PEDIATRICS®
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Identifying Factors Predicting Immunization Delay for Children Followed in an Urban Primary Care Network Using an Electronic Health Record

Alexander G. Fiks, Evaline A. Alessandrini, Anthony A. Luberti, Svetlana Ostapenko, Xuemei Zhang and Jeffrey H. Silber

Pediatrics 2006;118;e1680; originally published online November 6, 2006;
DOI: 10.1542/peds.2005-2349

ARTICLE

Identifying Factors Predicting Immunization Delay for Children Followed in an Urban Primary Care Network Using an Electronic Health Record

Alexander G. Fiks, MD[a,b], Evaline A. Alessandrini, MD, MSCE[a,b], Anthony A. Luberti, MD, MS[a], Svetlana Ostapenko, MA[a], Xuemei Zhang, MS[c], Jeffrey H. Silber, MD, PhD[c]

[a]Pediatric Research Consortium, [b]Pediatric Generalist Research Group and [c]Center for Outcomes Research at Children's Hospital of Philadelphia, and Departments of Pediatrics and Anesthesiology and Critical Care Medicine, University of Pennsylvania School of Medicine and Children's Hospital of Philadelphia, Philadelphia, Pennsylvania

The authors have indicated they have no financial relationships relevant to this article to disclose.

ABSTRACT

OBJECTIVE. An opportunity exists to use increasingly prevalent electronic health records to efficiently gather immunization, clinical, and demographic data to assess and subsequently reduce barriers to immunization. The objective of this study was to use data entered at the point of care within an electronic health record to identify factors that predispose children in an inner-city population to immunization delay.

METHODS. Retrospective cohort data from an electronic health record were used to evaluate the association between demographic, clinical, and immunization variables on immunization delay at 24 months. Patients 2 to 5 years old as of May 31, 2003, with an office visit between May 31, 2002, and May 31, 2003, were selected ($N = 5464$). Univariate and multivariable models were developed to predict vaccination delay at 24 months per the Advisory Committee on Immunization Practices guidelines.

RESULTS. Overall up-to-date immunization rates at 3, 7, 13, and 24 months were 75%, 45%, 82%, and 71%. Multivariable models using electronic health record data showed that early immunization status was the strongest predictor of immunization delay at 24 months. Multivariate analysis revealed that children who were inadequately immunized at 3 months of age were more than 4.5 times as likely to be immunization delayed at 24 months. In this analysis, patient and caregiver factors associated with immunization delay included insurance status and nonparent caregiver. Children who were premature were less likely to be delayed.

CONCLUSIONS. Using an electronic health record with information entered at the point of care, we found that early immunization status is a strong predictor of immunization delay for young children that can be identified as early as 3 months of age. Electronic health records may prove useful to clinicians and health systems in identifying children at high risk for immunization delay.

www.pediatrics.org/cgi/doi/10.1542/peds.2005-2349

doi:10.1542/peds.2005-2349

Key Words
immunization assessment, medical informatics, quality improvement, urban

Abbreviations
DTP— diphtheria-tetanus-pertussis
DTaP— diphtheria-tetanus-acellular pertussis
MMR—measles-mumps-rubella
Hib—*Haemophilus influenzae* type b
4:3:1:3:3— 4 DTP/DTaP, 3 polio, 1 MMR, 3 Hib, and 3 hepatitis B vaccines
EHR— electronic health record
CHOP—Children's Hospital of Philadelphia
OR— odds ratio
CI— confidence interval

Accepted for publication Jun 9, 2006

Address correspondence to Alexander G. Fiks, MD, Primary Care Center at University City, Children's Hospital of Philadelphia, St Leonard's Court, Suite 110, 39th and Chestnut Streets, Philadelphia, PA 19104. E-mail: fiks@email.chop.edu

