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Original article

Meningococcal Vaccination Among Adolescents in the United States: A Tale of Two Age Platforms

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A B S T R A C T

Purpose: Despite recommended routine vaccination with meningococcal conjugate vaccine (MenACWY) at ages 11–12 years with a booster at age 16 years, national estimates indicate MenACWY uptake is lower in older adolescents than younger adolescents. This study aimed to identify factors associated with MenACWY uptake among adolescents.
Methods: Commercial Claims and Encounters (CCAE) and Medicaid *MarketScan* Databases from 2011 to 2016 were retrospectively analyzed (2017) to determine receipt of ≥1 dose of MenACWY during early (10.5 through 13 years) and late (15.5 through 18 years) adolescence. Multivariable logistic regression and nonlinear decomposition analyses were used to identify factors associated with MenACWY vaccination, potential missed opportunities, and differences between age groups.
Results: A larger proportion of younger adolescents than older adolescents received MenACWY: CCAE, 71.7% versus 48.9% ($p < .001$); Medicaid, 59.3% versus 31.8% ($p < .001$), respectively. In multivariable models (CCAE), older adolescents were less likely than younger ones to receive MenACWY (adjusted odds ratios [95% confidence intervals]: .68 [.67, .69]) and more likely to have a potential missed opportunity (1.27 [1.25, 1.28]). Decomposition results showed lower MenACWY uptake in older adolescents is largely attributed to fewer non-MenACWY vaccines received, fewer preventive care visits, and interaction with nonpediatric healthcare providers.
Discussion: Missed opportunities and infrequent preventive care encounters contribute to lack of vaccination in younger and older adolescents. However, the disparity in uptake between the two age groups was largely attributable to differences in healthcare utilization, suggesting a need for

IMPLICATIONS AND CONTRIBUTION

This study underscores the impact of healthcare utilization on MenACWY vaccination. Solidifying a vaccination platform for ages 16–18 years by encouraging annual preventive care visits and campaigns to increase vaccine eligibility assessment among designated healthcare providers and alternative vaccination providers may reduce missed opportunities and benefit all adolescent vaccinations beyond MenACWY.

Conflicts of interest: S.K.K. and E.E. are employees of RTI Health Solutions. L.T. was an employee of RTI Health Solutions at the time of this study and is currently an employee of Aledade, Inc. RTI Health Solutions was contracted and funded by the GSK group of companies to perform the study. D.E.I. and E.P. are employees of Truven Health Analytics, an IBM Watson Health Company, which was subcontracted by RTI Health Solutions to perform analyses for this study. P.N., J.W., and C.H. are employees of the GSK group of companies and hold shares in the GSK group of companies.

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unique strategies to increase uptake among older adolescents, such as solidifying a vaccination platform for ages 16−18 years through encouragement of annual preventive care visits.

Invasive meningococcal disease is a serious, life-threatening disease caused by *Neisseria meningitidis* associated with high morbidity and mortality [1]. In 2017, serogroups C, W, and Y accounted for nearly half of cases in persons aged 11 years and older in the United States (U.S.) [2].

Since 2010, the Advisory Committee on Immunization Practices (ACIP) recommends routine administration of a meningococcal vaccine covering serogroups A, C, W, and Y (MenACWY) for all adolescents aged 11−18 years (a single dose and a booster dose at age 11 or 12 years and 16 years, respectively). If the first dose is administered at age 13−15 years, a booster dose should be provided at age 16−18 years. Unless they become at increased risk, there is no need for a booster dose for adolescents who receive a first dose after their 16th birthday [3].

According to the 2017 National Immunization Survey-Teen (NIS-Teen), 83.6% of adolescents aged 13 years had received at least one dose of MenACWY, whereas only 44.3% of adolescents aged 17 years had received both the primary and booster doses [4]. Differences in adherence to the ACIP recommendations between the two age cohorts may be partly due to different healthcare utilization patterns [5−8]. The American Academy of Pediatrics recommends annual preventive care visits for individuals aged 3−21 years [9]. Within the Childhood and Adolescent Immunization Schedule, a robust vaccination platform aligning multiple routine vaccinations at ages 11−12 years (tetanus-diphtheria-acellular pertussis [Tdap], human papillomavirus, MenACWY primary dose, and influenza) is built around annual preventive care visits for younger adolescents. However, older adolescents have fewer routinely recommended vaccinations (influenza, MenACWY booster dose, meningococcal B [category B recommendation]) spread over a larger age range (12−18 years) [10,11].

