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The ImmProve Project: Leveraging electronic health record data to promote immunization delivery

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Abstract

Objective—Though an essential pediatric preventive service, immunizations are challenging to deliver reliably. Our objective was to measure the impact on pediatric immunization rates of providing clinicians with electronic health record-derived immunization prompting.

Methods—Operating in a large, urban, hospital-based pediatric primary care clinic, we evaluated 2 interventions to improve immunization delivery to children ages 2, 6, and 13 years: point-of-care, patient-specific electronic clinical decision support (CDS) when children overdue for immunizations presented for care and provider-specific bulletins listing children overdue for immunizations.

Results—Overall, the proportion of children up-to-date for a composite of recommended immunizations at ages 2, 6, and 13 years was not different in the intervention (CDS active) and historical control (CDS not active) periods; historical immunization rates were high. The

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proportion of children receiving 2 doses of hepatitis A immunization prior to their second birthday was significantly improved during the intervention period. Human papilloma virus (HPV) immunization delivery was low during both control and intervention periods and was unchanged for 13-year-olds. For 14-year-olds, however, 4 of the 5 highest quarterly rates of complete HPV immunization occurred in the final year of the intervention. Provider-specific bulletins listing children overdue for immunizations increased the likelihood of identified children receiving catch-up hepatitis A immunizations (hazard ratio: 1.32 [95% confidence interval (CI): 1.12–1.56]); results for HPV and the composite of recommended immunizations were of a similar magnitude but not statistically significant.

Conclusions—In our patient population, with high baseline uptake of recommended immunizations, electronic health record-derived immunization prompting had a limited effect on immunization delivery. Benefit was more clearly demonstrated for newer immunizations with lower baseline uptake.

Keywords

immunizations; clinical decision support systems; quality improvement

INTRODUCTION

Childhood immunizations are one of the great public health achievements of the past 100 years.^{1, 2} It is ironic, therefore, that childhood immunization delivery remains perniciously unreliable. In 2011, more than 1 in 4 US children ages 19–35 months had not received all recommended immunizations, with worse performance for newer immunizations (hepatitis A (HepA) 52% fully immunized).³ Among adolescents, 30% lacked meningococcal conjugate vaccination (MCV), 22% lacked a tetanus/diphtheria/pertussis (Tdap) booster, and only 1 in 3 young women were fully immunized with human papillomavirus vaccine (HPV).⁴

Three general principles underpin reliable immunization delivery: children must have access to clinical venues providing immunizations; they must present for care when immunizations are due; and providers must consistently recognize when children are due and deliver immunizations. The first principle, which is affected by health insurance, language barriers, and geography, among many other factors, is complex, well-studied,⁵ and not examined here. The second principle highlights discrepancies between families' and providers' expectations regarding the timing and purpose of preventive medical care.^{6, 7} Robust adherence to the third principle is often assumed by providers, despite a substantial and growing literature on “missed opportunities” for immunizations.^{7–13}

We evaluated 2 interventions aimed at improving childhood immunization rates in primary care. The first intervention involved electronic health record (EHR)-derived immunization prompts, in the form of clinical decision support (CDS) when overdue children presented for care, and was intended to reduce missed opportunities by calling attention to needed immunizations (principle #3 above). The second intervention comprised quarterly, provider-specific bulletins listing patients who were overdue for immunizations and was intended to improve the likelihood that overdue children would present for care via reminding by their primary care physician (principle #2 above). Our primary aim was to measure the impact of these interventions on immunization delivery to children ages 2, 6, and 13 years.

METHODS

Study location

The study was conducted in an urban, hospital-based pediatric primary care clinic staffed by general pediatric and adolescent medicine faculty and fellows, pediatric residents, pediatric nurse practitioners, and medical students. This comprehensive medical home—housed within an academic medical center—served more than 7,300 children ages 0–21 years in 2009–10 with 16,000 annual visits. The patient population was predominantly African American (92%) and Medicaid-insured (80%).