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

IMMUNIZATION RATES HAVE been designated as 1 of 10 leading health indicators for the nation by *Healthy People 2010*.[1] Immunization rates serve as excellent measures of the quality of pediatric care, because immunization schedules are standardized, widely accepted, and optimized to protect children from life-threatening illness. However, levels of vaccination have not universally reached goals of 90% coverage, with children in minority populations at greatest risk of delay.[2]

Despite the recognized importance of immunizations, multiple studies have found discrepancies in immunization rates between different groups of children. Previous work has demonstrated that mothers living in poverty were more than twice as likely to have incompletely vaccinated children,[3] and baseline rates among inner-city children were nearly 20% below those in more affluent suburbs.[4] Immunization rates for 4 diphtheria-tetanus-acellular pertussis (DTP/DTaP); 3 polio; 1 measles-mumps-rubella (MMR); 3 *Haemophilus influenzae* type b (Hib); and 3 hepatitis B vaccines (4:3:1:3:3) at 24 months of age were >13% lower among black children than white children in the 2003 National Immunization Survey for Philadelphia.[2] Given these disparities, continued work is needed to devise strategies to best identify young children at risk.

With rapid changes in information technology occurring in US health care systems, an opportunity exists to improve patient outcomes through the application of medical information gathered as part of routine visits. Increasingly prevalent electronic health records (EHRs), which internally maintain immunization records for each child, represent a promising tool in the characterization and reduction of barriers to immunization. The objective of this study was to use data entered at the point of care within an EHR to identify factors that predispose children in an inner-city population to immunization delay. By studying the predictive strength of factors known early in life, this study tests the hypothesis that children at increased risk of immunization delay at 24 months of age can be identified using EHR data by 3 months of age.

METHODS

Setting and EHRs

The Children's Hospital of Philadelphia (CHOP) primary care network consists of 4 urban Philadelphia, Pennsylvania, practices, with a combined total of >72 000 annual visits. Nearly 45 pediatricians and 5 nurse practitioners provide care at these sites. In addition, these practices are the continuity clinic sites for ~120 pediatric residents.

All practices in the network began using the EHR EpicCare (Epic Systems Corporation, Verona, WI) between June 2001 and June 2002. Demographic and financial information for patients seen in the health system before this time was entered into a previous EHR (IDX; General Electric Company, Fairfield, CT) and transferred into EpicCare on implementation of the system within each practice. Clinical information for patients seen before EpicCare implementation was abstracted into the EHRs by clinicians for complex patients or by trained abstractionists for other patients and confirmed during the subsequent office visit. Since implementation, EpicCare has been the sole source of documentation for all health care encounters and telephone calls to each practice. The EHR includes patient demographics, birth, social, family, and past medical history including problem lists with *International Classification of Diseases, Ninth Revision* codes, medication orders, and laboratory and radiology results.

The immunization database within the EHR provides a comprehensive record of all vaccines received by a patient. To ensure that the desired vaccine product is administered, all orders are dictionary driven and based on *Current Procedural Terminology* codes, allowing the desired immunization to be selected from a menu of specific options. Furthermore, all ordered immunizations must be recorded at the point of care for charts to be completed. Before EpicCare implementation, immunizations were entered at the point of care via another EHR, TDS 7000 (Eclipsys Corporation, Boca Raton, FL). These records were then transferred electronically to EpicCare. When patients were identified as missing vaccine doses during routine clinical care, records of previous vaccinations were obtained from a citywide immunization database and entered by nursing staff or providers into the EHR. This procedure was followed at both sick and well visits. For new patients from within or outside Philadelphia County, vaccine records were also requested directly from families and their former medical providers and then entered into the electronic record.

Design and Patient Population

This retrospective cohort study included all patients between 24 and 60 months of age as of May 31, 2003, with at least 1 primary care network office visit between May 31, 2002, and May 31, 2003 ($N = 5464$).

