Timeliness and completeness of routine childhood vaccinations in children by two years of age in Alberta, Canada

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ABSTRACT

OBJECTIVES: Assessing timeliness and completeness of vaccine administration is important for evaluating the effectiveness of immunization programs. Few studies have reported timeliness, particularly in Canada. The objective of this study was to examine timeliness of the receipt of vaccination for each routine childhood recommended vaccine by 24 months of age among children in a community-based pregnancy cohort in Calgary, Alberta.

METHODS: Survey data from a community-based pregnancy cohort in Alberta were linked to Public Health vaccination records of children (n = 2763). The proportion of children receiving early, timely, delayed, or no vaccination was calculated. A dose was considered *early* if it was administered before the recommended age in days as per the vaccination schedule, *timely* if administered at any time from start of recommended age in days to age in days when delay counts were initiated, and *delayed* if it was administered on or after age in days when delay counts were initiated. Series completion rates were also calculated.

RESULTS: For multi-dose vaccines, over 80% of children had timely doses at 2, 4 and 6 months. By 12 months, this proportion decreased to 65% (95% CI: 63%–66%) for meningococcal conjugate group C, 61% (95% CI: 59%–62%) for measles antigen-containing vaccines and 64% (95% CI: 62%–65%) for varicella antigen-containing vaccines. At 18 months, only 55% (95% CI: 53%–56%) of the children had a timely 4th dose of diphtheria, acellular pertussis, tetanus, polio, and *Haemophilus influenzae* type b vaccine. Eventual series completion rate for all recommended vaccines was 77% (95% CI: 75%–79%).

CONCLUSION: The timeliness and completeness of routine childhood vaccination in preschool children in this community-based pregnancy cohort is lower than provincial targets. Data on timeliness of vaccination can inform further work on barriers and enablers to vaccination in order to meet provincial targets.

KEY WORDS: Vaccination; immunization; timeliness; completeness; child

La traduction du résumé se trouve à la fin de l'article.

Can J Public Health 2017;108(2):e124–e128
doi: 10.17269/CJPH.108.5885

Completion of the routine childhood vaccination schedule is typically reported at 12 months, 24 months, and 7 years of age without considering how close to the recommended timeline the vaccine was actually administered.[1–4] For example, the proportion of children who received all recommended vaccines by 24 months of age is a commonly accepted measure described by the World Health Organization[5] and the Public Health Agency of Canada.[6] However, it is equally important to assess timeliness along with completeness of vaccination administration for evaluating effectiveness of immunization delivery programs in preventing disease.[7,8]

Assessment of timeliness captures delay in acquisition of immunity through late vaccination which is important in the context of potentially severe infections in young infants, such as pertussis and *Haemophilus influenzae* type b or *Streptococcus pneumoniae*.[1] Timeliness is also an issue when vaccinations are given earlier than recommended or subsequent doses are administered after a shorter than recommended interval, which can significantly shorten the duration of protection and decrease overall levels of protection.[9] In countries with high vaccination uptake, timeliness is also an important public health goal, as non-adherence to recommended vaccination schedules could undermine the benefits of immunization at both the individual and population level. Despite this, only the United States has closely monitored timeliness,[7,8,10–12] with just a few studies from Europe[13–15] and one from Australia.[1] Little is known about timeliness of vaccination in Canada as only one study has examined "up-to-date" status of children under two years of age in Nova Scotia.[16]

In this study, timeliness of receipt of vaccination by dose was examined for each recommended vaccine, in addition to series completion status of all routine childhood vaccines in children up to 24 months of age in a community-based pregnancy cohort in Calgary, Alberta.

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Conflict of Interest: None to declare.

METHODS

Study population and design

This study was an administrative data linkage project using an existing cohort as the original data source. The All Our Babies (AOB) study is a prospective community-based pregnancy cohort in Calgary, Alberta. Women (n = 3387) were surveyed during their first trimester of pregnancy between May 2008 and December 2010, and then again at 4, 12, 24 and 36 months post-partum. Details on the recruitment, eligibility criteria, and data collection for the cohort have been previously reported.[17] For the purpose of this study, women were included if they consented to linkage of their survey data with health records at recruitment and provided a provincial health number (PHN) (n = 2855, 84%). Participants with successful versus unsuccessful linkage to health records were significantly more likely to report a lower income and less likely to report being married or common-law; no other significant differences in terms of remaining socio-demographics (age, education, ethnicity, born in Canada) were found (data not shown).