Patient population

We targeted children in 3 age groups (1.5–3.5, 5.5–7.5, and 12.5–14.5 years) cared for by pediatric residents; patients cared for by non-residents (e.g., pediatric nurse practitioners) comprised approximately 5% of the overall clinic patient population and were excluded. For 2 age groups, we chose windows incorporating the age at which the National Committee for Quality Assurance Healthcare Effectiveness Data and Information Set (HEDIS) immunization measures assess immunization delivery (2- and 13-year-olds).¹⁴ For the third group (6-year-olds), we chose an age where a bundle of immunizations is recommended by the Centers for Disease Control and Prevention (CDC).¹⁵ Children were included if they were currently in one of the 3 age windows and had at least one clinic visit in the year prior to the 2nd/6th/13th birthday.

Target immunizations

The targeted immunizations and minimum number required mimicked corresponding HEDIS measures (Figure 1).¹⁴ For the “Composite A” measures, children were considered up-to-date (UTD) if they had received at least the minimum number required by HEDIS for each component immunization. While included in HEDIS measures, we excluded rotavirus because it is not eligible for catch-up after age 8 months and influenza because its delivery is seasonal.

Study design

We evaluated 2 interventions simultaneously using 2 overlapping study designs (Figure 2):

Intervention #1—Intervention #1 involved CDS prompting providers to administer needed immunizations for all children presenting to the clinic, regardless of visit purpose (Appendix A). Every 3 minutes, a ColdFusion™ application queried the clinic’s Admission-Discharge-Transfer database for newly registered patients, who were compared to tables generated quarterly capturing overdue immunizations. If a patient was overdue, an automated text page identifying the patient and overdue immunizations was sent to the clinic charge nurse, who then activated an “overdue” flag on the clinic’s electronic tracking board and listed the overdue immunizations in the EHR triage note. Prior to ordering immunizations, providers were encouraged to check the CDS against CDC recommendations to insure the prompted immunization(s) was truly due. We considered randomizing patients to receive / not receive intervention #1, but worried that providers might grow to interpret the absence of CDS prompting as an indication that a child was UTD for immunizations, and not that he might be due for immunization but in the control group. As a result, all patients were exposed to intervention #1 during the study period. We evaluated intervention #1 as an interrupted time series, with historical data collected from a 3-year period (January 1, 2007—December 31, 2009) and intervention data collected for 7 quarters (January 1, 2010—September 30, 2011). We compared children exposed to

intervention #1 (but not exposed to intervention #2 below) during the intervention period to children from the historical period.

Intervention #2—Intervention #2 was provided to half of the pediatric residents. Residents are assigned to specific morning or afternoon continuity clinic groups and are supervised by a consistent preceptor. Residents were randomized at the clinic group level (e.g., Monday morning) to receive either quarterly paper bulletins (Appendix B) listing each of their assigned patients in the target age ranges overdue for immunizations (N=55 residents) or usual care (i.e., no bulletins (N=52 residents)). Providers receiving bulletins were encouraged by the research team to review the bulletin and follow-up with the families of overdue children. Providers could also optionally use the bulletins to provide feedback to the research team, including what actions they took. Intervention #2 occurred during the intervention period described for intervention #1 and was evaluated at the patient level as a randomized controlled trial. We compared children exposed to interventions #1 and #2 to children exposed only to intervention #1 to isolate the effects (if any) of intervention #2. Historical data were not used in the evaluation of intervention #2.

The data underlying both interventions derived from a HEDIS-based immunization counting algorithm which ignored immunization timing. We chose this approach because it is substantially easier to implement than a CDC-based approach and, therefore, more easily generalizable. Our HEDIS-based algorithm generated both false positive (e.g., HepA#1 given 2 months ago = “due” by our algorithm / “not due” by CDC) and false negative prompts (e.g., 4 pneumococcal conjugate vaccine (PCV13) immunizations given prior to age 1 = “not due” by our algorithm / “due” by CDC). While we did not measure the sensitivity and specificity of our underlying data, our prior analyses of nationwide immunization data suggested most flagged children would be due for immunizations at the index visit.¹⁶

Provider & staff training

The research team provided an educational session describing the study protocol and interventions to providers and clinic staff. All providers received educational materials detailing the CDS prompts (strengths and limitations), the included immunizations and minimum number required, and the CDC catch-up schedule for overdue immunizations. Providers randomized to receive intervention #2 were provided a sample bulletin (Appendix B) with instructions from the research team about how to use it.

Measures and analysis

Outcome measures, specified prior to study initiation, were different for the 2 interventions, as were our analytic strategies.