The main outcome measure was up-to-date immunization status at 24 months of age for DTP/DTaP, polio, MMR, Hib, and hepatitis B (4:3:1:3:3). The principal independent variable of interest was immunization delay at 3 months of age. Immunization delay at 7 or 13 months was also considered. Delay was defined according to the recommended childhood immunization schedule and remained consistent throughout the period under study.[5–7] To be up-to-date at 3 months of age a child required at least 1 DTP/DTaP, polio, Hib, and hepatitis B vaccine, and to be up-to-date at 7 or 13 months of age a child required at least 3 DTP/DTaP and 2 polio, Hib, and hepatitis B vaccines.

Other independent variables studied included patient

and caregiver characteristics. Patient factors included gender, race (categorized as white, non-Hispanic black, Hispanic, Asian, and other), chronic medical problems, and insurance type as of the last office visit during the study period (categorized as commercial, Medicaid, self-pay, or other). The chronic conditions considered were defined by a previously published list, identified from the EHR problem list, and include sickle cell disease, cerebral palsy, prematurity, congenital heart disease, and congenital or chromosomal anomalies.[8] Patients with each of these conditions command increased attention in outpatient pediatric practice, and each problem is present at birth and, therefore, precedes any vaccination. Caregiver characteristics studied included relation to the patient as of the last visit (defined as mother, father, or other and captured by the office registration staff), age (≤20 or >20 years of age), and income derived from census tract data based on 5-digit zip codes and divided into lowest quartile, middle 50%, and highest quartile for Philadelphia. For the income scale, the lowest group had family incomes of or less than $21 329, the middle group had incomes between $21 329 and $30 099, and the highest group had incomes of more than $30 099.

Statistical Analysis

Demographic, clinical, and immunization status variables were described by using proportions. In the first phase of the analysis, the relationship between individual independent variables and immunization status at 24 months of age was determined by using unadjusted relative risks. To specify the absolute increase in risk of immunization delay at 24 months for each independent variable, the attributable risk of immunization delay was calculated. The attributable risk was defined as the risk of delay at 24 months in those with the variable of interest minus the risk in all others or, where specified, minus the risk in the reference group (for variables such as race and insurer).

We next developed 4 logistic-regression models to predict vaccination delay at 24 months of age. A model that included all demographic and clinical variables, as well as immunization status at 3 months, was the central focus of the analysis. For comparison, we developed a base model with all demographic and clinical variables but no previous immunization status, as well as 2 additional models that added immunization status at either 7 or 13 months to the base model. The log-likelihood ratio statistic was used to evaluate the overall significance of the models, and the *C* statistic was calculated to explain the discriminative ability of each model. To ensure that minimal bias was introduced by the implementation of the EHR during the study period, a limited analysis was performed by using these models with only patients <36 months of age.

To validate the multivariable models, patients were randomly assigned to a derivation or validation data set. The multivariable models were initially built by using the derivation data set and then applied to the validation set. After testing for differences in model parameters between data sets and not finding significant ones (*P* value for likelihood ratio test = .40), the 2 data sets were combined for the estimation of the final models.

The study was approved by the institutional review board of CHOP.

RESULTS

Study Population

A total of 5464 patients met inclusion criteria. The cohort was nearly equally divided between males (53%) and females (47%). The vast majority of patients identified themselves as black (85%); white children comprised 8%, and Asian/Pacific Islander children 1% of the study cohort. The majority of patients were insured by Medicaid (67%), 4% had one of the chronic medical conditions considered, and 7% had a nonparent listed as the primary caregiver.

Immunization Rates

Overall up-to-date immunization rates for the entire study sample at 3, 7, 13, and 24 months were 75%, 45%, 81%, and 71%, respectively. If the population was limited to children born between June 1, 2000, and May 31, 2001 (the youngest patients in the cohort), rates at 3, 7, 13, and 24 months were similar (78%, 44%, 81%, and 74%, respectively).