In Alberta, childhood vaccinations are covered by the province's publicly funded universal health care insurance plan, administered by public health nurses in community-based clinics and recorded electronically in regional vaccination databases. Vaccination data entry by support staff into regional databases is routinely audited to ensure acceptable accuracy in data entry, and random chart audits are conducted as well. Afterwards, the immunization data from regional databases are entered into the Immunization and Adverse Reaction to Immunization (Imm/ARI) database; Imm/ARI represents the only single repository for immunization service delivery events in Alberta. The AOB survey data were linked to Calgary Zone Public Health administrative databases (Phantim and Medipatient) using a combination of maternal PHN, and maternal and child date of birth. Vaccination records containing information on vaccines administered and dates of vaccination up to 24 months of life were extracted for 2763 children (3% missing; Figure 1). Ethical approval for this study was received from the Conjoint Health Research Ethics Board at the University of Calgary (ID: REB14-0925).

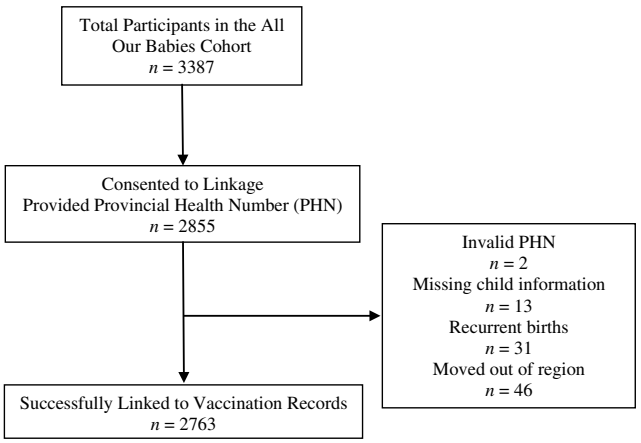

Figure 1. Total sample derived from linkage of the All Our Babies cohort with public health vaccination records

Vaccination recommendations

The vaccination schedule is determined by the Ministry of Health in Alberta and includes recommended ages and age ranges for routine administration, minimum age, and minimum intervals between doses within a series. This study comprised children receiving their vaccines between July 2008 and December 2012 and included the following vaccines: diphtheria, acellular pertussis, tetanus, polio, and *Haemophilus influenzae* type b (DTaP-IPV-Hib, available July 2008 to December 2012); pneumococcal conjugate 7 (PCV7, available July 2008 to June 2010); pneumococcal conjugate 13 (PCV13, available July 2010 to December 2012); meningococcal conjugate group C (Men-C, available July 2008 to December 2012); varicella (Var, available May 2008 to August 2010); measles, mumps and rubella (MMR, available May 2008 to August 2010) and measles, mumps, rubella and varicella (MMRV, available September 2010 to December 2012) (Table 1).

Definition of timeliness

Timeliness of vaccination in terms of early, timely or delayed was calculated by dose for each recommended vaccine. The age in days (and reported as whole months) when a child received each vaccine dose was calculated by subtracting their date of birth from the vaccination administration date. This age in days was compared to the recommended age ranges outlined in Table 1. Each recommended age (in months) ended at the greatest number of days that could compose the given number of months as per previous vaccine compliance studies.[7,8,10] For example, the recommended age of 2 months ended when the child turned 3 months old at 90–92 days, so a child would be considered *delayed* if they had received the recommended dose on or after 93 days of age. A dose was considered *early* if it was administered before the recommended age in days as per the vaccination schedule, *timely* if administered at any time from start of recommended age in days to age in days when delay counts were initiated, and *delayed* if it was administered on or after age in days when delay counts were initiated. A child who did not receive a particular vaccine dose was classified as *not received*. It is important to note that some minimal acceptable ages for vaccination may not correspond with the recommended age.