Age-based immunization platforms may stimulate vaccination uptake as they institutionalize a distinct vaccination process for patients and providers at a specific healthcare encounter. A vaccination platform at age 11−12 years has been supported by the ACIP, the American Academy of Pediatrics, the American Academy of Family Physicians, and the American Medical Association since 1996 [12] and established an expectation for a healthcare visit that integrates administration of several routine vaccinations and a catch-up assessment with other preventive services provided to adolescents. In 2003, the National Vaccine Advisory Committee published standards for healthcare providers to effectively deliver pediatric immunizations [13], which likely propelled implementation of the younger adolescent platform into practice. However, with the absence of a well-established vaccination platform for older adolescents, lower MenACWY uptake in this population may be due in part to a lack of compliance with recommended annual preventive care encounters and missed opportunities for vaccination [6,14]. Generalizable contemporary assessments comparing healthcare resource utilization between older and younger adolescents within the context of MenACWY vaccination are largely lacking. Further exploration of similarities and differences in healthcare utilization factors associated with vaccination in these two age groups may inform interventions to increase immunization rates.

Using data from a large U.S. database of administrative healthcare claims from commercially insured and Medicaid-enrolled adolescents, we aimed to quantify differences in MenACWY uptake among younger adolescents (aged 10.5 through 13 years) and older adolescents (aged 15.5 through 18 years) within the context of their specific healthcare utilization patterns during the age ranges in which routine MenACWY vaccination (primary and booster, respectively) is anticipated. Examining healthcare resource utilization during these same age ranges allows us to not only understand how opportunities for vaccine uptake may differ between younger and older adolescents but also to examine how differences in the patterns of healthcare utilization (e.g., type of providers, type of visits) between younger and older adolescents contribute to the disparity in MenACWY uptake between these two age groups.

This study is complementary to the published NIS-Teen data. Besides using a different large sample data source, the following aspects are worth noting: the published NIS-Teen only report estimated coverage among adolescents aged 13−17 years by age at interview; there is no subsequent analysis of factors associated with differences in uptake by age at vaccination and no analysis of potential missed opportunities. The present work addresses these additional aspects, which were not previously published elsewhere to the best of our knowledge.

Methods

A retrospective analysis (GSK study identifier: HO-16-17936) of a large set of de-identified patient-level healthcare claims was conducted using the Commercial Claims and Encounters (CCAE) and Multi-State Medicaid (Medicaid) *MarketScan* Research Databases, maintained by Truven Health Analytics, LLC, an IBM Company (Truven Health). These databases contain demographic characteristics, health plan information, healthcare experiences through procedure codes and prescription drug claims data provided by a sample of large employers, providers/healthcare facilities, and insurance plans. The CCAE database includes patients from all U.S. census regions (nearly 30 million children as of 2015) and includes an indicator of residence, whereas the Medicaid database includes data from a select number of geographically dispersed states (comprising approximately 13 million children as of 2015). The CCAE population consists of individuals covered by employer-sponsored private health insurance, whereas the Medicaid sample includes low-income families and other groups eligible for the joint public federal and state insurance [15].

The RTI Institutional Review Board determined this study did not constitute research with human subjects as defined by the U.S. Code of Federal Regulations (45 CFR 46.102) and thus did not require institutional review board approval or informed consent.

Study population

Adolescents continuously enrolled in medical and pharmacy plans from ages 10.5 through 13 years during the study period constituted the population of younger adolescents, whereas the older adolescents group consisted of adolescents continuously enrolled from ages 15.5 through 18 years between April 1, 2011, and September 30, 2016 (CCAE cohort) or January 1, 2011, and December 31, 2016 (Medicaid cohort). The variation in end dates between the two cohorts reflects differences in data lag of fully adjudicated claims and refresh dates of the datasets at the time of the analysis. The specific age ranges were positioned to capture vaccine administration around the preferred ages recommended by ACIP for routine immunization: 11–12 and 16 years, respectively. As a provider may vaccinate an individual attending a well-child visit slightly before their 11th or 16th birthday in practice, the age range of interest began 6 months before the respective birthday to capture any adequately early vaccinations. The observation period for older adolescents extended through 18 years to capture doses received before graduating from high school or starting college. The younger adolescent observation period extended through 13 years to match the 3.5-year observation duration of older adolescents.

Measures

The main outcomes were receipt of at least one dose of MenACWY and presence of missed opportunities and missed preventive care encounters among younger and older adolescents.

MenACWY vaccination was identified by inpatient or outpatient medical claims with a Current Procedural Terminology (CPT) code indicating MenACWY vaccination or a pharmacy claim with National Drug Code consistent with MenACWY during the observation period (Table S1).

A potential missed opportunity was defined as a preventive care, well-child, or vaccine-only visit occurring in the outpatient office setting (identified using relevant International Classification of Diseases, Ninth Revision [ICD-9], International Statistical Classification of Diseases and Related Health Problems, 10th Revision [ICD-10], and CPT codes; Tables S2 and S3) during which the individual was age eligible for MenACWY vaccination but did not receive it. This operational definition of missed opportunities is readily actionable in practice and has been used to describe utilization in other studies [16].

Missed preventive care encounters were defined as having no preventive care, well-child, or vaccine-only visits during the respective age range. Missed preventive care encounters represent a measure of preventive healthcare underutilization, which may be addressed through public health interventions aiming at educating populations with no preventive care or healthcare access.