Predictors of Immunization Delay at Age 24 Months

In the univariate analysis (Table 1), early immunization delay was most strongly associated with delay at 24 months of age. In particular, children with immunization delay at 3 months of age were 2.6 times more likely to be delayed and had a 34% absolute increase in risk of immunization delay at 24 months of age. Patient and caregiver characteristics were overall less strongly associated with immunization status at 24 months of age. However, children in the "other" race category, with sickle cell disease, Medicaid, no insurance, or "other" insurance, or a nonparent as the primary caregiver were significantly more likely to have immunization delay at 24 months. Prematurity was associated with improved immunization rates.

Results of the multivariable model including immunization status at 3 months of age (Table 2) demonstrate similar findings. Among patient and other caregiver factors, "other" race, no insurance or "other" insurance, and having a nonparent caregiver were associated with immunization delay, and prematurity with improved immunization rates at 24 months of age. In this analysis, immunization delay at 3 months remained most strongly predictive of delay at 24 months of age (adjusted odds

TABLE 1 **Univariate Analysis of Factors Available in an EHR Associated With Immunization Delay at 24 Months of Age ($N = 5464$)**

Variable	No. of Patients	Percentage of Cohort	Immunization Delay at 2 y, %	Relative Risk (95% CI)[a]	Attributable Risk (95% CI)[b]
Immunization status					
Immunization delay at 3 mo	1354	24.8	54.4	2.64 (2.45 to 2.86)	0.34 (0.31 to 0.37)
Patient					
Male	2887	52.8	28.8	0.99 (0.91 to 1.07)	0.00 (−0.03 to 0.02)
White	421	7.7	24.9	Reference	Reference
Non-Hispanic black	4662	85.3	29.0	1.16 (0.98 to 1.38)	0.04 (−0.01 to 0.08)
Hispanic	61	1.1	29.5	1.18 (0.78 to 1.80)	0.05 (−0.08 to 0.17)
Asian	71	1.3	29.6	1.19 (0.80 to 1.76)	0.05 (−0.07 to 0.16)
Other	249	4.6	34.1	1.37 (1.08 to 1.74)	0.09 (0.02 to 0.16)
Sickle cell disease	16	0.3	50.0	1.73 (1.06 to 2.83)	0.21 (−0.03 to 0.46)
Cerebral palsy	19	0.4	26.3	0.91 (0.43 to 1.93)	−0.03 (−0.22 to 0.17)
Prematurity	116	2.1	14.7	0.50 (0.32 to 078)	−0.15 (−0.21 to −0.08)
Congenital heart disease	37	0.7	24.3	0.85 (0.52 to 1.38)	−0.05 (−0.19 to 0.09)
Congenital or chromosomal anomalies	49	0.9	24.5	0.85 (0.52 to 1.38)	−0.04 (−0.17 to 0.08)
Commercial insurance	1495	27.4	25.3	Reference	Reference
Medicaid insurance	3663	67.0	29.6	1.17 (1.06 to 1.30)	0.04 (0.02 to 0.07)
Self-pay	267	4.9	37.8	1.50 (1.25 to 1.79)	0.13 (0.06 to 0.19)
Other insurance	39	0.7	43.6	1.72 (1.19 to 2.49)	0.18 (0.03 to 0.34)
Primary caregiver					
Mother	4477	81.9	28.2	Reference	Reference
Father	608	11.1	27.8	0.99 (0.86 to 1.13)	0.00 (−0.04 to 0.03)
Nonparent	379	6.9	39.6	1.40 (1.23 to 1.60)	0.11 (0.06 to 0.16)
<20 y old	1142	20.9	29.0	1.00 (0.90 to 1.11)	0.00 (−0.03 to 0.03)
Top quartile income[c]	1272	23.3	29.2	Reference	Reference
Middle 50% income	2691	49.2	29.2	1.00 (0.90 to 1.11)	0.00 (−0.03 to 0.03)
Bottom quartile income	1501	27.5	28.2	0.97 (0.86 to 1.09)	0.00 (−0.04 to 0.03)