Intervention #1—We measured the proportions of children in each age cohort that were UTD for all immunizations in the age-specific Composite A on their index (2nd, 6th, or 13th) birthday. Our 2-year enrollment windows around these time points permitted 6 months’ time for patients to receive any needed immunizations prior to the cut point. We hypothesized that some children might become UTD sooner as a result of the intervention, but not in time for the HEDIS cutoffs. Our secondary outcome measures, therefore, were the proportions of children in each cohort that were UTD for immunizations one year following their index birthday (i.e., on the 3rd, 7th, or 14th birthday). Children were analyzed in the quarter during which their sentinel birthday occurred, and the proportion of children UTD in each quarter was plotted from the first quarter of 2007 until the third quarter of 2011. A binomial regression was fitted to the data with a single linear spline at the conclusion of the historical period (4th quarter of 2009), and the fitted line was added to the plot. Tests of the null hypothesis that the slope of the fitted line (in logit-scale) remained the same after the

introduction of intervention #1 as before were performed and p-values reported. The introduction of new immunization recommendations complicated our historical data. For example, when a new recommendation to administer 2 varicella immunizations (instead of 1) was introduced in 2007,¹⁷ initial compliance (by definition) was zero, but ramped-up quickly as children with a history of only 1 varicella immunization presented to clinic and were immunized. Due to observed “ramp-up” effects in the historical data, which were also related to new Tdap and MCV recommendations in 2006¹⁸, our statistical testing compared the intervention period (January 1, 2010—September 30, 2011) to only the year preceding the intervention (January 1—December 31, 2009) for immunizations subject to ramp-up (i.e., Composite A). For immunizations where recommendations were stable during the study window (i.e., HPV, HepA), we used data from the entire historical period.

Intervention #2—The method of Kaplan-Meier was used to determine the effectiveness of the provider bulletins, which was assessed at the patient level. The outcome was the time for a patient to receive any Composite A immunization, among those missing at least one. This time-to-event was measured from either the date on which the child aged into a target age window or the start date of the study if already within a target age window. Censoring occurred when a child aged out of the target age window without having received any Composite A immunizations or at the termination of the study. Estimated survival functions for each group were calculated using the Kaplan-Meier plots; the log-rank test was used to test the null hypothesis of no treatment difference in survival functions. Similar analyses were conducted for HepA (among children in the youngest age group) and HPV (among children in the oldest age group).

This study was approved by the Johns Hopkins University School of Medicine Institutional Review Board, which granted a waiver of informed consent, as well as registered at www.clinicaltrials.gov (NCT01794286).

RESULTS

Intervention #1

Intervention fidelity—Over the lifespan of intervention #1, 2,109 text pages were generated when overdue patients in the target age ranges presented for care, and 92% of these were flagged by nursing staff on the clinic electronic tracking board and recorded in the triage note. Immunizations were ultimately delivered to 53% of children flagged.

Composite A immunizations—There was no clinically meaningful change in the proportion of children UTD for composite A immunizations at ages 2/3, 6/7, or 13/14 years (Figure 3), with high baseline immunization rates in all 3 age groups. A significant ramp up was observed during the historical period for both the 6/7-year-olds (due to new recommendation for varicella booster in 2007¹⁷) and 13/14-year-olds (due to new Tdap and MCV recommendations in 2006¹⁸).

Hepatitis A immunization—There was a statistically and clinically significant inflection in the proportion of children UTD for hepatitis A by age 2, comparing the intervention period to the historical period (Figure 4). A gradually increasing proportion of children UTD for hepatitis A by age 3 was observed in both the historical and intervention periods, with no inflection at the time of study initiation.

Human papillomavirus immunization—HPV completion rates were low for both 13- and 14-year-old girls (Figure 4). The intervention did not improve the proportion of 13-year-olds UTD for HPV, which was actually slightly worse during the intervention than the

control period. While the rate of increase in the proportion UTD by age 14 also slowed somewhat after study initiation, the proportion UTD continued to increase throughout the study period, with 4 of the 5 highest quarters observed occurring during the final 4 quarters of the intervention period.

