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Frequency and Cost of Vaccinations Administered Outside Recommended Ages — 2014; Six Immunization Information System Sentinel Sites

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Abstract

Objective: To quantify vaccinations outside recommended ages by analyzing immunization information system (IIS) records.

Study Design: We analyzed de-identified records of doses administered during 2014 to persons age ≤17 years within six IIS Sentinel Sites (10% of US population). We quantified doses administered outside of recommended ages according to the Advisory Committee on Immunization Practices childhood immunization schedule and prescribing information in package inserts, and calculated revaccination costs. To minimize misreporting bias, we analyzed publically funded doses where reported lot numbers and vaccine types were consistent.

Results: Among 3,394,047 doses with maximum age recommendations, 9,755 (0.3%) were given after the maximum age. One maximum age violation required revaccination: 1,344 (0.7%) of 194,934 doses of the 0.25 mL prefilled syringe formulation of quadrivalent inactivated influenza vaccine (Fluzone) administered after age 2 years (revaccination cost: $111,964). We identified 7,529,165 childhood, adolescent and lifespan doses with minimum age recommendations, among which 9,542 (0.1%) were administered before the minimum age. The most common among these were quadrivalent injectable influenza vaccines (3,835, or 0.7% of 526,110 doses administered before age 3 years) and Kinrix (DTaP-IPV) (2,509, or 1.2% of

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Disclosure and Conflicts of Interest

The authors have no financial relationships or conflicts of interest to report relevant to this article. No honoraria, grants, or other form of payment were given to anyone to produce the manuscript (the work was conducted using regular agency operating funds). This study was a secondary data analysis determined to be public health practice, and was exempted from human subjects review. Discussion of specific vaccines or off-label practices does not indicate endorsement of any product or practice. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

208,218 doses administered before age 4 years). Revaccination cost for minimum age violations (where recommended) was $179,179.

Conclusion: Administration of vaccines outside recommended ages was rare, reflecting general adherence with recommendations. Error rates were higher among several vaccines, some requiring revaccination. Vaccine schedule complexity and confusion among similar products might contribute to errors. Minimization of errors reduces wastage, excess cost, and inconvenience for parents and patients.

Keywords

IIS; vaccine; error; wastage; revaccination

Introduction

The US Food and Drug Administration approves vaccines for defined indications and age ranges. The Advisory Committee on Immunization Practices (ACIP) issues recommendations to guide vaccination practices in the United States.[1, 2] These recommendations include minimum and maximum ages and intervals for vaccination, and determining which age-related errors require revaccination. Over the years, the US childhood immunization schedule has increased in complexity as new vaccines have been introduced and recommendations have expanded.[1, 3, 4]

For some vaccines, recommended dose volumes vary between age groups. For example, several products are available within the class of inactivated influenza vaccines. Prior to 2016, one of these was licensed for 0.25 mL intramuscular injection in children age 6–35 months (Fluzone Quadrivalent, Sanofi Pasteur, Swiftwater, Pennsylvania). This product (and other inactivated influenza vaccines) should be administered as a 0.5 mL dose to persons age ≥36 months, and revaccination procedures are specified for scenarios where administered vaccines or dose volumes are incorrect for the vaccinated patient.[5, 6]

Introduction of new vaccines and increasing complexity of the immunization schedule increases the opportunity for vaccination errors, which can potentially leave patients less protected from vaccine preventable diseases and generate additional costs, particularly in instances where revaccination is required. These errors waste vaccine, require additional clinical staff time and resources, and inconvenience patients and caregivers. Errors also have the potential to decrease patient confidence in the healthcare system.

Previous studies have sought to document age-related vaccination errors. During 1997, one clinic analyzed 6,983 vaccine doses administered during a three month period to children <5 months of age and found 4.1% of doses to be invalid, with 35.5% of patients receiving at least one invalid dose.[7] During 2000, it was estimated that 10.5% of a nationally representative sample of 19–35 month olds in the United States received at least one dose before the minimum age or minimum interval, requiring revaccination;[8] the national proportion of children receiving an invalid dose requiring revaccination was estimated to be 8% during 2005.[9] A more recent study analyzed vaccination errors reported to the Vaccine Adverse Event Reporting System during 2000–2013,[10] and identified 5,947 errors (27% of

total error reports) classified as “inappropriate vaccine schedule,” indicating vaccines administered outside recommended ages or had improper spacing between doses.

