—especially to prevent outcomes such as death that are rare at the outset.

For the most recent period (2005–2009), the NNV for the most severe but rare outcome of infant pertussis death was at least 1 million, for ICU admission it was approximately 100 000, and for hospitalization it was >10 000 based on 35% parent-attributable infant risk. The range of parental attribution we explored (35%–55%) would result in conservative estimates of the NNV. As shown in Table 2, even a 35% parental attribution is more than expected for either parent after accounting for when the source could not be identified and when in that instance it was less likely to have been a parent. By further allowing for even as much as 55% of infants to have been infected by their parents, we show that the NNV remains high even with extreme assumptions of parental contribution. These estimates are based on parental immunization to prevent serious pertussis outcomes across the first full year of life: for the abbreviated period of risk concentrated in the first 3–6 months of life, the NNV increases owing to a shortened timeline for impact (Table 3). The fertility rate per woman is 1.7 in Québec and 1.5 in BC [39] with a distribution of 35%–40%, 10%–15%, and 5%–6% of parents in either province having 2, 3, or ≥4 children, respectively [40, 41]. On that basis, even assuming that protection from parental pertussis immunization might span 2–3 consecutive offspring (depending on birth interval), the NNV would remain substantial at one-half or even one-third of our estimates. If other household/family members (ie, grandparents) are included, the NNV would further increase for each additional contact, particularly

Table 2. Summary of Published Studies: Percentage of Infants Infected by a Parent

First Author (Country) [Ref]	Year	Number of Index Infants With Confirmed Pertussis, Setting, and Age	Method of Parental Diagnosis as Source and Defined Onset Before Index Infant	Identified Sources, Proportion (%)			Source of Infection in All Infants (%)	
				Father	Mother	Either	Not Known	Either Parent[a]
de Greeff (Netherlands) [23]	2006–2008	164 hospitalized, ≤6 months	PCR, culture, serology, cough onset ≥1 week prior	17%	38%	55%	41% (68/164 included in the analysis)	32%
Wendelboe (4 countries) [24]	2003–2004	Hospital = 75; not in hospital = 20, ≤6 months	PCR, culture, serology, symptom onset 7–30 days prior	NA	NA	55%	52% (of 91 included in the analysis)[b]	26%
Kowalzik (7 countries) [25]	2001–2004	99 pediatric ICU, <1 year	PCR, culture, serology, cough onset ≥7 days prior	10%	50%	60%	73% (64/88 included in the analysis)	16%
Elliott (Australia) [26]	2001	140 hospitalized, <1 year	Physician report of coughing contacts (source not otherwise ascertained)	11%	40%	51%[c]	49%	26%
Bisgard (US) [27]	1999–2002	774; 616 included in source analysis, hospital or outpatient, <1 year	Report by parents of any contacts with cough illness and contact 7–20 days before; assigned to contact spending most time with index infant	15%	32%[d]	47%	57% (352/616)	20%
Bonmarin (France) [28]	1996–2005	1688 hospital or outpatient, <6 months	Physician report based on clinical presumption	NA	NA	55%	47% (None identified = 24%; unspecified = 23%)	29%–42%
Halperin (Canada) [7]	1991–1997	1082 hospitalized, <2 years (<50% laboratory confirmed)	Cough ≥2 weeks	NA	NA	20%	60%	8%

Abbreviations: ICU, intensive care unit; NA, not available; PCR, polymerase chain reaction.

[a] Derived as follows: [(1-Not Known) × (Either Parent Among Identified Sources)].

[b] In sensitivity analysis allowing symptom onset 2–6 days and 31–48 days before onset in the index case, 38% of infants were without known source. When asymptomatic household contacts with laboratory-confirmed pertussis were considered as possible sources, 22% of infants were then without known source. Similar parent contribution was reported to be found based on sensitivity analysis (but not presented).

[c] A parent was the identified contact in 58% of infants <8 weeks of age, 50% between 8–15 weeks, 40% between 16–23 weeks, and none of the infants >24 weeks of age.

[d] Mothers were the identified contact for 35% of infants <4 months of age and 17% of infants 4–11 months of age.

Table 3. Number Needed to Vaccinate to Prevent Serious Outcome in Infants (by Age Category in Months) Through Parent Pertussis Immunization[a]

	No. Hospitalization/ICU Admissions	Infant Risk per 100 000 Hospitalization/ICU Admission	Percentage Attributed to a Parent	
			35% NNV Hospitalization/ICU Admission	55% NNV Hospitalization/ICU Admission
<12 months				
Québec				
2005–2009	265/32	57/7	11 756/97 353	7481/61 952
High hosp (2009)	87/13	89/13	7522/50 342	4787/32 036
Low hosp (2007)	20/2	22/2	31 033/310 326	19 748/197 480
British Columbia				
2005–2009	71/14	33/7	20 177/102 325	12 840/65 116
High hosp (2005)	24/7	59/17	11 357/38 939	7227/24 779
Low hosp (2007)	6/0	14/0	47 569/→ ∞	30 271/→ ∞
<6 months				
Québec				
2005–2009	233/30	50/6	13 370/103 843	8508/66 082
High hosp (2009)	73/12	75/12	8965/54 537	5705/34 705
Low hosp (2007)	20/2	22/2	31 033/310 326	19 748/197 480
British Columbia				
2005–2009	62/12	29/6	23 106/119 379	14 704/75 969
High hosp (2005)	20/5	49/12	13 629/54 514	8673/34 691
Low hosp (2007)	5/0	12/0	57 082/→ ∞	36 325/→ ∞
<3 months				
Québec				
2005–2009	155/29	33/6	20 099/107 424	12 790/68 361
High hosp (2009)	49/11	50/11	13 356/59 495	8499/37 860
Low hosp (2007)	14/2	15/2	44 332/310 326	28 211/197 480
British Columbia				
2005–2009	48/11	23/5	29 845/130 232	18 992/82 875
High hosp (2005)	16/5	39/12	17 036/54 514	10 841/34 691
Low hosp (2007)	4/0	9/0	71 353/→ ∞	45 406/→ ∞