Intervention #2

Intervention fidelity—Over the lifespan of intervention #2, seven rounds of bulletins (232 total) were delivered to an average of 33 residents each quarter. On average, 26 residents (77%) returned the bulletins to the research team each quarter with feedback on their actions taken. Of the 1,769 total patients for whom residents indicated an action taken, the 4 most commonly reported actions were “sent patient a letter with my signature” (42%), “called patient / family personally” (18%), “no action: patient has received missing shots” (10%), and “no action: patient already has upcoming appointment scheduled” (9%).

Immunization timeliness—Among children in all 3 age groups who were overdue for at least 1 Composite A immunization, those whose providers were receiving bulletins subsequently received at least 1 Composite A immunization at a marginally faster rate than those whose providers were not, though this result was not statistically significant (hazard ratio 1.26 [95% confidence interval (CI): 0.98–1.62]) (Figure 5). A year after being identified as overdue, more than half of children in both groups still had not received any additional Composite A immunizations. Among children overdue for hepatitis A immunization in the youngest age group, being cared for by a provider receiving bulletins was associated with an increased likelihood of receiving a hepatitis A immunization during the intervention period (hazard ratio 1.32 [95% CI: 1.12–1.56]). An analysis of children overdue for HPV immunization in the oldest age group found an effect of a similar magnitude but that was not statistically significant (hazard ratio 1.27 [95% CI: 0.91–1.77]). Despite variance in the statistical significance of these results, the hazard ratios defining the impact of the provider-specific bulletins on the delivery of catch-up immunizations was quantitatively similar for all three immunization categories.

DISCUSSION

Immunization rates for US children remain sub-optimal. We evaluated 2 interventions designed to improve immunization rates in an urban, low-income patient population by alerting providers which of their patients were overdue (bulletin) and when patients presented for care (CDS). In a patient population with high baseline immunization uptake, our CDS intervention did not improve overall immunization rates among 2-, 6-, and 13-year olds. Our CDS intervention did improve the likelihood that children would be fully immunized against hepatitis A by age 2. The bulletin intervention marginally improved the timeliness of immunization catch-up among children with delayed immunizations, particularly those overdue for hepatitis A.

Myriad clinic-based interventions to improve immunization rates have been studied, with mixed results. Reminder/recall systems, upon which our provider bulletins were based, lead to relatively consistent, if modest, improvements in immunization delivery to children.¹⁹ Programs with tiered interventions, typically beginning with mail/phone reminder/recall and then escalating to case management/home visitation,^{20, 21} appear to be more effective than reminder/recall alone. Systems involving EHR-derived CDS, upon which our point-of-care reminders were based, are variably effective and typically complex to develop.^{22, 23} By using a HEDIS-based, rather than CDC-based, approach, we tested an algorithm that might be simpler for practices without extensive information technology support to implement.

A growing literature describes essential attributes of effective CDS.^{24–26} Given the limited impact of our intervention, it is worth reflecting on the strengths and weaknesses of our CDS. Advantages included: focus on a clinical topic of broadly accepted importance; widespread provider agreement on the recommended action (i.e., immunization of under-immunized children); timely provision of actionable information at the point of care; minimal impact on physician workflow; simplicity of information provided; and attention to alert fatigue. Disadvantages included: periodic inaccuracies in CDS content; and our inability to robustly collect information on episodes where providers did not follow CDS recommendations. Future research efforts should consider the ways in which CDS can be locally tailored to maximize its effectiveness.

In 2006, the CDC began recommending universal HepA immunization of children, beginning at age 12 months.²⁷ Achieving UTD HEDIS status by age two years requires 2 doses of HepA between ages 12 and 24 months. The AAP recommends 3 preventive care visits within this interval (12, 15, and 18 months),²⁸ but the 6-month minimum interval between HepA immunizations²⁹ precludes the use of the 15 month visit for this purpose. Therefore, HepA has a narrow “margin for error” compared to other immunizations with numerous catch-up opportunities. The finding that our intervention improved UTD status for HepA by age 2 suggests that for immunizations with tight, visit-based constraints, EHR-derived CDS may be of benefit. Our low baseline rates may also have contributed to the effectiveness of our interventions on HepA immunization.