To provide an estimate of errors among routinely recommended vaccines in persons <18 years of age, we used provider-reported vaccination records from six immunization information systems (IIS), quantifying the frequency of vaccination outside minimum and maximum recommended ages. IISs are confidential databases that record vaccine doses administered to persons residing within defined jurisdictions, and perform a spectrum of functions that improve vaccination practices.[11] Fully-functioning IISs serve providers at the time and location of clinical care by consolidating immunization histories submitted by multiple providers, and supporting helping identify vaccinations that are due, or that must be repeated due to age or interval errors. Provider-reported, population-based IIS data are uniquely suited to provide comprehensive assessments of age-related vaccination errors across large populations.

Methods

Data sources

During 2014, IIS Sentinel Sites were located in Michigan, Minnesota, North Dakota, six contiguous Oregon counties, Wisconsin, and New York City, and these geographic areas contain approximately 10% of the US population under 19 years of age.[12] These sites receive competitive cooperative agreement funding through the Centers for Disease Control and Prevention (CDC), and all meet high IIS data quality standards, with at least 85% of persons <19 years of age and at least 85% of provider sites in these jurisdictions participating in their respective IIS. These sites transmit quarterly batches of de-identified IIS records to the CDC to enable public health studies. Data submissions are processed through the “IIS Trends in Immunization Practices System,” a SAS®-based (version 9.3, SAS Institute, Inc., Cary, NC) program which performs data quality processing functions, including removing suspected duplicate records,[13] and conducting data cleaning to remove records with errors in critical date fields or product identifiers.

IIS Sentinel Sites queried their respective IIS during January 2015 and transmitted the de-identified vaccination records to CDC. We analyzed routinely recommended vaccines given to persons age 0 through 17 years during January 1, 2014 through December 31, 2014. We utilized reported “CVX codes” to identify the type of vaccine that was administered. These numerical identifiers are defined by CDC and are used by IIS and other information systems in order to identify vaccines that are indicated for protection against the same disease, and have the same formulation, concentration, and manufacturing process. Vaccines that share these aspects receive the same CVX code, even if trade names or manufacturers differ. CVX codes were grouped according to their indication for total counts of vaccines given for each disease[14], and related CVX codes (e.g., preservative-containing and preservative-free influenza vaccines that are reported as distinct CVX codes) are described as a single product type for instances where age recommendations were identical for the grouped products.

In order to minimize the effects of misreporting, wherein the vaccine type reported differed from the vaccine type that was administered, we restricted the analysis to doses that were

"verified." We verified doses by comparing the reported lot number to reference tables that linked known lot numbers of publically purchased vaccines to corresponding CVX codes; this table contained all lot numbers for vaccines purchased or distributed through CDC's centralized distribution system during July 2013 through December 2014 (personal communication with J Santoli and L Galloway, Nov 17, 2015). For instances where it was necessary to distinguish between products that shared a CVX code, we identified products by examining reported trade name and manufacturer codes.

Analyses

We used SAS® (version 9.3, SAS Institute, Inc., Cary, NC) and Excel® 2010 (Microsoft Corp., Redmond, Washington) to perform all analyses. For each vaccine type within a routinely recommended vaccine type grouping, we quantified doses administered outside the vaccine type's recommended ages, as defined by the "preferable vaccine type begin/end age," identified in Clinical Decision Support for immunizations (CDSi) version 3.1,[15] with the exception of products for which recommendations changed between 2014 and the release of CDSi version 3.1. CDSi resources systematically document ACIP recommendations; where ACIP recommendations were not available, these tables rely on product labeling for determining recommended ages. Counts of doses outside recommended ages were included regardless of dose number or intervals between doses. Narrative description of individual products was limited to vaccines with at least 100 doses administered outside recommended ages; products with fewer errors were included in tables. We were unable to exclude vaccinations deliberately administered off-schedule from dose counts because submitted data did not include information describing patient travel, local outbreaks, or other indications of deliberate off-label administration. Underlying health conditions and other indicators of increased risk were not available for individual vaccination records, which prevented allowances for recommendations specific to these groups. For doses administered from multi-dose vials, we were unable to determine dose volume, and in such instances, dose volumes were assumed to be correct for the patient's age.

Revaccination cost (c) was calculated as $c = n(p + a + w + t)$, where n = the number of verified doses requiring revaccination p = price per dose for vaccines purchased through 2014 CDC vaccine contracts[16], a = administrative cost per vaccination for vaccines administered at a public clinic (set to $8.34 per dose), w = cost for caregiver time (set to $18.48 per hour for two hours of time taken off from work), t = transit cost for commuting to the provider's office (set to $23.84). For instances where multiple formulations or products were grouped, prices were averaged. Costs for vaccine administration, transportation costs, and caregiver time were based on previous reports and adjusted to 2014 dollars using general and medical Consumer Price Indices[17].

