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Prenatal vaccination of mothers and hepatitis B vaccination of their infants

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ABSTRACT

Tetanus, diphtheria, and acellular pertussis (Tdap) vaccination and influenza vaccination are recommended during pregnancy primarily to prevent influenza and pertussis in mothers and their infants. This study examines associations between prenatal Tdap vaccination and influenza vaccination of mothers and hepatitis B vaccination of their infants. A retrospective cohort study was conducted using data from electronic medical records from 15,468 deliveries to 14,925 mothers occurring April 2, 2014-December 3, 2016 at a university hospital in Texas. Hepatitis B vaccine receipt in the first 3 days of life was dichotomized. Margins post-estimation commands in Stata SE 15.1 were used to obtain predicted probabilities and risk differences after estimating odds ratios in logistic regression with robust variance estimates. Adjusted models included maternal age, race/ethnicity, Medicaid use, year of delivery, parity, and gravidity. Infants of mothers who received prenatal influenza vaccination in the 2014–2015 and 2015–2016 influenza seasons were more likely than those of mothers who did not to receive a hepatitis B vaccine in their first 3 days of life (adjusted risk difference (RD) 2.8%, 95% confidence interval (CI) 1.5–4.1% and RD 2.2%, 95% CI 0.9–3.5%, respectively). Hepatitis B vaccination was also higher among infants of Tdap-eligible mothers who received prenatal Tdap vaccination during pregnancy compared to those of mothers who did not (adjusted RD 9.1%, 95% CI 7.6–10.5%). Overall, prenatal vaccination was significantly associated with uptake of infant hepatitis B vaccine.

1. Introduction

Childhood vaccination remains below Healthy People 2020 (HP2020) targets on several measures. The first vaccine a child is recommended to receive is the hepatitis B birth dose recommended to occur within 24 h of birth for healthy infants weighing ≥2000 g (Schillie et al., 2018). The HP2020 target for the hepatitis B birth is 85% of infants having a hepatitis B vaccination within their first 3 days of life, yet national estimates from 2013 to 2015 show only 73.3% of infants received their first hepatitis B vaccine within their first 3 days of life (U.S. Department of Health and Human Services, 2018).

Interventions developed thus far have had little success in increasing childhood vaccination rates (Dubé et al., 2015). This may be because previous studies have primarily focused their interventions on parents who present to the pediatrician's office for their child's well child visit (Harvey et al., 2015). Although parents report that they would like to receive information about childhood vaccines before their child is born (Vannice et al., 2011), little, if any, information is provided during pregnancy (Wu et al., 2008). This demonstrates a need for innovative intervention strategies.

Prenatal care may provide an opportunity to implement targeted interventions as prenatal vaccination is already discussed during these visits. The influenza vaccine and the tetanus toxoid, reduced diphtheria toxoid, and acellular pertussis (Tdap) vaccine are both recommended during pregnancy (American College of Obstetricians and Gynecologists, 2018a). Prenatal influenza vaccination has been recommended for over a decade (American College of Obstetricians and Gynecologists, 2004; Centers for Disease Control and Prevention, 2008) and prenatal Tdap vaccination has been recommended since 2011 (Centers for Disease Control and Prevention, 2011), but uptake has been slow. It has been shown that reasons behind refusal of prenatal vaccinations are strikingly similar to those behind refusal of childhood vaccination (Strassberg et al., 2018; Yuen and Tarrant, 2014). In addition, mothers who reported not receiving the influenza vaccine during pregnancy had children who were less likely to be up to date on their vaccines by age 3 (Fuchs, 2016). Another study showed children

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were more likely to receive influenza vaccines if their parents also received them (Robison and Osborn, 2017). Early, targeted interventions of parents at risk of undervaccinating their children are needed.

To increase childhood vaccination and appropriately target interventions, it is important to understand the association between maternal factors and childhood vaccination uptake. The objective of this study was to use electronic medical records to examine the uptake of prenatal influenza and Tdap vaccination among a large cohort of women and investigate whether there is an association between the receipt of prenatal vaccinations and pediatric hepatitis B vaccination in the first 3 days of life.