Abbreviations: → ∞, approaches infinity; hosp, hospital; ICU, intensive care unit; NNV, number needed to vaccinate.

[a] Assumes 85% parent vaccine effectiveness in preventing all infant serious outcomes.

since they would contribute proportionately less to infant illness. Because as found elsewhere most siblings are already included in the routine pediatric immunization program in Canada, their consideration within the cocoon strategy would be moot.

Although it is not a formal economic evaluation, the NNV is a useful epidemiologic construct to anticipate the order of magnitude of resources and involvement required to achieve program goals. Because death due to pertussis is rare and the clinical course typically includes full recovery without residual disability, these NNV estimates for parental pertussis cocoon immunization can be used to generate ballpark costs. Multiplying the NNV by immunization costs (vaccine + administration >$20 [Cdn]) shows that the cost per infant hospitalization (~$200 000), ICU admission (>$2 million), or death (>$20 million) prevented through parental pertussis immunization is likely to be extreme.

The main limitation of this analysis is that it is predicated on surveillance and administrative data, potentially affecting validity and generalizability of the findings. Updated surveillance trends are likely to be generally reliable, whereas their representation of true absolute rates may be questioned. Healthcare is free at service delivery in Canada, limiting barriers to utilization or hospitalization. For this analysis, serious outcome rates were based on clinical diagnosis captured through administrative data and showed a similar pattern of decline to other surveillance indicators. However, in neither province were hospitalization or mortality records further validated as truly due to pertussis, so some misclassification of respiratory illness due to other causes is possible; this would tend to overestimate pertussis-related risk and further underestimate the NNV. It is also possible that some severe pertussis cases were unrecognized/unreported, although this is less likely for infants in whom the

clinical presentation is more typical compared with older age groups. That the proportion of infants hospitalized in BC admitted to ICU was approximately double that of Québec may be a flag for underrecognition of hospitalized cases in BC. Even if we applied a 2-fold adjustment for underdiagnosis of severe pertussis in infants, however, the NNVs for the cocoon program would remain substantial.

With respect to generalizability, it is precisely our point that a recommendation for the cocoon program is crucially dependent upon, and should take into account, the local epidemiologic context in which it is being proposed. In 2010, the state of California experienced one of the worst pertussis epidemics in >50 years (~25 per 100 000 overall; ~450 in infants <6 months) [42], whereas on the same western coast and just to the north, BC, Canada was experiencing sustained low rates of pertussis since 2005, with 2010 incidence per 100 000 overall (~2.5) and in infants (<20) below 20-year-historic rates. The California experience renewed awareness and interest in the pertussis cocoon program as proactive prevention to be broadly implemented. However, parental immunization accrues maximal benefit during cyclical peaks and over the short 3-month period of heightened newborn risk; it is not otherwise amenable to advance ongoing population implementation where infant risk is already low. Even assuming an infant hospitalization rate as high as 450 per 100 000, the NNV for parental cocoon immunization would still exceed 1000. We thus present these data from Canada as illustration to encourage other regions contemplating the cocoon program to also consider the NNV based on knowledge of their own epidemiology.

The cocoon program was proposed based on numerator analysis, indicating that a substantial proportion of infected infants acquire their illness from parents. However, numerator data analysis alone is insufficient to guide public policy decisions because it does not reflect the resources required to achieve population-level outcome reduction, an insight provided by the NNV. Based on NNV analysis in the context of low pertussis incidence, we conclude that the parental cocoon program is inefficient and resource intensive for the prevention of serious pertussis outcomes in early infancy.

Notes

Acknowledgments. Clinical and laboratory-confirmed pertussis notifications were submitted by clinicians and transmitted through local health authorities to provincial agencies. Hospitalizations and ICU admissions were obtained from MED-ECHO in Québec and from the Discharge Abstract Database, Management Information Branch, Planning and Innovation Division of the British Columbia (BC) Ministry of Health. Mortality data were obtained from vital statistics agencies for each province. Population denominators were obtained from the Institut de la Statistique du Québec and from P.E.O.P.L.E. 35 Population Projections (BC STATS) in BC. We acknowledge the sources of these data.

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Potential conflicts of interest. In the 36 months before manuscript submission, D. M. S. was Principal Investigator on a clinical trial for which influenza vaccine was provided free by Sanofi Pasteur, and G. D. S. received funding for an unrelated study from GlaxoSmithKline and for a TdaP immunogenicity and reactogenicity study from Sanofi Pasteur. All other authors report no potential conflicts.

All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

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