Statistical analysis

For descriptive analyses, categorical variables were summarized by number and percentage of individuals in each category, whereas continuous variables were summarized by the mean, standard deviation, median, and interquartile ranges. Comparisons for continuous variables were assessed with *t*-tests and comparisons of categorical variables with chi-square tests, using an α of .05 to determine statistical significance. All outcomes are presented separately for younger and older adolescents and by payer type (i.e., CCAE and Medicaid).

Multivariable logistic regression was used to identify factors associated with MenACWY vaccination and potential missed opportunities and to adjust comparisons of primary endpoints between younger and older adolescents for demographic and baseline characteristics. All models included a fixed base set of independent variables to which additional variables were added by forward selection to optimize the Akaike information criterion, following an information-theoretic approach to model selection [17,18]. Base variables included sex, age category, study entry year, health plan type, region (for CCAE only) and race (for Medicaid only). Additional independent variables with low intervariable correlation were selected including total number of outpatient office visits, number of preventive care/well-child visits, attributed provider type (i.e., type of provider associated with >50% of outpatient encounters; if no provider type was associated with >50% of outpatient encounters, the patient was assigned "no attributed provider"), total number of non-MenACWY vaccines, and healthcare costs during the observation period. For the final models, adjusted odds ratios along with 95% confidence intervals (95% CIs) and *p* values are presented for each included variable.

A modified Oaxaca-Blinder decomposition method for nonlinear models with binary outcomes [19] was used to evaluate contribution of different characteristics to the gap in the outcomes between younger and older adolescents. The decomposition method allows for estimating the individual influence of each covariate to the observed intergroup difference for outcomes of interest [20,21].

All analyses were conducted in *SAS* version 9.4 (SAS Institute, Cary, NC). The nonlinear decomposition analysis used a publicly available *SAS* macro [19]. The pooled sample was used to produce the nonlinear decomposition estimates, drawing 1,000 random subsamples to ensure a 1:1 match in sample size for the two age groups and randomizing the order of variables included in the model in each simulation; standard errors were approximated using the delta method [19].

Results

A total of 376,825 younger adolescents and 419,814 older adolescents met the inclusion criteria in the CCAE study population (Medicaid: 310,383 and 206,301 younger and older adolescents, respectively). Results from the CCAE population are presented in the main text and supplemented with findings from the Medicaid population where differences were observed. The *MarketScan* Medicaid sample comprised data from a limited number of states; thus, generalizability to the entire U.S. Medicaid population may be limited. Therefore, the full results from the Medicaid analysis are reported in the Supplemental Materials.

Among commercially insured patients, MenACWY uptake was greater in younger adolescents than older adolescents (71.7% vs. 48.9%; $p < .001$; Table 1). Within each age group, MenACWY uptake was similar in females and males but higher in the urban setting compared with the rural setting and increased over time as individuals entering the observation period in 2013 had a higher uptake than those entering in 2011 (Table 1). Across all individual characteristics, uptake was consistently lower in older adolescents than younger adolescents (Table 1; all comparisons $p < .001$). In the Medicaid population, uptake was also higher in younger adolescents compared with older adolescents (59.3% vs. 31.8%; $p < .001$)

Table 1
Baseline characteristics by age group (CCAE)

a) Differences in vaccination uptake by age group and baseline characteristics

Characteristics	Age group: Younger adolescents 10.5 through 13 y[a] Total, N	Younger adolescents: Received ≥1 MenACWY vaccine, n (%)	Older adolescents 15.5 through 18 y[a] Total, N	Older adolescents: Received ≥1 MenACWY vaccine, n (%)	Intergroup difference, %
Overall	376,825	270,186 (71.70)	419,814	205,131 (48.86)	**22.84**
Sex					
Female	184,990	132,626 (71.69)	205,834	104,598 (50.82)	**20.87**
Male	191,835	137,560 (71.71)	213,980	100,533 (46.98)	**24.73**
Year of entry into sample					
2011	174,862	120,866 (69.12)	192,754	88,320 (45.82)	**23.30**
2012	157,277	115,639 (75.53)	177,419	90,244 (50.86)	**22.67**
2013	44,686	33,681 (75.37)	49,641	26,567 (53.52)	**21.85**
Geographic region					
Northeast	72,940	52,488 (71.96)	82,794	49,159 (59.38)	**12.58**
North Central	86,380	63,691 (73.73)	97,403	48,698 (50.00)	**23.73**
South	150,403	108,852 (72.37)	165,768	77,959 (47.03)	**25.34**
West	66,053	44,471 (67.33)	72,520	28,688 (39.56)	**27.77**
Missing/unknown	1,049	684 (65.20)	1,329	627 (47.18)	**18.02**
Health plan type					
Comprehensive	4,806	3,058 (63.63)	7,411	2,855 (38.52)	**25.11**
Exclusive provider organization	5,832	4,354 (74.66)	6,040	3,139 (51.97)	**22.69**
Health maintenance organization	52,882	39,330 (74.37)	60,295	31,486 (52.22)	**22.15**
Point of service	35,737	24,271 (67.92)	37,230	17,853 (47.95)	**19.97**
Preferred provider organization	228,928	162,474 (70.97)	258,261	122,982 (47.62)	**23.35**
Point of service with capitation	984	723 (73.48)	981	533 (54.33)	**19.15**
Consumer-directed health plan	28,041	21,482 (76.61)	29,227	15,686 (53.67)	**22.94**
High deductible health plan	13,855	10,202 (73.63)	12,616	6,692 (53.04)	**20.59**
Missing	5,760	4,292 (74.51)	7,753	3,905 (50.37)	**24.14**
Urban/rural residence					
Urban	327,869	241,603 (73.69)	363,087	185,546 (51.10)	**22.59**
Rural	48,237	28,078 (58.21)	55,820	19,111 (34.24)	**23.97**
Unknown	719	505 (70.24)	907	474 (52.26)	**17.98**
Attributed provider type[b]					
Family medicine provider	47,164	25,073 (53.16%)	72,535	25,475 (35.12%)	**18.04**
Pediatrician	180,095	148,099 (82.23%)	96,475	67,098 (69.55%)	**12.68**
Internal medicine provider	4,528	2,818 (62.23%)	8,264	2,633 (31.86%)	**30.37**
Obstetrician/gynecologist	130	64 (49.23%)	3,627	899 (24.79%)	**24.44**
Other provider type	52,908	35,518 (67.13%)	89,038	42,187 (47.38%)	**19.75**
No consistent provider	92,000	58,614 (63.71%)	149,875	66,839 (44.60%)	**19.11**