Results

Summary of doses analyzed included

Among six IIS Sentinel Sites, 13,701,588 doses were reported as having been administered during 2014 to persons age ≤17 years. The number of doses reported per site ranged from 341,160 in North Dakota to 4,007,973 in New York City. Among all 13,701,588 vaccination

records, 8,106,501 (59.2%) included lot numbers that were appropriate for the reported vaccine type (CVX code), and were therefore deemed “verified” (Table 1); we were unable to verify most doses purchased with private funds because our reference database (containing known lot number–vaccine type pairings) was populated from ordering systems for publically funded vaccines. Within all verified doses, 7,957,387 (98.2%) were reported by the provider organization where the vaccine was administered and 147,247 (1.8%) were reported by another party as a historical record; 1,867 (>0.1%) were missing data in the field used to indicate the reporting entity (data not shown).

Childhood and lifespan vaccines administered after maximum recommended ages

We analyzed childhood and lifespan vaccines to determine how often they were administered after each product’s respective maximum recommended age. We identified 3,394,047 verified doses with a maximum age recommendation. Among these, 9,755 (0.3%) were given after the maximum age. (Table 2). The vaccine most frequently administered after the recommended maximum age was Prevnar-13 (PCV 13) for which 1,717 doses were administered after the day the child turned 4 years of age, accounting for 0.2% of 765,618 verified Prevnar-13 doses in our analysis (Table 2). We identified 1,344 (0.7% of 194,934 doses) pediatric (0.25 mL) doses of Fluzone Quadrivalent administered to persons older than two years of age (the 0.25 mL dosage is recommended for persons age 6–35 months). Unlike other maximum age violations analyzed in this study, this scenario requires revaccination with an age-appropriate product and dose volume; repeating these 1,344 doses with a 0.5 mL dose of Fluzone Quadrivalent would cost $111,964, including direct and indirect costs (Table 2).

Childhood, and lifespan vaccines administered before minimum recommended ages

We identified 6,243,943 verified doses of childhood and lifespan vaccines with minimum age recommendations. Among these, 8,920 (0.1%) were given before the vaccine’s minimum age (Table 3). Collectively, quadrivalent injectable influenza vaccines were the vaccine type that was most frequently administered before the minimum recommended age. This group includes Flulaval Quadrivalent, Fluzone Quadrivalent, Fluarix Quadrivalent preservative free, Fluzone Quadrivalent preservative free, and Flulaval Quadrivalent preservative free. Among 526,110 verified doses of quadrivalent injectable influenza vaccines, 3,835 (0.7%) 0.5 mL doses were administered before the recommended minimum age of 3 years (Table 3; doses from multi-dose vials were excluded from this error count to avoid counting 0.25 mL doses of products that can be appropriately administered at ages 6 months–35 months). Although these 0.5 mL/dose product are not recommended at ages 6 months through 35 months, inadvertent administration within this age group does not necessitate revaccination. We identified 127 doses of injectable quadrivalent influenza vaccines administered prior to age 6 months (with a four day grace period), an age group for which no influenza vaccines are recommended, which requires revaccination. Among minimum age violations that required revaccination, the most costly were Havrix and Vaqta (HepA, Pediatric/adolescent), for which 428 doses (0.1% of 832,386 doses) were administered before age 12 months; the estimated cost to repeat these doses is $39,447. Within the six IIS Sentinel Sites, we estimated the total revaccination cost of the childhood and lifespan vaccines that were administered before recommended ages to be $142,917.

Among DTaP-containing vaccines, DTaP-IPV (Kinrix) was the most frequently administered too early. Among 208,218 DTaP-IPV (Kinrix) verified doses, 2,509 (1.2%) were administered before the minimum recommended age of 4 years. The minimum recommended age for all other DTaP-containing vaccines is six weeks, and for each of these products, <0.1% of these doses were administered before six weeks of age (Table 3).

Adolescent vaccines administered before minimum recommended ages

Among 1,285,222 verified doses of vaccines indicated for adolescents, 622 (<0.1%) were given before their respective minimum recommended age. Adacel and Boostrix (Tdap) were most frequently administered before its recommended minimum age; 391 verified doses (0.1% of 281,224) were administered before age 7 years. Among adolescent vaccines requiring revaccination, the most costly were 170 doses of Gardasil (HPV4) (<0.1% of 637,615 doses) administered before age 9 years. Revaccination of these 170 doses would cost $31,741.