2. Methods

A retrospective cohort study was conducted using data from electronic medical records for births occurring from April 4, 2014-December 3, 2016 at a university hospital in Texas. April 4, 2014, was the start date because it was the first day of a new pregnancy and birth electronic medical record system. All pregnancy episodes (N = 15,715) in the electronic medical record were extracted along with linked deliveries with the exception of those pregnancy episodes which were part of a clinical trial at any point during pregnancy (n = 227, all singleton births). After excluding births occurring prior to 20 weeks gestation (n = 20), there were 15,468 deliveries to 14,925 mothers (Fig. 1). If a mother had more than one pregnancy and birth in the eligible time frame for a given analysis, each birth was eligible to be included. Prenatal vaccine uptake was defined by records with completed orders for vaccination or clinic staff updating the vaccination status in the records due to administration at an outside location. Hepatitis B vaccine uptake was defined by a completed vaccination order. Vaccination records are synchronized with the state Immunization Information System and are also updated when a patient or parent reports vaccination. Prenatal Tdap and influenza vaccination were dichotomized for receipt at any time during pregnancy and neonatal hepatitis B vaccination was dichotomized for receipt during the first 3 days of life. Hepatitis B vaccine receipt was indicated if at least one baby in a set of multiples (201 twin births, 5 triplet births) had received a hepatitis B vaccine in the first 3 days of life. Two records for hepatitis B vaccination were excluded from predictive analyses due to errors in date of vaccination compared to date of birth.

Prenatal influenza vaccination was assessed for the 2014–2015 and 2015–2016 influenza seasons. Women who received an influenza vaccine August 1 or later in each year were considered vaccinated for the upcoming influenza season, whether the vaccination occurred before or during her pregnancy. Women who were pregnant during October–January of each influenza season were included in analyses for influenza vaccination uptake. For the 2014–2015 influenza season, 6209 births were available for analysis, including 6199 mothers with one eligible pregnancy and 5 mothers with two eligible pregnancies. For the 2015–2016 influenza season, 6428 births were available for analysis, including 6408 mothers with one eligible pregnancy and 10 mothers with two eligible pregnancies. Some pregnancies (n = 466) were eligible to be included in both influenza seasons.

Prenatal Tdap eligibility was assessed where prenatal Tdap vaccination was a predictor. The American College of Obstetricians and Gynecologists recommends that Tdap vaccination occur between 27 weeks and 36 weeks 6 days of gestation (American College of Obstetricians and Gynecologists, 2017). In models where prenatal Tdap vaccination eligibility was required, those who had initiated prenatal care prior to delivery and delivered at ≥27 weeks gestation were considered eligible (n = 14,347) to have received the prenatal Tdap vaccine. Those who had prenatal care but delivered before 27 weeks (n = 57), those who had no prenatal care and delivered at ≥27 weeks (n = 1020), and those who had no prenatal care and delivered before 27 weeks or had an unknown gestational age (n = 44) were considered ineligible to have received the Tdap vaccine. To evaluate prenatal Tdap eligibility, gestational age was imputed for 216 pregnancies using median gestational age for decile of birth weight by sex where birth weight and infant sex were available (Eberg et al., 2017). Gestational age was not available or imputed in 51 births where sex (n = 20), birth weight (n = 18), or both (n = 13) were unknown.

2.1. Statistical analyses

Chi-squared tests examined differences between dichotomous variables and t-tests examined differences between continuous variables. Unadjusted and adjusted log odds of hepatitis B vaccination were estimated using logistic regression (not presented) and margins post-estimations commands were used to obtain predicted probabilities and risk differences (RD) between groups. Maternal characteristics available in the electronic medical record were adjusted for in analysis and included age, race/ethnicity, Medicaid use, year of delivery, parity, and gravidity. Robust variance estimates were used to account for clustering of births by mother. Births where all fetuses or infants had fetal or neonatal demise were excluded from predictive analyses (n = 101 births; including 99 singletons, 1 set of twins, and 1 set of triplets).