Analysis

Descriptive statistics were produced to describe the characteristics of the sample using frequencies and proportions. For each vaccine and dose, the proportions and 95% binomial exact confidence intervals were calculated for children who were early, timely or delayed on vaccination and those who did not receive a particular vaccine dose by age 2. Of note, PCV7 and PCV13 were not included in the calculation of timeliness, given the challenges posed by the change in the timing and number of doses midway through the cohort recruitment period. For calculation of vaccine schedule completion rate, the proportion of children completing the vaccination schedule for each vaccine and all routine childhood vaccines by age 2 was calculated.

RESULTS

The majority of mothers included in this study were aged 25–34 years (71%), married (95%), born in Canada (78%), white/Caucasian (79%) and had a household income greater

Table 1. Recommended ages and interval for specific doses of vaccines in Alberta Routine Childhood Immunization Program (2008–2014)*

Vaccine	Dose	Recommended age in months	Minimum age in days (weeks)†	Minimum interval‡ to next dose in days (weeks)	Age in days when delay counts initiated§
DTaP-IPV-Hib	1st	2	42 (6)	28 (4)	93
	2nd	4	70 (10)	28 (4)	154
	3rd	6	98 (14)	168 (24)	216
	4th	18	365 (52)	–	581
PCV13	1st	2	42 (6)	28 (4)	93
	2nd	4	70 (10)	56 (8)	154
	3rd	12	365 (52)	–	397
PCV7	1st	2	42 (6)	28 (4)	93
	2nd	4	70 (10)	28 (4)	154
	3rd	6	98 (14)	56 (8)	216
	4th	18	365 (52)	–	581
Men-C	1st	2	56 (8)	28 (4)	93
	2nd	4	84 (12)	28 (4)	154
	3rd	12	365 (52)	–	397
MMR/MMRV	1st	12	365 (52)	–	397
Varicella/MMRV	1st	12	365 (52)	–	397

Note: DTaP-IPV-Hib = Diphtheria, acellular pertussis, tetanus, polio, and *Haemophilus influenzae* type b vaccine; PCV7 = Pneumococcal conjugate vaccine 7; PCV13 = Pneumococcal conjugate vaccine 13; Men-C = Meningococcal conjugate (Group C) vaccine; MMR = Measles, mumps and rubella vaccine; MMRV = Measles, mumps, rubella and varicella vaccine; Var = Varicella vaccine.
* Determined by Alberta Ministry of Health, see http://www.health.alberta.ca/health-info/imm-routine-schedule.html.
† Minimum acceptable age.
‡ Minimum acceptable interval since previous dose in the series.
§ Adapted from Lumen et al. (2005).

Table 2. Characteristics of participants in the All Our Babies study with children with documented vaccination status (n = 2763)

Characteristics	*n* (%)
Maternal age, years	
≤24	157 (6.1)
25–34	1821 (70.8)
≥35	593 (23.1)
Paternal age, years	
≤24	65 (3.1)
25–34	1218 (58.6)
≥35	797 (38.3)
Marital status	
Single	123 (4.5)
Married/common law	2613 (95.5)
Divorced/separated/widowed	0 (0.0)
Maternal education	
Graduated high school or less	287 (10.4)
Complete or incomplete college, university or trade	2031 (73.9)
Complete or incomplete post-graduate studies	430 (15.6)
Born in Canada	
Yes	2148 (78.1)
No	604 (21.9)
Ethnicity	
White/Caucasian	2171 (79.0)
Other	578 (21.0)
Total household income	
<$40,000	218 (8.2)
$40,000–$79,999	569 (21.4)
≥$80,000	1876 (70.4)

than $80,000 (70%) (Table 2). For multi-dose vaccines (DTaP-IPV-Hib and Men-C), over 80% of children had timely doses at 2, 4 and 6 months (Table 3). By 12 months, this proportion decreased to 65% for Men-C, 61% for measles antigen-containing vaccines (MMR/MMRV) and 64% for varicella antigen-containing vaccines (Var/MMRV). At 18 months, only 55% of the children had a timely fourth dose of DTaP-IPV-Hib vaccine. Less than 1% of children had early doses across all vaccines. The proportion of children who did not receive any vaccine doses ranged from 2.1% for the first dose of DTaP-IPV-Hib to 14.9% for the fourth dose of DTaP-IPV-Hib.