Adult vaccines administered to persons age ≤17 years

We identified 35,352 instances of adult vaccines administered to persons age ≤17 years. However, we were unable to verify these doses since the lot number database we used for verification was populated from a system used to order federally purchased childhood vaccines. The most frequent adult vaccines administered to persons ≤17 years were the adult Hepatitis A vaccines Havrix and Vaqta, (1.0 mL) (18,232 doses administered to persons age 17 years or younger) and the adult Hepatitis B vaccines Recombivax adult and Engerix-B (11,754 doses administered to persons age 17 years or younger) (data not shown).

Variation between sites

The frequency of vaccination outside recommended minimum or maximum ages was largely consistent between sites. For each vaccination scenario examined, the frequencies generally differed by no more than three percentage points when comparing each of the six Sentinel Sites (excluding instances with fewer than 10 reported doses). The two exceptions to this were Afluria – preservative free, and Fluarix, which had more variable rates of administration before their recommended minimum ages. The largest inter-site difference was observed Fluarix; in one site 594 (20%) of 2,977 verified Fluarix doses were administered prior to age three years, compared with the five other sites, where frequency of Fluarix administration before age 3 years ranged from 1% to 6% (data not shown).

Discussion

This study provides a comprehensive analysis of administration of vaccines to children and adolescents at incorrect ages within the six IIS Sentinel Sites. Minimum age recommendations are established for most vaccines, and maximum age recommendations exist for some. Among vaccines with a maximum age recommendation, fewer than one in three hundred doses were administered after the recommended age, and overall, administration prior to recommended minimum ages was even more rare. However, several individual vaccines had much more frequent instances of early administration, and given the large numbers of doses administered, even a small percentage of errors can result in a

substantial number of clinical occurrences. The highest rate of minimum age errors was observed among Hiberix, with 68.6% of verified doses given before age 12 months. Other vaccines indicated for protection against *H. influenzae* type b can be administered as young as six weeks, potentially contributing to confusion among products. On January 14, 2016, Hiberix was approved by the US Food and Drug Administration for all three doses of the primary infant vaccination series, however, Hiberix was only approved and recommended for the booster dose of this series during the time period considered within this study.[18] Other vaccines commonly administered before minimum recommended ages included quadrivalent inactivated influenza vaccines recommended for persons age 3 years or older, and some of these instances might be attributable to confusion with similar influenza vaccines, which were recommended for persons as young as 6 months.

The vaccines most frequently administered outside recommended ages were within vaccine type groupings that contain multiple products with varying age recommendations. The seasonal influenza vaccine schedule exemplifies this complexity, with an array of 20 products categorized into 12 product types (12 CVX codes) with eight distinct minimum recommended ages (some of which depend on the dose volume administered), and five varying maximum age recommendations. Notable among these were 1,344 verified doses of the 0.25 mL prefilled syringe formulation of quadrivalent inactivated influenza vaccine (Fluzone) that were administered after vaccine's recommended age range of 6 through 35 months. We were unable to differentiate between the pediatric (0.25 mL) and full (0.5 mL) volumes for doses administered from multi-dose vials because data describing dose volume were not available, potentially leading to an underestimate of some minimum age violations. Additionally, it is possible that some reported doses might include instances where two 0.25 mL doses of Fluzone Quadrivalent were given during a single clinical encounter to a person requiring a 0.5 mL dose, although this practice would be off-label.[5] In such circumstances, the algorithms used in our study would have identified the second 0.25 mL dose as a duplicate entry, and would have removed it from the dataset, thereby reducing the impact of this possible scenario.