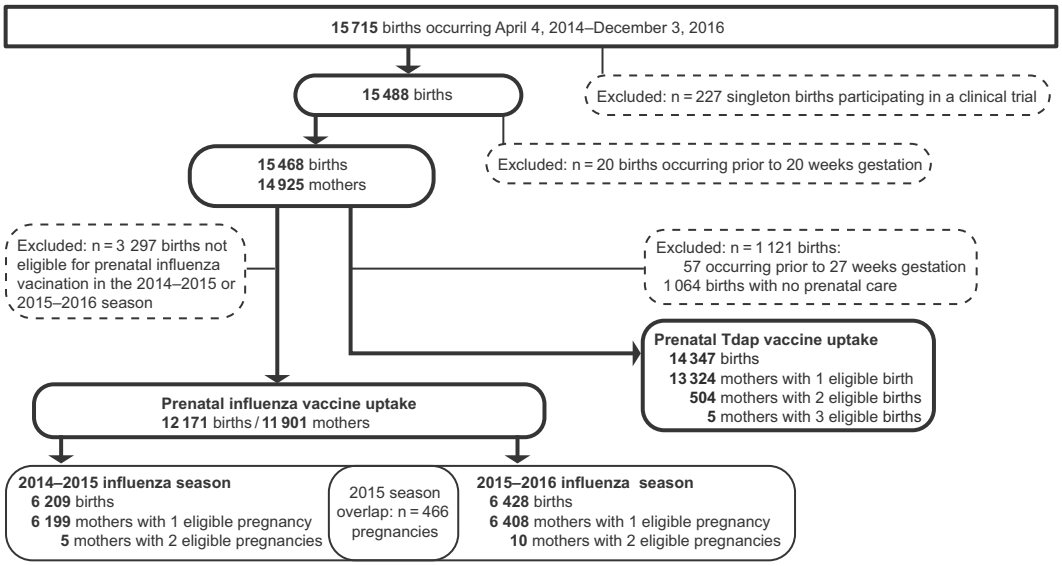

Fig. 1. Retrospective cohort flow chart for inclusion and exclusion of births occurring at a hospital in Southeast Texas from April 4, 2014-December 3, 2016.

Table 1
Demographic and pregnancy characteristics of mothers who delivered a baby at a safety net hospital in southeast Texas by receipt of prenatal influenza vaccine in the 2014–2015 and 2015–2016 influenza seasons (n = 12,171 births).[a]

2014–2015 influenza season (n = 6209 births)

	Prenatal influenza vaccination (n = 3028, 48.77%)	No prenatal influenza vaccination (n = 3181, 51.23%)	p-Value[b]	Overall
Age at delivery, years, mean (SD)	27.55 (6.28)	27.15 (6.08)	0.011	27.35 (6.18)
Parity, mean (SD)	1.40 (1.39)	1.36 (1.40)	0.289	1.38 (1.49)
Gravidity, mean (SD)	2.75 (1.71)	2.86 (1.86)	0.022	2.81 (1.79)
Race/ethnicity, n (column %)			< 0.001	
Non-Hispanic white	358 (11.82)	833 (26.19)		1191 (19.18)
Hispanic white	2332 (77.01)	1749 (54.98)		4081 (65.73)
Non-Hispanic black	236 (7.79)	455 (14.30)		691 (11.13)
Non-Hispanic Asian	77 (2.54)	79 (2.48)		156 (2.51)
Other or unknown	25 (0.83)	65 (2.04)		90 (1.45)
Insurance, n (column %)			< 0.001	
Medicaid	2892 (95.51)	2867 (90.13)		5759 (92.75)
Private or other	136 (4.49)	314 (9.87)		450 (7.25)

2015–2016 influenza season (n = 6428 births)