Overall, 77% of the children completed all routine childhood vaccinations by 24 months of age (Table 4). Series completion rates at 24 months were 85% for DTaP-IPV-Hib, 88% for measles antigen-containing vaccines (MMR/MMRV), 89% for PCV antigen-containing vaccines (PCV7/PCV13), 90% for varicella antigen containing vaccines (Var/MMRV) and 91% for Men-C.

DISCUSSION

In general, the proportion of children with timely vaccination decreased with advancing age across all vaccines in this community-based pregnancy cohort in Calgary, Alberta. By 12 months of age, the proportion of children not receiving their vaccination on time had doubled compared to the proportions between 2 and 6 months, with the highest proportion not receiving their vaccination on time found at 18 months of age. By 24 months of age, series completion rates did not meet target rates of 97%–98% outlined in Alberta's Immunization Strategy.[18] The Alberta strategy was developed in 2007 to increase immunization rates in the province using seven strategic directions, including enhancing accessibility, improving technology, and strengthening research and evaluation.[18]

In Canada, few provinces have centralized vaccination databases, thereby making it challenging to assess the timeliness of vaccination in children. Only one other study in Canada has assessed timeliness of routine childhood vaccination and it too revealed that the 12 and 18 month vaccinations had the lowest proportion of children receiving timely doses.[16] In addition, they had a similarly small proportion (<1%) of children who received their vaccinations early.[16]

Nationally, cross-sectional surveys are administered to assess completeness of vaccine coverage. Earlier surveys suffered from low

Table 3. Timeliness status of routine childhood vaccination among children by two years of age in the All Our Babies cohort (n = 2763)

Vaccine	Dose	Recommended age in months	Early* (%)	95% CI	Timely† (%)	95% CI	Delayed‡ (%)	95% CI	Not received (%)	95% CI
DTap-IPV-Hib	1st	2	6 (0.2)	0.07–0.4	2447 (88.6)	87.3–89.7	251 (9.1)	8.0–10.2	59 (2.1)	1.6–2.7
	2nd	4	9 (0.3)	0.1–0.6	2344 (84.9)	83.4–86.1	320 (11.6)	10.4–12.8	90 (3.2)	2.6–3.9
	3rd	6	9 (0.3)	0.1–0.6	2225 (80.6)	79.0–81.9	401 (14.5)	13.2–15.8	128 (4.6)	3.8–5.4
	4th	18	12 (0.4)	0.2–0.7	1506 (54.6)	52.6–56.3	834 (30.1)	28.4–31.9	411 (14.9)	13.5–16.2
Men-C	1st	2	3 (0.1)	0.02–0.3	2441 (88.4)	87.0–89.5	253 (9.1)	8.1–10.2	66 (2.4)	1.8–3.0
	2nd	4	8 (0.3)	0.1–0.5	2333 (84.5)	83.0–85.7	316 (11.4)	10.2–12.6	106 (3.8)	3.1–4.6
	3rd	12	3 (0.1)	0.02–0.3	1788 (64.8)	62.8–66.4	725 (26.2)	24.6–27.9	247 (8.9)	7.9–10.0
MMR/MMRV	1st	12	12 (0.5)	0.2–0.7	1677 (60.7)	58.8–62.5	731 (26.4)	24.8–28.1	343 (12.4)	11.2–13.7
Var/MMRV	1st	12	–	–	1758 (63.7)	61.8–65.4	727 (26.3)	24.6–27.9	278 (10.0)	8.9–11.2

Note: DTaP-IPV-Hib = Diphtheria, acellular pertussis, tetanus, polio, and *Haemophilus influenzae* type b vaccine; Men-C = Meningococcal C conjugate vaccine; MMR = Measles, mumps and rubella vaccine; MMRV = Measles, mumps, rubella and varicella vaccine; Var = Varicella vaccine.
* Early: < recommended age in days (as stated in Table 1).
† Timely: recommended age in days to < age in days when delays were initiated (as stated in Table 1).
‡ Delayed: ≥ age in days when delays were initiated up to 2 years (as stated in Table 1).