This report identified approximately $291,000 in direct and indirect revaccination costs that would have been incurred if each error was rectified within the six IIS Sentinel Sites during 2014, which likely represents a small percentage of all costs borne to administer the doses examined. Nationally, the annual expense would likely be over ten-fold higher given that 10% of the US population resides within the Sentinel Site jurisdiction, and our study was limited to vaccine lots that were purchased through federal contracts. Actual costs could be lower because revaccination can occur when patients present for other clinical services. However, our endpoints and revaccination costs focused on the absolute minimum and maximum ages for each vaccine, and other factors can result in a dose being invalidated and requiring revaccination, including intervals between doses and age requirements specified for particular dose numbers within a series. The complexity of the age and interval recommendations among primary and catch-up series presents substantial potential for dose invalidation that is not included in our analysis. During 2000 and 2002, it was estimated that 10–21% of children age 19–35 months of age in the United States received unnecessary vaccinations subsequent to completion of a vaccine series.[19, 20] One study of childhood records surveyed in 2000 estimated that the national cost to repeat a single vaccination for

all children 19–35 months of age with an invalid dose would range from $10M to $18M.[8] We did not calculate how often revaccination occurred in instances where it was recommended, but such an analysis would be insightful. Integration of clinical decision support for immunizations into immunization information systems and electronic medical record systems offers a means of preventing, detecting, and correcting vaccination errors, and improved interoperability between these systems directly improves these clinical practices.[21]

The six Sentinel Sites which contributed data for these analyses can be considered to be a convenience sample containing 10% of the US population age birth through 17 years. Although these data were not adjusted to be representative of the entire US population, the examined vaccination rates were largely consistent between sites, suggesting that the observations were likely typical. Furthermore, our focus on doses that were verified based on the reported lot number effectively focused the analysis on publically-purchased doses. Frequency of vaccination outside recommended ages was generally higher when non-verified doses were included, but it is unclear whether this difference is attributed to misreporting, or different vaccination practices among public and private vaccine providers.

The Institute of Medicine presented a comprehensive approach to reducing medication errors, with systems-oriented strategies to reduce errors, including designing vaccine names, labels, and packaging to enhance clarity in clinical environments, ensuring availability of pharmaceutical decision support, making relevant information available at the point of care, and reducing reliance on memory.[22] High-functioning immunization information systems support good vaccination practices, and bi-directional information exchange with medical record systems has been shown to increase administration of age-appropriate vaccinations and decrease overimmunization.[21, 23] Although familiarity with ACIP recommendations should continue to be encouraged, reduction of errors will require assistance from clinical tools, particularly during atypical vaccination scenarios, and system-wide redundancies to review the appropriateness of vaccines prior to administration. Clinical decision support and vaccine forecasting functions are designed to ensure correct application of these recommendations at the point of clinical care. Prevention of the errors identified in this study would require identification of specific products (e.g., through scanned barcodes, inventory lot numbers, manual selection, etc), and flagging products that are inappropriate for a given patient. High-functioning immunization information systems are capable of preventing some vaccination errors through forecasting correct vaccines, and by flagging invalid vaccinations that require revaccination, which reduces both extra-immunization and under-immunization.[20, 21, 23] This analysis utilized data from IIS Sentinel Sites that possess advanced functionality, and error rates might be higher in other sites where this functionality is less available to providers at the point of clinical care. Among the scenarios examined, we found a very small number of vaccination schedule errors, despite the complexity of the childhood vaccination schedule and sporadic error reports submitted to other passive reporting systems. Maximizing the completeness of IIS data and development of clinical decision support functionality are critical components to supporting providers to optimize the quality of their vaccination services, thereby maximizing vaccination rates among their patients, and minimizing the burden of vaccine-preventable diseases.

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List of abbreviations:

IIS	Immunization information system
ACIP	Advisory Committee on Immunization Practices
CDSi	Clinical Decision Support for immunizations

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Table 1.

Routinely Recommended Vaccines Administered to Persons Age 0–17 Years, by Vaccine Group — 2014; Six IIS Sentinel Sites[1].

Vaccine Group	Doses Reported n	Doses Verified n (%)
Seasonal influenza vaccines	2,922,149	1,452,768 (49.7%)
Hepatitis-containing vaccines[2]	2,525,401	1,713,772 (67.9%)
Diphtheria, tetanus and pertussis-containing vaccines[3]	2,323,887	1,637,278 (70.5%)
Poliovirus-containing vaccines	1,651,143	1,119,655 (67.8%)
Pneumococcal vaccines[4]	1,470,124	767,327 (52.2%)
Haemophilus influenzae type b-containing vaccines	1,390,199	862,483 (62.0%)
Human papillomavirus vaccines	907,063	640,507 (70.6%)
Varicella vaccines[5]	874,913	482,291 (55.1%)
Rotavirus vaccines	873,068	528,481 (60.5%)
Mumps, measles, and rubella-containing vaccines[6]	828,753	536,821 (64.8%)
Meningococcal-containing vaccines	584,059	356,479 (61.0%)
Herpes zoster (shingles) vaccine[7]	124	14 (11.3%)
Total doses administered[7]	13,701,588	8,106,501 (59.2%)

[1] Michigan, Minnesota, North Dakota, six contiguous Oregon counties, Wisconsin, and New York City.