A similar phenomenon complicates HPV immunization in adolescence. While the minimum age is 9 years, the CDC recommends initiation at age 11.²⁹ Coupled with AAP recommendations for annual adolescent preventive care visits,²⁸ adolescents would need HPV immunizations during 2 preventive care visits and at least 1 non-preventive care visit to meet the 13-year-old standard.

This visit pattern is rare among adolescents.³⁰ Yet, in contrast to HepA in young children, our intervention had no impact on the proportion of 13-year-olds meeting the HEDIS target, which remained similar to published data.^{4, 31–33} This finding is consistent with research suggesting that adolescents are challenging to immunize. Two recent Rochester studies found that telephone outreach alone to improve adolescent immunization rates was largely unsuccessful,³⁴ while a tiered program involving mailed reminders, phone contact, and home visits succeeded.²⁰ A study in Denver private practices demonstrated a positive effect of a combined letter/phone intervention targeting adolescents, but acknowledged that the residential stability of their suburban patient population may have contributed to the effectiveness of the intervention.³⁵ A similar study in an urban center reached parents by phone only half the time, though adolescent children of those reached were more likely to be immunized in the follow-up period.³⁶ Non-clinic-based immunization strategies, including home visits and school-based immunization outreach, as well as strengthened middle school immunization requirements,^{37, 38} will likely be needed to reach national targets for adolescent immunization delivery.

Measurement of immunization delivery, like the immunization schedule itself, is complex. For example, delays in receipt of multi-dose immunizations typically cannot be remedied in one visit. An individual receiving zero HPV immunizations by age 12.5 years would need 3 additional visits over at least a 6-month span to become fully immunized – a near impossibility by the thirteenth birthday. Immunization measures based on up-to-date status, therefore, are a lagging indicator. “Missed opportunity” metrics, in contrast, yield actionable results faster and ask: “Did this child receive all immunizations for which he was eligible today?” Standard immunization measures also largely ignore the timeliness of immunizations. A child receiving measles/mumps/rubella immunization on her first birthday

is scored identically to one receiving measles/mumps/rubella on the day before her second birthday. From a public health perspective, being immunized almost a year earlier is an important difference not reflected by measurement strategies using fixed age cutoffs.³⁹ Finally, we observed large secular trends in immunization rates, mostly related to the uptake of new CDC immunization recommendations and consistent with published data.⁴⁰ This finding highlights the need for measuring baseline data over time and/or controlled studies in order to account for potentially large secular shifts.

Our study was subject to several important limitations. First, the potential impact of our study was limited to children in three 2-year age windows. Since the end of the study period, we have expanded the intervention to all clinic patients. Second, our study involved resident providers, one-third of whom graduated and were replaced by new interns annually. We reassigned graduating residents' patients to new residents in the same treatment group, but a small number of patient reassignments (<2%) resulted in the patient's new provider being in a different study group; these patients were censored at the time they switched study groups. In addition, like most continuity clinic practices, residents spent only one half-day per week in clinic on average, limiting their time to address their lists of overdue children. Third, our data systems could not discern whether patients who went unimmunized at visits where the CDS was deployed were missed opportunities or circumstances where the immunizations were purposefully (and appropriately) withheld. Fourth, the high observed baseline immunization rates in our study population limited our potential for improvement as well as the statistical power to detect improvements. Finally, because we believed implementing CDS for only half of patients (or half of providers) would lead to confusion, we opted to deploy the CDS for all patients and providers at study onset, and to use a historical control period for comparison. This study design leaves open the possibility that unmeasured secular trends in immunization delivery could have impacted our results.

There were 3 potential sources of inaccuracy in the immunization data underpinning our interventions. First, data were extracted quarterly from the EHR. Because the data were not real-time, the accuracy of the data degraded throughout each quarter, as immunizations received during that quarter were not reflected until the next quarter's data release. This source of error was reduced by allowing the study coordinator to suppress future pages in that quarter for specific patient-immunization combinations. Second, a small minority of children received immunizations at other locations which were not captured in the EHR. Per clinic policy, providers were encouraged to "back-enter" historical immunization data from other locations. These historically entered immunizations were incorporated in the algorithm in future quarters. Third, our algorithms counted only the number of each type of immunization previously received, consistent with HEDIS methodology. When children received immunizations at nonstandard times, the CDS derived from these counts could become inconsistent with CDC recommendations, as detailed above.¹⁶

CONCLUSION

Immunizations are a vital preventive service but challenging to deliver reliably. We found that, in a setting with high baseline immunization coverage, a labor-intensive immunization improvement effort had only a modest impact on immunization delivery. Future research efforts should focus on further refining both provider- and patient/family-focused tools for prompting more reliable provider action and patient participation in the immunization delivery process.