b) Healthcare utilization by age group and vaccination status

Characteristics	Younger adolescents 10.5 through 13 y[a]: Total	Younger: Received ≥1 MenACWY vaccine	Younger: Did not receive MenACWY	Older adolescents 15.5 through 18 y[a]: Total	Older: Received ≥1 MenACWY vaccine	Older: Did not receive MenACWY
Number of individuals	376,825	270,186	106,639	419,814	205,131	214,683
Number of preventive care/well-child visits (per individual)						
Mean (SD)	2.16 (1.57)	2.44 (1.27)	1.43 (1.98)	1.74 (1.56)	2.40 (1.48)	1.12 (1.37)
Median	2	3	1	2	2	1
Q1, Q3	1, 3	2, 3	0, 2	0, 3	1, 3	0, 2
Number of outpatient office visits (per individual)						
Mean (SD)	10.32 (9.15)	11.07 (9.03)	8.42 (9.19)	11.26 (10.27)	12.92 (10.41)	9.67 (9.88)
Median	8	9	6	9	10	7
Q1, Q3	4, 14	5, 14	3, 11	4, 15	6, 17	3,13
Total number of non-MenACWY vaccines received (per individual)						
Mean (SD)	4.02 (2.70)	4.84 (2.42)	1.93 (2.21)	2.20 (2.31)	3.54 (2.22)	.91 (1.54)
Median	4	5	1	2	3	0
Q1, Q3	2, 6	3, 6	0, 3	0, 4	2, 5	0, 1
Healthcare costs ($, per individual)						
Mean (SD)	8,089.08 (40,303.42)	8,342.24 (38,976.50)	7447.64 (43,478.10)	11,510.78 (46,234.39)	12,207.48 (41,837.24)	10,845.07 (50,067.51)
Median	2,900	3,215	2,066	4,287	5,166	3,415
Q1, Q3	1,401.74, 6,636.90	1,647.74, 7,080.14	768.19, 5,374.65	1,633.97, 10,693.29	2,277.74, 11,780.21	1,070.59, 9,491.73

Boldface indicates statistical significance ($p < .001$).
CCAE = Commercial Claims and Encounters; MenACWY = quadrivalent meningococcal conjugate vaccine against meningococcal disease due to serogroups A, C, W, and Y; SD = standard deviation; Q1 = quartile 1; Q3 = quartile 3; y = years.
[a] All outcomes for both the younger adolescents and older adolescents were measured during an observation period of 3.5 y with continuous enrollment.
[b] Attributed provider was defined by the type of provider associated with >50% of encounters. If there were two providers each with 50%, the individual was assigned "no consistent provider."

and uptake distributions by individual characteristics were similar to the commercially insured population (Table S4).

In the CCAE sample, 91.9% of the younger vaccinated adolescents received MenACWY at ages 11–12 years. Among the older vaccinated adolescents, the majority (64.2%) received it at ages 17–18 years, after the recommended age of 16 years (Figure 1A). Pediatricians administered most vaccinations in both younger and older adolescents, although the proportion of older adolescents receiving vaccination through a pediatrician was lower than in the younger age group (61.8% vs. 73.7%; $p < .001$) (Figure 1B). In both age groups, MenACWY vaccination occurred most often in conjunction with other vaccination during preventive care or well-child visits although the proportion was significantly lower for older than for younger adolescents (39.4% vs. 74.6%; $p < .001$). Nearly one-third of older adolescents received MenACWY vaccination during a preventive care or well-child visit where no other vaccines were received (Figure 1C). These findings were consistent in the Medicaid sample, except "other physician" was the most frequent vaccination provider, followed by pediatrician, and there was no notable difference in the proportion of younger and older adolescents vaccinated by these provider types (Figure S1).