	Prenatal influenza vaccination (n = 3337, 51.91%)	No prenatal influenza vaccination (n = 3091, 48.09%)	p-value[b]	Overall
Age at delivery, years, mean (SD)	27.45 (6.27)	27.25 (6.01)	0.196	27.35 (6.15)
Parity, mean (SD)	1.33 (1.31)	1.41 (1.44)	0.029	1.37 (1.37)
Gravidity, mean (SD)	2.75 (1.64)	2.90 (1.86)	< 0.001	2.82 (1.75)
Race/ethnicity, n (column %)			< 0.001	
Non-Hispanic white	548 (16.42)	955 (30.90)		1503 (23.38)
Hispanic white	2426 (72.70)	1519 (49.14)		3945 (61.37)
Non-Hispanic black	243 (7.28)	473 (15.30)		716 (11.14)
Non-Hispanic Asian	92 (2.76)	82 (2.65)		174 (2.71)
Other or unknown	28 (0.84)	62 (2.01)		90 (1.40)
Insurance, n (column %)			< 0.001	
Medicaid	3076 (92.18)	2686 (86.90)		5762 (89.64)
Private or other	261 (7.82)	405 (13.10)		666 (10.36)

[a] Each of a mother's pregnancies and births overlapping with an influenza season (October–January) was considered for demographic characteristics, pregnancy outcomes, and vaccination in this table. In the 2014–2015 influenza season, 6199 mothers had 1 eligible pregnancy and 5 mothers had 2 eligible pregnancies. In the 2015–2016 influenza season, 6408 mothers had 1 eligible pregnancy and 10 mothers had 2 eligible pregnancies. Some pregnancies were eligible to be included in both influenza seasons (n = 466).

[b] p-Values were calculated using t-tests for continuous variables and chi-squared tests for categorical variables.

Sensitivity analyses were conducted to examine the effects of restricting to a mother's first birth in the dataset, excluding twin/triplet births, using the individual infant as the unit of analysis (as opposed to birth), restricting to births at 36 weeks gestation or later, restricting to infants > 2,000 g at birth, and including cases of fetal and neonatal demise. Analyses were conducted using Stata SE Version 15.1 (StataCorp, 2017) with statistical significance assessed at $p \leq 0.05$. The University of Texas Medical Branch Institutional Review Board approved this study (#13-0421).

3. Results

Overall, mean maternal age was 27.4 years (range: 13–51 years). Mothers were primarily Hispanic white, non-Hispanic white, and non-Hispanic black (Tables 1-2). The vast majority of births were Medicaid-funded. Demographic differences in prenatal vaccination varied by year and vaccine. Mothers who received prenatal influenza vaccination in the 2014–2015 season were slightly older, had lower gravidity but similar parity, were more likely to have Medicaid coverage, and were more likely to be Hispanic white (Table 1) than those who did not receive prenatal influenza vaccination. In the 2015–2016 influenza season, there were no differences in maternal age by prenatal influenza vaccination, but those who received prenatal influenza vaccination had lower parity and gravidity, were more likely to be Hispanic white, and were more likely to have Medicaid coverage compared to those who did not received prenatal influenza vaccination (Table 1). Mothers who received prenatal Tdap vaccination were older, had lower parity and gravidity, were more likely to be Hispanic white (Table 2) compared to mothers who did not receive prenatal Tdap vaccination. There was no difference in Medicaid coverage among those with and without prenatal Tdap vaccination.

Prenatal Tdap (67.1% overall, 76.2% for eligible pregnancies) and influenza (48.8% for 2014–2015 and 51.9% for 2015–2016 influenza seasons) vaccination coverage were both low. Out of 15,365 live births, 14,105 (91.8%) received a hepatitis B vaccination within the first 3 days of life. Hepatitis B vaccine uptake was significantly higher among infants of mothers who received the influenza vaccine during pregnancy compared to those of mothers who did not (95.2% vs. 91.4%, $p < 0.001$, for 2014–2015 and 94.4% vs. 91.0%, $p < 0.001$, for 2015–2016) (data not shown in tables). Infants of mothers who received prenatal Tdap vaccination were significantly more likely than those of mothers who did not to receive a hepatitis B vaccine when all births were included (94.9% vs. 85.5%, $p < 0.001$) and when only those births to mothers who were eligible to have received the Tdap vaccine were included (94.9% vs. 84.5%, $p < 0.001$) (data not shown in tables).