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Abbreviations

CDC	Centers for Disease Control and Prevention
CDS	clinical decision support
CI	confidence interval
DTaP	diphtheria/tetanus/acellular pertussis vaccine
EHR	electronic health record
HEDIS	Healthcare Effectiveness Data and Information Set
HepA	hepatitis A vaccine
HepB	hepatitis B vaccine
HiB	haemophilus influenza, type B vaccine
HPV	human papillomavirus vaccine
IPV	inactivated poliovirus vaccine
MCV	meningococcal conjugate vaccine
MMR	measles/mumps/rubella vaccine
PCV13	pneumococcal conjugate vaccine, 13-valent
Tdap	tetanus/diphtheria/acellular pertussis vaccine
UTD	up-to-date
VZV	varicella zoster virus vaccine

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WHAT'S NEW

Converting electronic health record (EHR) immunization data into actionable quality improvement tools is challenging. Newer immunizations and those with low baseline uptake may be most amenable to EHR-based quality improvement efforts.

Age group	Immunization	Abbreviation	Minimum number required
2-year-old group (1.5-3.5 years old)	diphtheria / tetanus / pertussis	DTaP	4
	measles / mumps / rubella	MMR	1
	varicella	VZV	1
	pneumococcal conjugate	PCV13	4
	polio	IPV	3
	hepatitis B	HepB	3
	haemophilus influenza, type B	HiB	3
	COMPOSITE A (7 listed above)¹		
	hepatitis A ²	HepA	2
6-year-old group (5.5-7.5 years old)	diphtheria / tetanus / pertussis	DTaP	5
	measles / mumps / rubella	MMR	2
	varicella	VZV	2
	polio	IPV	4
	COMPOSITE A (4 listed above)		
	hepatitis A	HepA	2
	hepatitis B	HepB	3
13-year-old group (12.5-14.5 years old)	diphtheria / tetanus / pertussis	Tdap	1 ³
	meningococcal conjugate	MCV	1
	COMPOSITE A (2 listed above)		
	human papilloma virus ⁴	HPV	3
	measles / mumps / rubella	MMR	2
	varicella	VZV	2
	polio	IPV	4
	hepatitis A	HepA	2
	hepatitis B	HepB	3

¹ The 2-year-old Composite A is identical to "Combination 3" in HEDIS 2010.

² The 2-year-old Composite A + HepA is identical to "Combination 4" in HEDIS 2010.

³ Dose must have been administered between 10 and 13 years of age.

⁴ Limited to females only.

Figure 1.
Included immunizations and minimum number required

	Intervention #1 Computerized decision support	Intervention #2 Provider-specific bulletins
Methodology	Interrupted time series	Randomized controlled trial
Implementation	Provided to all clinicians for every relevant patient visit during the intervention period	Provided to half of clinicians (block randomized at the clinic group level) during the intervention period
Intervention group	Children exposed to intervention #1 but NOT intervention #2	Children exposed to intervention #1 AND intervention #2
Intervention period	1/1/10 to 9/30/11	1/1/10 to 9/30/11
Comparator group	Children exposed to neither intervention #1 NOR intervention #2 (historical control)	Children exposed to intervention #1 but NOT intervention #2 (contemporaneous control)
Comparator period	1/1/07 to 12/31/09	1/1/10 to 9/30/11
Outcome evaluated	Proportion of children up-to-date for immunizations on day of sentinel birthday (2, 6, or 13 years)	Time to receipt of next missing immunization among those missing at least 1 target immunization

Figure 2.
Study design

Figure 3.
Proportion of children up-to-date for Composite A immunizations, by quarter of sentinel birthday

Figure 4.
Proportion of children up-to-date for HepA and HPV immunizations, by quarter of sentinel birthday

Figure 5.
Kaplan-Meier survival estimates for children overdue for one or more Composite A immunizations (“Event” = receipt of one or more Composite A immunizations)