[a] Unadjusted relative risk represents a comparison between those with the variable of interest and all other patients in the cohort or reference patients in the cohort where indicated.
[b] Attributable risk is the risk in those with the variable of interest minus the risk in all others or reference patients where indicated.
[c] Refers to income level of census tract based on 5-digit zip code.

ratio [OR]: 4.54; 95% confidence interval [CI]: 3.98 to 5.19). To address the potential for bias in data entry over time, models were developed that included only patients <36 months of age as of May 31, 2003. The association between early immunization delay and vaccination status at 24 months was unchanged.

Analyses were performed on each of 4 multivariate models to assess their predictive strength. A base model that incorporated patient and caregiver factors but had no immunization variables had a *C* statistic of 0.56. The discriminative ability of the models that included immunization delay at 3, 7, or 13 months improved appreciably on the base model, with *C* statistics of 0.68, 0.71, and 0.77, respectively. Furthermore, 3 models that included only 1 factor (immunization status at 3, 7, or 13 months) had *C* statistics of 0.65, 0.69, and 0.75, respectively, nearly matching that of the full 3-, 7-, and 13-month models.

DISCUSSION

As EHRs become increasingly common in pediatric settings, study of their potential in understanding key markers of health such as immunization status is warranted. To our knowledge, this study represents the only work to date to comprehensively study factors associated with immunization delay for routine pediatric vaccinations in young children using this technology. Through the example of early childhood vaccination, the results from this project highlight the utility and limitations of an EHR as a research tool and its potential impact in identifying from an early age children at high risk for adverse health outcomes.

In this study, among a broad range of patient-, caregiver-, and immunization-specific predictors, one factor (early immunization delay) was the most important factor predicting being up-to-date at 24 months. Even adjusting for all factors considered, children with delay at 3 months were >4.5 times more likely than other children to be delayed at 24 months. Because delayed early vaccination status is easily identified and has proven to be predictive of incomplete immunization in multiple settings, it could be used as a practical marker for providers to target outreach to patients at highest risk.[9–14] Beginning these interventions at an early age is especially important, because visits are most frequent during the first year of life. More broadly, efforts to improve immunizations rates may have far-reaching consequences in improving the overall delivery of preventive services to young children.[3,15,16]

Supporting the validity of the EHR as an immunization research tool, the results obtained from this study match those of previous studies that have used a variety

TABLE 2 **Multivariate Regression Analysis of Factors Associated With Immunization Delay at 24 Months of Age ($N = 5464$)**

Variable	Base Model		Base Model With 3-mo Immunization Status	
	Adjusted OR	95% CI	Adjusted OR	95% CI
Immunization status				
Immunization delay at 3 mo	Excluded from model	Excluded from model	4.54[a]	3.98–5.19
Patient				
Male	0.98	0.87–1.10	0.97	0.86–1.10
White	Reference		Reference	
Non-Hispanic black	1.18	0.93–1.51	1.26	0.97–1.62
Hispanic	1.21	0.66–2.20	1.34	0.71–2.51
Asian	1.27	0.72–2.22	1.40	0.78–2.52
Other	1.48[c]	1.04–2.10	1.50[c]	1.03–2.16
Sickle cell disease	2.20	0.82–5.90	2.50	0.89–7.04
Cerebral palsy	1.10	0.39–3.15	0.73	0.25–2.18
Prematurity	0.40[a]	0.24–0.68	0.40[a]	0.23–0.68
Congenital heart disease	0.86	0.40–1.84	0.78	0.35–1.73
Congenital or chromosomal anomalies	0.81	0.42–1.58	0.82	0.41–1.65
Commercial insurance	Reference		Reference	
Medicaid insurance	1.24[b]	1.06–1.44	1.08	0.92–1.26
Self-pay	1.78[a]	1.35–2.35	1.53[b]	1.14–2.05
Other insurance	2.24[c]	1.17–4.28	2.02[c]	1.01–4.02
Primary caregiver				
Mother	Reference		Reference	
Father	1.09	0.89–1.34	0.98	0.79–1.21
Nonparent	1.63[a]	1.31–2.03	1.39[b]	1.10–1.76
<20 y old	1.01	0.87–1.17	1.03	0.88–1.21
Top quartile income	Reference		Reference	
Middle 50% income	0.99	0.85–1.15	1.01	0.86–1.18
Bottom quartile income	0.92	0.78–1.09	0.96	0.80–1.15
C statistic	0.56		0.68	