Table 4. Series completion status of routine childhood vaccination among children by two years of age in the All Our Babies cohort (n = 2763)

Vaccine	No. of doses	Received (%)	95% CI	Did not receive (%)
DTaP-IPV-Hib	4	2352 (85.1)	83.7–86.4	411 (14.9)
PCV antigen (PCV7/PCV13)	3/4/5	2454 (88.8)	87.5–89.9	309 (11.2)
Men-C	3	2516 (91.0)	89.9–92.0	247 (9.0)
Measles antigen (MMR/MMRV)	1	2420 (87.6)	85.6–88.1	343 (12.4)
Varicella antigen (Var/MMRV)	1	2485 (89.9)	88.7–91.0	278 (10.1)
All routine childhood vaccines	–	2129 (77.0)	75.4–78.6	544 (23.0)

Note: DTaP-IPV-Hib = Diphtheria, cellular pertussis, tetanus, polio, and *Haemophilus influenzae* type b vaccine; PCV7 = Pneumococcal conjugate vaccine 7; PCV13 = Pneumococcal conjugate vaccine 13; Men-C = Meningococcal conjugate (Group C) vaccine; MMR = Measles, mumps and rubella vaccine; MMRV = Measles, mumps, rubella and varicella vaccine; Var = Varicella vaccine.

sample sizes and self-reported data;[19] recently, however, survey sample sizes have increased to better represent provinces and territories, and one third of the data are cross-checked with vaccination records.[3] Although timeliness has not been assessed, the most recent estimates of coverage rates for childhood vaccinations at 24 months from the national survey show a high of 91% for polio (3 doses) versus 77% and 73% for DTaP and Hib (4 doses each) respectively. This difference in the types of vaccines is hypothesized to be due to children being behind on their 18-month vaccinations.[3] Studies in other countries show similar patterns, with a drop in timeliness of vaccination between 8 and 18 months.[14,18] This suggests that the current practice of using coverage rates at 24 months (or earlier time points), without consideration of timeliness, to evaluate immunization programs masks the true risk for children who may have received their vaccinations too early or late, leaving them vulnerable to vaccine-preventable diseases.

Several studies have identified the need to assess timeliness of vaccination, since only considering vaccination levels at a given age overestimates protection.[14,15,17] Currently, timeliness is not routinely used as an indicator to evaluate immunization programs in Alberta and elsewhere in Canada.[20,21] Recently, the Canadian Immunization Registry Network has recommended that two broad coverage estimates including up-to-date coverage and on-time coverage be used.[22] Disease risk due to vaccination delay varies as it depends on the vaccine, disease circulation, transmissibility, likelihood of importation and severity of outcome.[7] In Alberta, despite a low incidence of vaccine-preventable diseases,[18] there have been recent outbreaks of both measles[23] and pertussis,[24] making timely vaccination particularly critical.

A higher proportion of children were completely vaccinated for all recommended vaccines at age 2 in our community-based pregnancy cohort in Calgary (77%) compared to an estimate of 71% from a large, population-based Alberta birth cohort.[25] While a majority of children were vaccinated completely in our study, it was far short of the target of 97%–98% of children at age two being completely vaccinated that was set for Alberta.[3] While in our study, DTaP-IPV-Hib had the lowest proportion of children completing the series (85%), in the provincial birth cohort, PCV7 was the lowest at 75%.[25] Both these vaccines required 4 doses, with the final dose at 18 months, the time point at which the lowest proportion of timely vaccinations is seen. In the Canadian context, many mothers return from subsidized maternity leave at 12 months, which may impede the timely completion of an 18-month, 4-dose series; however, the decrease in series completion between 12 and 18 months has been recognized in the US, where mothers often return to work sooner.[26]