In the multivariable logistic regression model (CCAE cohort), older adolescents, attributed provider types other than pediatrician, and rural versus urban setting were associated with a decreased likelihood of receiving MenACWY (each $p < .001$, Figure 2A). Factors associated with an increased likelihood for receiving MenACWY included the number of preventive care/well-child visits, total number of non-MenACWY vaccines received, and regions other than Northeast (each $p < .001$). Multivariable analysis of the Medicaid data yielded largely similar findings. However, "other physician" was associated with a slightly higher likelihood of vaccination compared with pediatricians. Additionally, all "non-white" race categories (not available in the CCAE data) were associated with an increased likelihood of vaccination compared with whites (Figure S2).

Nonlinear decomposition results indicated that 68.3% of the observed gap in vaccination uptake between younger and older adolescents may be attributed to variables included in the model, whereas the reminder of the intergroup difference was unexplained. Variables that contributed substantially to the intergroup difference in vaccination receipt were number of non-MenACWY vaccines received, number of preventive care/well-child visits, and attributed provider type (Figure 2B). Similar results were obtained for the Medicaid sample (Figure S2).

Descriptive analysis (CCAE cohort) showed that a larger proportion of older adolescents had at least one potential missed opportunity (31.9%) compared with younger adolescents (21.6%). The proportion of older adolescents with a missed preventive care encounter was nearly three times the proportion observed in younger adolescents (17.9% and 6.2%, respectively; Figure 3). A similar trend was observed in the Medicaid cohort (Figure S3). In the multivariable logistic regression model for the commercially insured cohort, older adolescents, attributed provider types other than pediatrician, and living in a rural setting were independently associated with an increased likelihood of having at least one potential missed opportunity (each $p < .001$, Figure 2C). In addition, the Northeast region was associated with a lower probability of having at least one potential missed opportunity. The most important variables contributing to the gap in potential missed opportunities between the two age groups based on nonlinear decomposition analysis were total number of non-MenACWY vaccines received and attributed provider type (Figure 2D). In the Medicaid sample, total number of non-MenACWY vaccines received was the most important explanative factor to the observed intergroup difference (Figure S2).

Discussion

Our study is complementary to the NIS-Teen survey data and findings. Our analysis is based on large nationwide samples of documented vaccination claims across different payers, with focus on investigating impact of healthcare resource utilization

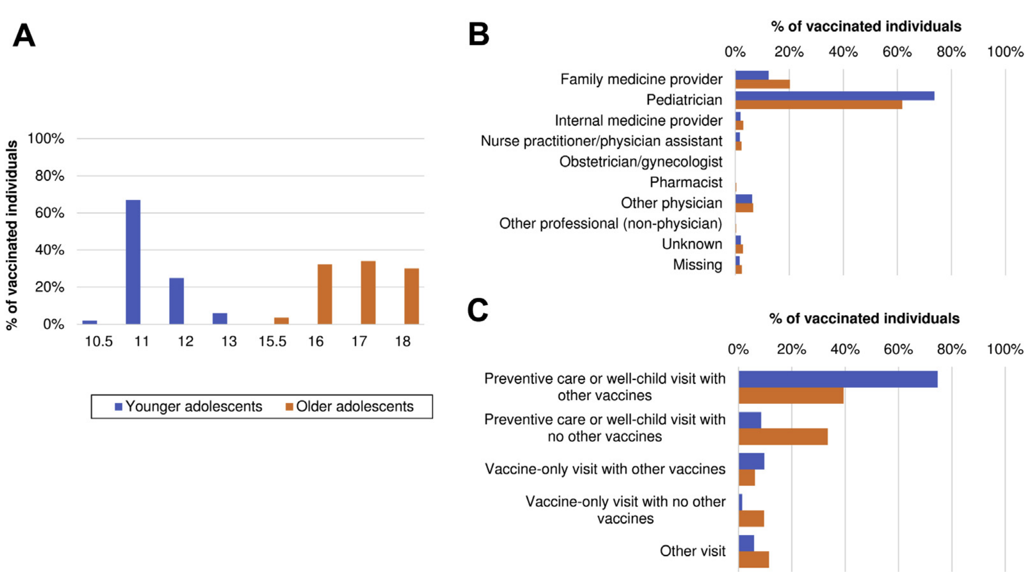

Figure 1. MenACWY vaccination event characteristics in CCAE sample: age at vaccination (A), vaccination provider (B), and visit type (C) among younger versus older adolescents. CCAE = Commercial Claims and Encounters; MenACWY = quadrivalent meningococcal conjugate vaccine against meningococcal disease due to serogroups A, C, W, and Y.