[a] $P < .001$.
[b] $P < .01$.
[c] $P < .05$.

of retrospective and prospective strategies to identify predictors of immunization delay in high-risk populations. Consistent with previous studies, we found that insurance status and family structure are associated with immunization status.[3,11,17,18] In our study, having a nonparent as the primary caregiver for a child compared with the mother increased the risk of immunization delay at 2 years of age. Children without commercial insurance were more likely to be delayed. In addition, although multiple medical conditions present from birth were considered, only prematurity and sickle cell disease were found to be significantly associated with immunization status. This pattern is consistent with earlier work that did not show an association between many chronic medical conditions and immunization status.[18]

In relying on EHR data, our study has several strengths and limitations. EHR data are readily available on large patient populations, do not require the time or expense associated with prospective data collection, and are derived from the actual patient chart without translation. However, during the implementation of an EHR, the potential exists for information to be omitted. The electronic translation of immunization records, as well as demographic and insurance information directly from other electronic systems in the practices studied, has been shown to result in more complete data.[19] For clinical information, the dual processes of abstraction and physician review used in the health system studied ensured that providers had the opportunity to review the information in the EHR. Finally, the consistency of results between the youngest patients in the cohort, those most likely to have received care using the current EHR before 24 months of age, and the overall group suggests that results were not biased by the implementation process.

As with any patient chart, the completeness of EHR data for children joining practices after the neonatal period depends on obtaining patient records. For immunizations, a lack of early vaccine records for patients transferring into the practices studied could have potentially increased the measured effect of not being vaccinated by 3 months of age on immunization delay at 24 months of age, because these children may not have been caught up on immunizations by 24 months and did not have shots in our health system by this early age. To address this concern, we again considered the association of early immunization delay and delay at 24 months for only patients <36 months of age at the end of the study period, the subset of the population most likely to have received care in our health system at an early age.

The persistence of the highly significant association of lack of immunization by 3 months and immunization delay at 24 months in this group suggests that this association did not arise from bias.

Despite these limitations, the EHR-based approach used for this study is particularly effective in tracking immunization status, the main outcome considered. Strongly supporting the validity of the immunization record in the EHR, the rate for 4:3:1:3:3 found in our study at 24 months of age of 71% up-to-date very closes matches the overall rate for Philadelphia throughout the study period. According to the National Immunization Survey, rates at 24 months were 68% in 1998, 69% in 2000, and 70% in 2003.[2,20,21] Further supporting the validity of the EHR for immunization research, previous studies have found that immunization databases like the one we used are less likely than other systems to have missing doses because information is entered at the point of care.[18] By conducting an electronic review of charts through the EHR, the process of manual chart review, subject to human error and involving considerable expense and time, was eliminated. Also limiting bias from missing vaccine doses, children with immunization delay at any of the 4 centers involved in this study had their vaccinations checked against the Philadelphia Kids Immunization Database/Tracking System Registry, a citywide immunization database, during sick or well visits when delay was recognized. Records were then updated directly within the EHR. The use of such registries to supplement data in patient charts has previously been shown to provide a better estimate of the number of children who are truly up-to-date.[22] As a result, although doses administered at nonstudy practices may have been missed, immunization data available reflects vaccination delivery both inside and beyond the health system considered.