[2] Includes hepatitis A vaccine, hepatitis B vaccine, and combination vaccines containing one or both of these components.

[3] Includes all vaccines indicated for protection against one or more of the following diseases: diphtheria, tetanus, or pertussis.

[4] Includes pneumococcal conjugate vaccines (7-valent and 13-valent), and 23-valent pneumococcal polysaccharide vaccine.

[5] Includes varicella vaccine; mumps, measles, rubella, and varicella combination vaccine; and herpes zoster vaccine.

[6] Includes mumps, measles, and rubella vaccine, and other vaccines containing one or more of these components.

[7] Combination vaccines and herpes zoster vaccine count toward more than one vaccine group, thus the total dose count is less than the sum of the individual counts shown here.

Table 2.

Childhood vaccines administered after recommended maximum ages — 2014; Six IIS Sentinel Sites[1].

Vaccine type (trade name)	Recommended maximum age[2]	Verified doses administered at age 0–17 years[3] n	Verified doses administered after recommended maximum age n (%)	Re-vaccination cost for verified doses ($)[4]
DT - Pediatric	6 years	294	21 (7.1)	N/A
DTaP (Infanrix and Tripedia)	6 years	196,547	963 (0.5)	N/A
DTaP, 5 pertussis antigens (Daptacel)	6 years	116,637	507 (0.4)	N/A
DTaP-HepB-IPV (Pediarix)	6 years	478,930	422 (0.1)	N/A
DTaP-IPV/Hib (Pentacel)	4 years	333,641	354 (0.1)	N/A
DTaP-IPV (Kinrix)	6 years	208,218	1,122 (0.5)	N/A
Hib-HepB (Comvax)	5 years[5]	1,490	10 (0.7)	N/A
MMRV (Proquad)	12 years	156,615	1,374 (0.9)	N/A
PCV 13 (Prevnar-13)	4 years	765,618	1,717 (0.2)	N/A
PRP-OMP (PedVaxHib)	4 years	300,975	245 (0.1)	N/A
PRP-T (Acthib and Hiberix)	4 years	226,379	279 (0.1)	N/A
Rotavirus, monovalent (Rotarix)	8 months[5]	42,424	76 (0.2)	N/A
Rotavirus, pentavalent (RotaTeq)	8 months[6]	371,345	1,321 (0.4)	N/A
Influenza, injectable, quadrivalent, preservative free, peds (Fluzone Quadrivalent, 0.25 mL dose)	2 years[7]	194,934	1,344 (0.7)	111,964
Total		3,394,047	9,755 (0.3)	111,964

[1] Michigan, Minnesota, North Dakota, six contiguous Oregon counties, Wisconsin, and New York City.

[2] Administration of listed vaccines after the recommended maximum age does not require revaccination, with the exception of the 0.25 mL dose of Fluzone Quadrivalent after age 2 years. Recommended ages were defined by the “preferable vaccine type begin/end age,” identified in Clinical Decision Support for immunizations (CDSi) version 3.1, with the exception of products for which recommendations changed subsequent between 2014 and the release of CDSi version 3.1.

[3] Doses were deemed “verified” if the reported lot number and CVX code were correctly matched, as defined by inventory documents for publically purchased vaccines.

[4] Revaccination cost (c) was calculated as c = n (p + a + w + t) where n = the number of verified doses requiring revaccination, p = price per dose for vaccines purchased through 2014 CDC vaccine contracts, a = administrative cost per vaccination for vaccines administered at a public clinic (set to $8.34 per dose), w = cost for caregiver time (set to $18.48 per hour for two hours of time taken off from work), and t = transit cost for bringing the patient to the provider’s office (set to $23.84). For instances where multiple formulations or products were grouped, prices were averaged.

[5] At the beginning of the study period, Comvax (HepB-Hib) was recommended before age 5 years for Hib and before age 6 years for HepB. This product was discontinued in the US during the study period.

[6] Maximum recommended age for rotavirus vaccination is the day the child turns 8 months old.

[7] Defined as CVX code 161, which corresponds to Fluzone – Quadrivalent in a 0.25 mL prefilled syringe. Administration of this product at age three years or older requires revaccination with an age-appropriate product and dose volume. Price listings for Fluzone – Quadrivalent (0.5 mL) were used for revaccination costs.