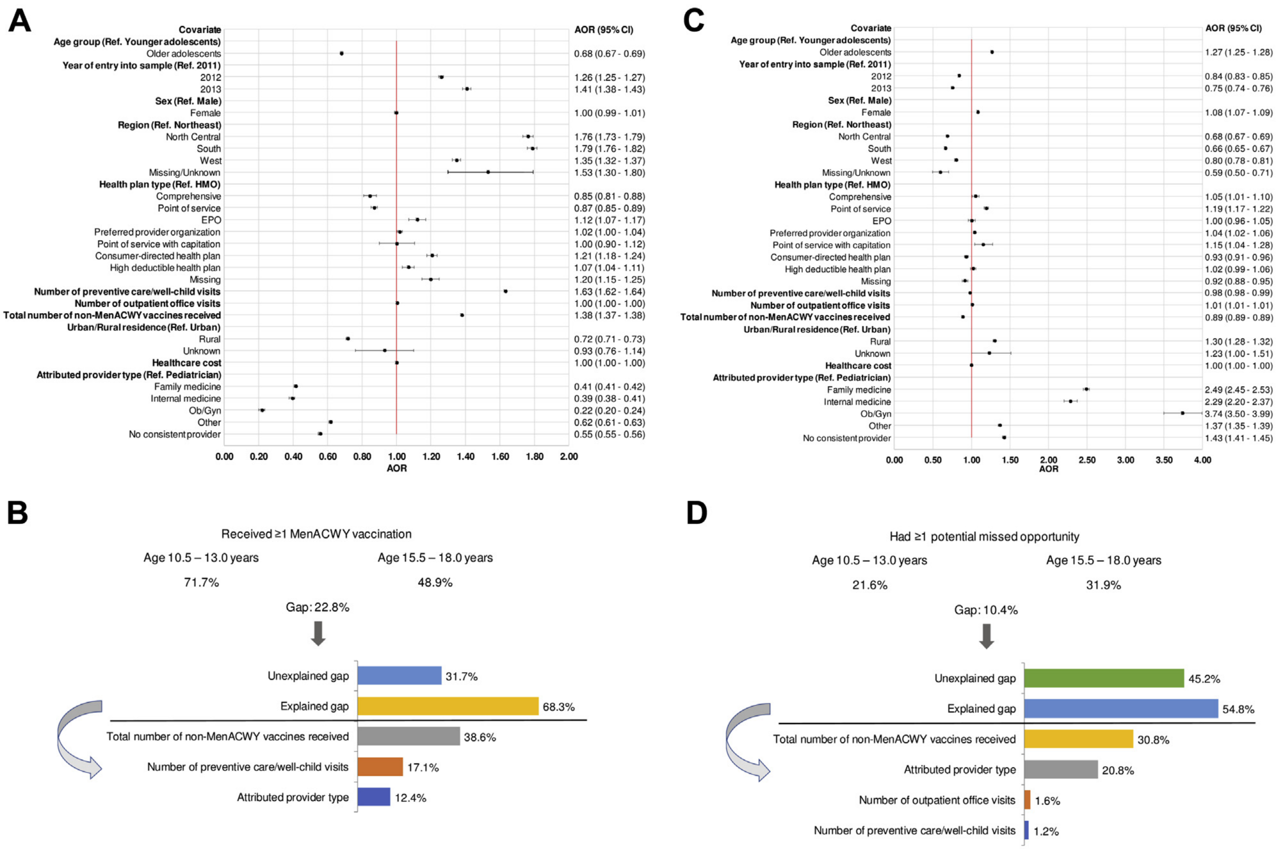

Figure 2. Variables associated with vaccination uptake, potential missed opportunities, and differences observed between age-groups (CCAE): variables associated with receipt of ≥1 MenACWY vaccination (multivariable regression model) (A), variables contributing to differences in MenACWY receipt between younger and older adolescents (nonlinear decomposition analysis) (B), variables associated with potential missed opportunities (multivariable regression model) (C), and variables contributing to differences in potential missed opportunities between younger and older adolescents (nonlinear decomposition analysis) (D). Independent variables included in the model were age group, year of entry into the sample, sex, region, health plan type, number of preventive care/well-child visits, number of outpatient office visits, total number of non-MenACWY vaccines received, urban/rural residence, healthcare costs, and attributed provider type. Panel (A) After adjusting for all selected variables in the multivariable model, the individual likelihood of receiving MenACWY was lower in the Northeast compared with other regions (adjusted odds ratio >1). In univariate analyses, vaccination uptake was among the highest in the Northeastern region, as adolescents in this region also had more preventive care and/or well-child visits and more non-MenACWY vaccines received overall. Panels (B) and (D) Explained gap corresponds to observed differences between age groups that could be explained by the independent variables included in the model, whereas the unexplained gap refers to observed differences between age groups that are attributed to variations in effects of unmeasurable or unobserved characteristics across age groups. AOR = adjusted odds ratio; CCAE = Commercial Claims and Encounters; EPO = exclusive provider organization; HMO = health maintenance organization; MenACWY = quadrivalent meningococcal conjugate vaccine against meningococcal disease due to serogroups A, C, W, and Y; Ob/Gyn = obstetrician/gynecologist.