EHRs that include immunization records, as well as clinical and demographic data from across multiple practices or entire health systems, represent a remarkable new resource to identify and study characteristics of children at risk of immunization delay at an early age. Using EHRs, groups of children can readily be identified by such factors as birth date, age at first or last visit, insurance type, zip code, or a specific diagnosis. Because information is collected prospectively as part of routine care, recall bias, even in a retrospective study, is minimized. Furthermore, although information in paper charts often requires interpretation because of issues of handwriting or a lack of strict matching of diagnoses to diagnostic codes, all immunizations and medical problems within the EHR are numerically coded and unique. In addition, the collection of clinical, demographic, and billing information in 1 system offers the opportunity to better understand the relationship of factors in each of these domains on the delivery of immunizations.

The ability to identify children at high risk of immunization delay from an early age is a key step in meeting the national goal of improved immunization rates. To meet this objective, the discussion of immunization practices has shifted increasingly to practical approaches for quality improvement.[15,23–25] The most dramatic benefit of the EHR may be the ability to collect data, which has occurred in this project, and then provide clinical alerts to providers which influence care in the office or trigger contact with families to encourage appointment scheduling. On the basis of EHR data, providers may also be educated regarding their own performance on such measures as vaccination rates. However, although work has begun to show the promise of office-based systems in improving preventive care, the potential impact of EHRs on the quality of care has not been widely studied in pediatrics.[23,24,26] Through the electronic review of >5000 charts within an EHR, we have found that immunization delay by as early as 3 months of age is strongly predictive of incomplete immunization at 2 years of age. As EHRs become increasingly prevalent, electronically captured clinical and demographic data may be easily used to guide pediatric care and facilitate rapid cycle quality improvement efforts for the health of children.

ACKNOWLEDGMENTS

This work was supported by an Ethel Brown Foerderer Fund for Excellence grant from CHOP.

We thank Jonathan Crossette, MPH, Robert Grundmeier, MD, and Orit Even-Shoshan for their helpful comments and technical insights during the course of this research. In addition, we recognize Barbara Watson, MD, for thoughtful review and Susan Healis for administrative support.

REFERENCES

1. US Department of Health and Human Services. *Healthy People 2010*. Conference ed. Washington, DC: US Department of Health and Human Services; 2000
2. US Department of Health and Human Services, National Center for Health Statistics. *The 2003 National Immunization Survey*. Hyattsville, MD: Centers for Disease Control and Prevention; 2004
3. Bates AS, Wolinsky FD. Personal, financial, and structural barriers to immunization in socioeconomically disadvantaged urban children. *Pediatrics.* 1998;101:591–596
4. Szilagyi PG, Schaffer S, Shone L, et al. Reducing geographic, racial, and ethnic disparities in childhood immunization rates by using reminder/recall interventions in urban primary care practices. *Pediatrics.* 2002;110(5). Available at: www.pediatrics.org/cgi/content/full/110/5/e58
5. American Academy of Pediatrics, Committee on Infectious Diseases. *1997 Red Book: Report of the Committee on Infectious Diseases*. King of Prussia, PA: Rittenhouse Book Distributors; 1997
6. American Academy of Pediatrics, Committee on Infectious Diseases. *2000 Red Book: Report of the Committee on Infectious Diseases*. Elk Grove Village, IL: American Academy of Pediatrics; 2000
7. American Academy of Pediatrics, Committee on Infectious Diseases. *2003 Red Book: Report of the Committee of Infectious Diseases*. Elk Grove Village, IL: American Academy of Pediatrics; 2003