Table 3.

Childhood and lifespan vaccines administered before recommended minimum ages — 2014; Six IIS Sentinel Sites[1].

Vaccine type (trade name)	Recommended minimum age[2]	Verified doses administered at age 0–17 years[3] n	Verified doses administered before recommended minimum age n (%)	Re-vaccination cost for Verified doses ($)[4]
DT - Pediatric	6 weeks	294	0 (0.0)	0
DTaP (Infanrix and Tripedia)	6 weeks	196,547	7 (0.0)	570
DTaP, 5 pertussis antigens (Daptacel)	6 weeks	116,637	13 (0.0)	1,054
DTaP-HepB-IPV (Pediarix)	6 weeks[5]	478,930	49 (0.0)	5,857
DTaP-IPV/Hib (Pentacel)	6 weeks	333,641	28 (0.0)	3,307
DTaP-IPV (Kinrix)	4 years[6]	208,218	2,509 (1.2)	N/A
Hep A, ped/adol (Havrix and Vaqta, 0.5 mL)	12 months	832,386	428 (0.1)	39,447
Hib-HepB (Comvax)	6 weeks[5]	1,490	0 (0.0)	0
IPV (Ipol)	6 weeks	114,356	9 (0.0)	703
MMR (M-M-R II)	12 months[7]	380,209	1,250 (0.3)	N/A
MMR (M-M-R II)	6 months[6,7]	380,209	61 (0.0)	5,282
MMRV (Proquad)	12 months	156,615	32 (0.0)	5,403
PCV 13 (Prevnar-13)	6 weeks	765,618	66 (0.0)	11,756
PRP-OMP (PedVaxHib)	6 weeks	300,975	27 (0.0)	2,107
PRP-T (Acthib)	6 weeks	204,933	28 (0.0)	2,101
PRP-T (Hiberix)	12 months[8]	172	118 (68.6)	8,855
Rotavirus, monovalent (Rotarix)	6 weeks	42,424	9 (0.0)	1,448
Rotavirus, pentavalent (RotaTeq)	6 weeks	371,345	55 (0.0)	7,130
Varicella (Varivax)	12 months	325,665	203 (0.1)	29,236
Influenza, injectable (Afluria and Afluria – preservative free)	9 years[6,9]	265	86 (32.5)	N/A
Influenza, injectable (Flulaval)	3 years[6]	1,565	8 (0.5)	N/A
Influenza, injectable, preservative free (Fluarix)	3 years[6]	9,439	709 (7.5)	N/A
Influenza, injectable (Fluvirin and Fluvirin – preservative free)	4 years[6]	3,667	68 (1.9)	N/A
Influenza, injectable (Fluzone and Fluzone – preservative free)	6 months	229,253	109 (0.0)	8,105
Influenza, injectable, quadrivalent, preservative free, peds (Fluzone – Quadrivalent, Peds)	6 months	194,934	127 (0.1)	10,556
Influenza, intradermal, quadrivalent, preservative free (Fluzone - Quad Intradermal)	3 years[6]	0	0 (0.0)	N/A

Vaccine type (trade name)	Recommended minimum age[2]	Verified doses administered at age 0–17 years[3] n	Verified doses administered before recommended minimum age n (%)	Re-vaccination cost for Verified doses ($)[4]
Influenza, injectable, quadrivalent (Flulaval quadrivalent, Fluzone Quadrivalent, Fluarix quadrivalent preservative free, Fluzone Quadrivalent preservative free, and Flulaval Quadrivalent preservative free)	3 years[6]	526,110	3,835[10] (0.7)	N/A
Influenza, live, intranasal (Flumist, Flumist Quadrivalent)	2 years[6]	448,255	336 (0.1)	N/A
Total		6,243,943	8,920 (0.1)	142,917

[1]Michigan, Minnesota, North Dakota, six contiguous Oregon counties, Wisconsin, and New York City.

[2]A four day grace period was applied to recommended minimum ages, and revaccination is required except where otherwise noted. Recommended ages were defined by the "preferable vaccine type begin/end age," identified in Clinical Decision Support for immunizations (CDSi) version 3.1, with the exception of products for which recommendations changed subsequent between 2014 and the release of CDSi version 3.1.

[3]Doses were deemed "verified" if the reported lot number and CVX code were correctly matched, as defined by inventory documents for publically purchased vaccines.