on MenACWY vaccine uptake. This allowed us to understand how opportunities for vaccine uptake may differ between younger and older adolescents and examine how differences in the patterns of healthcare utilization (e.g., type of providers, type of visits) contribute to the disparity in MenACWY uptake between these two age groups, recognizing the need to improve immunization rates particularly in older adolescents. We performed complex multivariable analyses with a modified Oaxaca-Blinder decomposition method for nonlinear models and identified healthcare utilization factors associated with receipt of MenACWY vaccination during the two age ranges and estimated the individual contribution of these factors to the observed differences in MenACWY uptake and missed opportunities for vaccination between younger and older adolescents. Results from this study provide large-scale contemporary evidence on the role of healthcare utilization in MenACWY vaccination among adolescents, which may further support development of targeted interventions that leverage current preventive healthcare recommendations and inform new policies and strategies toward improving vaccination in harder to reach adolescent populations.

This analysis based on large healthcare claims data showed that uptake of MenACWY vaccine was significantly and consistently lower in older adolescents aged 15.5 through 18 years compared with younger adolescents aged 10.5 through 13 years. Even after adjusting for individual demographic and healthcare resource utilization characteristics, older adolescents had a significantly lower likelihood of receiving a MenACWY vaccine compared with younger adolescents, despite routine ACIP recommendations.

Individuals seeking care mainly from nonpediatric providers were less likely to be vaccinated. This finding is in agreement with a study of adolescent healthcare utilization that reported most adolescents received vaccines during preventive care visits and by pediatricians [9]. The importance of healthcare utilization was further emphasized by results from the decomposition

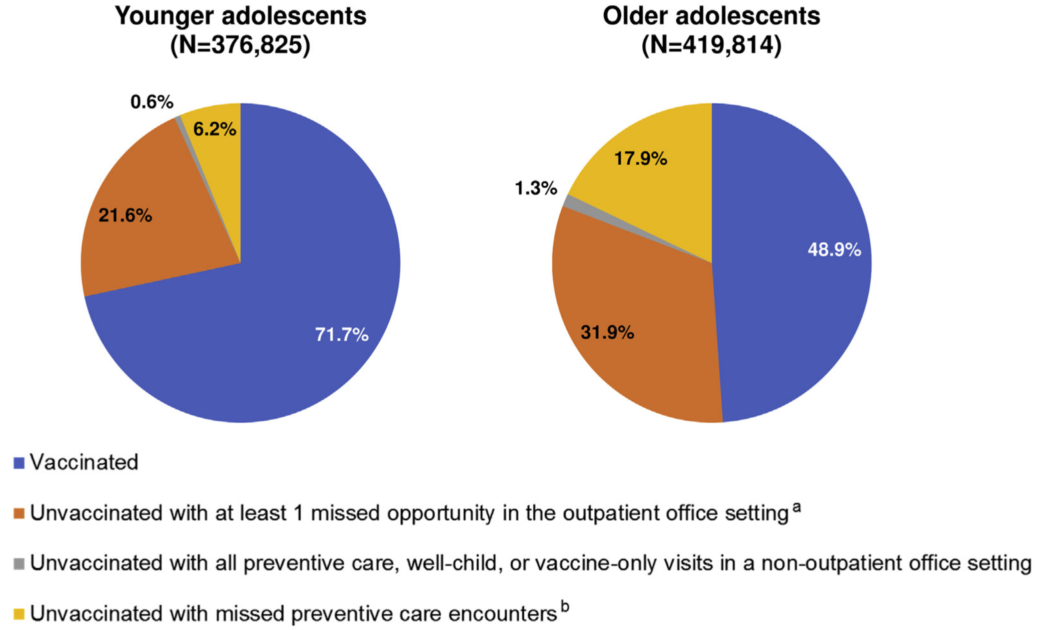

Figure 3. Healthcare utilization measures among younger versus older adolescents (CCAE): missed opportunities[a] and missed preventive care encounters[b] for MenACWY vaccination.[a] Potential missed opportunities were defined as any outpatient office visit coded as a preventive care, well-child, or vaccine-only visit at which the adolescent was eligible for MenACWY vaccination but did not receive it.[b] Missed preventive care encounters were defined as having had no preventive care, well-child, or vaccine-only visits in any care setting. CCAE = Commercial Claims and Encounters; MenACWY = quadrivalent meningococcal conjugate vaccine against meningococcal disease due to serogroups A, C, W, and Y.

analysis indicating that the total number of preventive care/well-child visits, total number of non-MenACWY vaccines received and attributed provider type could explain 68.3% and 71.4% of the intergroup difference in vaccination uptake of the CCAE and Medicaid sample, respectively. The descriptive results showed that individuals vaccinated with MenACWY received more non-MenACWY vaccines and had more preventive care/well-child visits compared with their unvaccinated peers. More preventive care visits can increase the number of opportunities to integrate vaccination history assessments and offer vaccination where eligible. Physician recommendation is a key factor associated with adolescent vaccination [22] and one of the strategies [23] supporting implementation of the 11- to 12-year-old vaccination platform that likely facilitated improved uptake among younger adolescents.