8. Silber JH, Gleeson SP, Zhao H. The influence of chronic disease on resource utilization in common acute pediatric conditions: financial concerns for children's hospitals. *Arch Pediatr Adolesc Med.* 1999;153:169–179
9. Ross A, Kennedy AB, Holt E, Guyer B, Hou W, Hughart N. Initiating the first DTP vaccination age-appropriately: a model for understanding vaccination coverage. *Pediatrics.* 1998;101: 970–974
10. Williams IT, Milton JD, Farrell JB, Graham NM. Interaction of socioeconomic status and provider practices as predictors of immunization coverage in Virginia children. *Pediatrics.* 1995; 96:439–446
11. Wood D, Donald-Sherbourne C, Halfon N, et al. Factors related to immunization status among inner-city Latino and African-American preschoolers. *Pediatrics.* 1995; 96:295–301
12. Guyer B, Hughart N, Holt E, et al. Immunization coverage and its relationship to preventive health care visits among inner-city children in Baltimore. *Pediatrics.* 1994;94:53–58
13. Bates AS, Fitzgerald JF, Dittus RS, Wolinsky FD. Risk factors for underimmunization in poor urban infants. *JAMA.* 1994; 272:1105–1110
14. Bobo JK, Gale JL, Thapa PB, Wassilak SG. Risk factors for delayed immunization in a random sample of 1163 children from Oregon and Washington. *Pediatrics.* 1993;91:308–314
15. Davis MM, Szilagyi PG. Can quality improvement reach into pockets of need for childhood immunizations? *Ambul Pediatr.* 2004;4:224–225
16. Adams WG, Geva J, Coffman J, Palfrey S, Bauchner H. Anemia and elevated lead levels in underimmunized inner-city children. *Pediatrics.* 1998;101(3). Available at: www.pediatrics.org/cgi/content/full/101/3/e6
17. Brenner RA, Simons-Morton BG, Bhaskar B, Das A, Clemens JD. Prevalence and predictors of immunization among inner-city infants: a birth cohort study. *Pediatrics.* 2001;108:661–670
18. Szilagyi PG, Rodewald LE, Humiston SG, et al. Missed opportunities for childhood vaccinations in office practices and the effect on vaccination status [published correction appears in *Pediatrics.* 1993;91:545]. *Pediatrics.* 1993;91:1–7
19. Kolasa MS, Chilkatowsky AP, Clarke KR, Lutz JP. How complete are immunization registries? The Philadelphia story. *Ambul Pediatr.* 2006;6:21–24
20. US Department of Health and Human Services, National Center for Health Statistics. *The 1998 National Immunization Survey*. Hyattsville, MD: Centers for Disease Control and Prevention; 2002
21. US Department of Health and Human Services, National Center for Health Statistics. *The 2000 National Immunization Survey*. Hyattsville, MD: Centers for Disease Control and Prevention; 2002
22. Stille CJ, Christison-Lagay J. Determining immunization rates for inner-city infants: statewide registry data vs medical record review. *Am J Public Health.* 2000;90:1613–1615
23. Adams WG, Mann AM, Bauchner H. Use of an electronic medical record improves the quality of urban pediatric primary care. *Pediatrics.* 2003;111:626–632
24. Bordley WC, Margolis PA, Stuart J, Lannon C, Keyes L. Improving preventive service delivery through office systems. *Pediatrics.* 2001;108(3). Available at: www.pediatrics.org/cgi/content/full/108/3/e41
25. Daley MF, Steiner JF, Kempe A, et al. Quality improvement in immunization delivery following an unsuccessful immunization recall. *Ambul Pediatr.* 2004;4:217–223
26. Johnson KB, Davison CL. Information technology: its importance to child safety. *Ambul Pediatr.* 2004;4:64–72

Identifying Factors Predicting Immunization Delay for Children Followed in an Urban Primary Care Network Using an Electronic Health Record

Alexander G. Fiks, Evaline A. Alessandrini, Anthony A. Luberti, Svetlana Ostapenko, Xuemei Zhang and Jeffrey H. Silber

Pediatrics 2006;118;e1680; originally published online November 6, 2006;
DOI: 10.1542/peds.2005-2349