One of the strengths of this study was the ability to link the cohort with computerized vaccination data for an accurate assessment of vaccination status and timeliness. However, there is a limitation in terms of generalizability given that the cohort represents the demographics of urban Calgary with mostly White/Caucasian mothers who are highly educated and have high incomes. Of note, reason for unsuccessful linkage of the cohort to health records was not solely due to lack of consent. There were additional factors,

such as data entry errors and incomplete PHNs, suggesting that "missingness" was likely non-differential. Given that this was a descriptive study, internal validity considerations are low and therefore impacts on external validity take precedence. Further, we cannot preclude data entry or coding errors in the administrative data, which could also impact the results. We recommend using the methodology adopted in this study to assess timeliness in bigger, more representative samples with quality administrative data on vaccinations status and timing to further advance this work. Finally, additional work could assess the average number of days children spend undervaccinated and explore factors associated with the number of days undervaccinated to suggest potential avenues for intervention. Examination of factors associated with timeliness in general and for specific vaccines would be informative.

CONCLUSION

Although a majority of children were completely vaccinated by 24 months of age, nearly a quarter were not and only just over half of the children received timely vaccinations at 18 months. Data on timeliness of vaccination can inform further work to examine barriers and enablers to vaccination to ensure that provincial targets, and herd immunity levels, can be met.

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Received: September 12, 2016
Accepted: December 18, 2016

RÉSUMÉ

OBJECTIFS : Il est important de déterminer l'opportunité et l'intégralité de l'administration des vaccins pour évaluer l'efficacité des programmes d'immunisation. Peu d'études abordent l'opportunité, particulièrement au Canada. Notre objectif était donc d'examiner l'opportunité des vaccinations reçues pour chacun des vaccins systématiquement recommandés aux enfants avant l'âge de 24 mois dans une cohorte communautaire de grossesses de Calgary (Alberta).

MÉTHODE : Les données d'enquête d'une cohorte communautaire de grossesses en Alberta ont été liées aux dossiers de santé publique sur la vaccination des enfants (n = 2 763). Nous avons calculé la proportion d'enfants ayant reçu leurs vaccins tôt, à temps, en retard ou pas du tout. Une dose était jugée avoir été administrée *tôt* si elle l'avait été avant l'âge recommandé en jours dans le calendrier de vaccination, *à temps* si elle avait été administrée entre le début de l'âge recommandé en jours et l'âge en jours où l'on a commencé la comptabilisation des retards, et *en retard* si elle avait été administrée à l'âge ou après l'âge en jours où l'on a commencé la comptabilisation des retards. Nous avons aussi calculé les taux d'achèvement des séries vaccinales.

RÉSULTATS : Pour les vaccins à doses multiples, plus de 80 % des enfants avaient reçu leurs doses à temps à 2, 4 et 6 mois. À 12 mois, cette proportion baissait à 65 % (IC de 95 % : 63 %–66 %) pour le vaccin conjugué contre le méningocoque du groupe C, à 61 % (IC de 95 % : 59 %–62 %) pour les vaccins contenant un antigène contre la rougeole et à 64 % (IC de 95 % : 62 %–65 %) pour les vaccins contenant un antigène contre la varicelle. À 18 mois, seulement 55 % (IC de 95 % : 53 %–56 %) des enfants avaient reçu à temps la 4^{e} dose du vaccin contre la diphtérie, la coqueluche acellulaire, le tétanos, la polio et l'*Haemophilus influenzae* de type b. Le taux d'achèvement éventuel des séries pour tous les vaccins recommandés était de 77 % (IC de 95 % : 75 %–79 %).

CONCLUSION : L'opportunité et l'intégralité de la vaccination systématique des enfants d'âge préscolaire dans cette cohorte communautaire de grossesses sont inférieures aux cibles provinciales. Les données sur l'opportunité de la vaccination peuvent éclairer d'autres travaux sur les obstacles et les incitateurs à la vaccination afin de respecter les cibles provinciales.

MOTS CLÉS : vaccination; immunisation; opportunité; intégralité; enfant