Not all conducive healthcare encounters led to MenACWY vaccine receipt: 31.9% of older adolescents and 21.6% of younger adolescents in the CCAE dataset remained unvaccinated despite having had at least one preventive care/well-child or vaccine-only outpatient visit during the study period. Controlling for baseline characteristics and healthcare utilization measures, older adolescents were more likely to have a potential missed opportunity compared with younger adolescents. The total number of non-MenACWY vaccines received and attributed provider type explained a large proportion of this intergroup difference.

In the Medicaid population, vaccine uptake was substantially lower than in the commercially insured population. This difference may be attributed to underestimation of uptake in the Medicaid population. Adolescents who have received the recommended vaccination under the federally sponsored Vaccines for Children program may not be fully reflected in this study as these vaccines may not generate a Medicaid claim. In a recent study among adolescents aged 13–17 years, Lu et al. [24] found similar MenACWY coverage between adolescents with any Medicaid (82.1%) and those insured privately (81.7%). That study was based on a survey of provider-reported vaccination histories and may provide a more representative overall coverage estimate in the Medicaid population.

In the Medicaid sample, uptake in both age groups was greater among black individuals than white individuals. This was consistent with results from the 2016 NIS-Teen survey that reported slightly higher one dose uptake among black only, non-Hispanic individuals (85.5%) than white only, non-Hispanic individuals (81.2%) [25]. Similarly, two-dose uptake (age 17 years only) was also estimated at a higher rate among black only, non-Hispanic individuals compared with white only, non-Hispanic individuals (44.6% and 38.7%, respectively) [25].

Taken together, these results support the importance of interventions to reduce missed opportunities, increase adherence to preventive care/well-child visits in both younger and older adolescents, and encourage vaccination through nonpediatric providers. Promoting simultaneous vaccinations may be a feasible strategy for younger adolescents. A study of vaccine uptake among 11-year-olds in New York City found that implementation of Tdap school entry requirement led to an increase of simultaneous meningococcal and Tdap vaccination from 29.0% in 2007% to 65.4% in 2013 [26]. Among older adolescents, there are fewer recommendations for routine vaccination, and a similar platform for simultaneous vaccination is still being established. Many adolescents and parents may be unaware or unmotivated to seek the booster dose at the first recommended age. Catch-up MenACWY vaccination through age 17–18 years (e.g., last year of high-school) might lead to overall increased vaccination levels in older adolescents as observed with middle school vaccination requirements [25].

Further exploration of current utilization patterns during older adolescence, including frequent places of service and common reasons for visits, may provide additional insight into strategies to increase MenACWY vaccine uptake (Figure S4).

Limitations

The *MarketScan* databases do not include information regarding social, cognitive, or policy factors (e.g., school entry vaccination requirements) that may influence vaccination behavior. Therefore, it was not possible to analyze the underlying reasons behind potential missed opportunities (e.g., not offering vaccination, vaccine refusal). Further research identifying reasons for missed opportunities is needed to design strategies to transform potential missed opportunities into vaccination events. Identifying a vaccination event is limited to vaccinations which generated a claim in the database. Non-MenACWY vaccines were only identified using CPT codes and misclassification might be possible. However, the number is likely small as CPT coding for billing is standard [27]. Evaluating uptake of two doses (primary and booster) of MenACWY vaccine was not within scope. Such an analysis here would require imposing an 8.5-year continuous observation period, which would result in a small and nongeneralizable sample of individuals. Finally, the Medicaid data included a subset of states and may not be fully generalizable to the entire U.S. Medicaid population, as vaccination uptake may vary by state [25].

Conclusions

MenACWY vaccine uptake was significantly higher in the younger adolescents compared with the older adolescents, even after controlling for demographic and healthcare utilization characteristics, and the difference was largely attributable to the number of non-MenACWY vaccines received, number of preventive care/well-child visits, and type of healthcare provider. Uptake increased over time in both age groups, but the presence of missed opportunities and missed preventive care encounters in both age groups suggest further room for improvement. The younger adolescents benefit from better adherence to preventive care recommendations, plausibly through the efforts of an established vaccination platform; hence vaccine uptake may be further increased by information campaigns and coadministration of other recommended vaccines. A substantial proportion of older adolescents had missed opportunities as well as missed preventive care encounters. Increasing MenACWY uptake in older adolescents might benefit by solidifying a vaccination platform at ages 16–18 years, before graduating from high school, while a child is insured under a parent/guardian and likely receiving care from a primary care provider, in conjunction with supporting adherence to regular preventive care visits and campaigns to increase awareness of designated healthcare providers or alternative vaccination providers. Future research should investigate additional factors driving missed opportunities (e.g., patient refusal, contraindication, lack of provider recommendation, lack of vaccine availability) to design targeted interventions that may help convert potential missed opportunities into vaccination events.

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Supplementary Data

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