[4]Revaccination cost (c) was calculated as c = n (p + a + w + t) where n = the number of verified doses requiring revaccination, p = price per dose for vaccines purchased through 2014 CDC vaccine contracts, a = administrative cost per vaccination for vaccines administered at a public clinic (set to $8.34 per dose), w = cost for caregiver time (set to $18.48 per hour for two hours of time taken off from work), and t = transit cost for bringing the patient to the provider's office (set to $23.84). For instances where multiple formulations or products were grouped, prices were averaged.

[5]A four day grace period was applied. Administration prior to four days before age six weeks is not considered valid for immunity, with the exception of the Hepatitis B component. Revaccination is required for the other vaccine components.

[6]A four day grace period was not applied to the recommended minimum age. Administration can be valid when administered to younger ages under certain circumstances.

[7]MMR doses are analyzed at two minimum age thresholds: 12 months and 6 months. ACIP recommends that persons age 12 months or older receive two doses of MMR vaccine separated by at least 28 days, and doses administered prior to four days before the child's first birthday should be repeated after the child's first birthday. Additionally, ACIP recommends that infants aged 6 months through 11 months should receive one dose of MMR if they will be traveling internationally, with two additional doses administered after age 12 months. Due to the recommendation for MMR vaccination among traveling infants, some doses given prior to age 12 months should not be counted as errors, and therefore revaccination costs are not included for the "<12 months" age grouping, and these doses are excluded from error count totals.

[8]On January 14, 2016, the minimum recommended age for Hiberix was changed from 12 months to six weeks.

[9]Although the package insert indicates Afluria for persons age ≥ 5 years, ACIP did not recommend usage in persons younger than age nine years during the study period.

[10]Doses administered from multi-dose vials of Fluzone Quadrivalent were excluded from counts of doses incorrectly given to persons age <3 years because 0.25 mL doses of this product are licensed for persons age 6 months through 35 months; administered dose volume was not included in this study, and is assumed to be consistent with product indications.

Table 4.

Adolescent vaccines administered before recommended minimum ages — 2014; Six IIS Sentinel Sites[1].

Vaccine type (trade name)	Recommended minimum age[2]	Verified doses administered at age 0–17 years[3] n	Verified doses administered before recommended minimum age n (%)	Re-vaccination cost for Verified doses ($)[4]
HPV2 (Cervarix)	9 years	2,892	4 (0.1)	678
HPV4 (Gardasil)	9 years	637,615	170 (0.0)	31,741
HPV9 (Gardasil9)	9 years	0	0 (0.0)	0
MenACWY-CRM (Menveo)	< 2 months[5]	52,680	1 (0.0)	148
MenACWY-D (Menactra)	< 9 months	303,784	25 (0.0)	3,695
Td (Decavac and Tenivac; adsorbed and not adsorbed)	7 years[6]	7,027	31 (0.4)	N/A
Tdap (Adacel and Boostrix)	7 years[6]	281,224	391 (0.1)	N/A
Total		1,285,222	622 (0.0)	36,262

[1] Michigan, Minnesota, North Dakota, six contiguous Oregon counties, Wisconsin, and New York City.

[2] A four day grace period was applied to recommended minimum ages, and revaccination is required except where otherwise noted. Recommended ages were defined by the "preferable vaccine type begin/end age," identified in Clinical Decision Support for immunizations (CDSi) version 3.1, with the exception of products for which recommendations changed subsequent between 2014 and the release of CDSi version 3.1.

[3] Doses were deemed "verified" if the reported lot number and CVX code were correctly matched, as defined by inventory documents for publically purchased vaccines.

[4] Revaccination cost (c) was calculated as c = n (p + a + w + t) where n = the number of verified doses requiring revaccination, p = price per dose for vaccines purchased through 2014 CDC vaccine contracts, a = administrative cost per vaccination for vaccines administered at a public clinic (set to $8.34 per dose), w = cost for caregiver time (set to $18.48 per hour for two hours of time taken off from work), and *t* = transit cost for bringing the patient to the provider's office (set to $23.84). For instances where multiple formulations or products were grouped, prices were averaged.

[5] Menveo is routinely recommended for persons age 11 through 15 years, and is thus listed with adolescent vaccines. However, this product is recommended for children age 2 through 23 months at increased risk for meningococcal disease. Data describing which patients were at increased risk was unavailable. Therefore, only doses administered prior to age 2 months were determined to be administered before the minimum recommended age.

[6] A four day grace period was not applied to the recommended minimum age (product can be valid when administered to younger ages under certain circumstances).