Hepatitis B vaccination in the first 3 days of life was 3.9% (95% CI: 2.6–5.1%) higher among infants of mothers who received prenatal influenza vaccination in the 2014–2015 influenza season compared to those who did not (Table 3) in the unadjusted model. The adjusted risk difference (RD) for hepatitis B vaccination of infants among mothers who received prenatal influenza vaccination compared to those who did not was 2.8% (95% CI: 1.5–4.1%). For the 2015–2016 influenza season, infants of mothers who received prenatal influenza vaccination

Table 2
Demographic and pregnancy characteristics of mothers who delivered a baby at a safety net hospital in southeast Texas (2014–2016) by receipt of prenatal tetanus, diphtheria, and acellular pertussis (Tdap) vaccine (n = 14,347 births).[a]

	Prenatal Tdap vaccination (n = 10,936, 76.2%)	No prenatal Tdap vaccination (n = 3411, 23.8%)	p-Value[b]	Overall
Age at delivery, years, mean (SD)	27.46 (6.23)	27.16 (6.11)	0.014	27.39 (6.20)
Year of delivery, n (column %)			< 0.001	
2014	2255 (20.62)	1483 (43.48)		3738 (26.05)
2015	4426 (40.47)	1033 (30.28)		5459 (38.05)
2016	4255 (38.91)	895 (26.24)		5150 (35.90)
Parity, mean (SD)	1.35 (1.35)	1.42 (1.49)	0.0145	1.36 (1.38)
Gravidity, mean (SD)	2.75 (1.69)	2.91 (1.91)	< 0.001	2.78 (1.74)
Race/ethnicity, n (column %)			< 0.001	
Non-Hispanic white	1893 (17.31)	877 (25.71)		2770 (19.31)
Hispanic white	7617 (69.95)	1865 (54.68)		9482 (66.09)
Non-Hispanic black	1003 (9.17)	506 (14.83)		1509 (10.52)
Non-Hispanic Asian	289 (2.64)	94 (2.76)		383 (2.67)
Other or unknown	134 (1.23)	69 (2.02)		203 (1.41)
Insurance, n (column %)			0.152	
Medicaid	10,009 (91.52)	3094 (90.73)		13,103 (91.34)
Private or other	927 (8.48)	316 (9.27)		1243 (8.66)

Tdap = Tetanus, diphtheria, and acellular pertussis.
[a] Each of a mother's eligible births in the time period between April 4, 2014-December 3, 2016 were considered for demographic characteristics, pregnancy outcomes, and vaccination in this table. A birth was eligible for inclusion if delivery occurred at ≥27 weeks gestation and the mother had at least one prenatal care visit. Of 13,833 mothers with 14,347 births, 13,324 mothers had 1 birth, 504 mothers had 2 births, and 5 mothers had 3 births.
[b] p-Values were calculated using t-tests for continuous variables and chi-squared tests for categorical variables.

were 3.5% (95% CI: 2.2–4.7%, unadjusted model) and 2.2% (95% CI: 0.1%–3.5%, adjusted model) more likely to have received hepatitis B vaccine in the first 3 days of life. There were no qualitative differences in results in sensitivity analyses.

When considering only mothers who were eligible to have received prenatal Tdap vaccination, infants of mothers who received prenatal Tdap vaccination had hepatitis B vaccination in the first 3 days of life that was 10.4% (95% CI: 9.1–11.7%) higher in the unadjusted model and 9.1% (95% CI: 7.6–10.5%) higher in the adjusted model than those whose mothers did not receive prenatal Tdap vaccination (Table 3). Results of sensitivity analyses revealed no qualitative differences.

4. Discussion

In this study, infants were more likely to have had a hepatitis B vaccine within their first 3 days of life if their mothers had received recommended vaccines during pregnancy. Even in this population with a high proportion of hepatitis B vaccination, this difference persisted. Previous research has shown that children are more likely to be up to date on their vaccines if their mothers reported receiving prenatal influenza vaccination. The current study adds to previous research by showing an association between prenatal Tdap vaccination and infant vaccination. Still, the uptake of prenatal vaccination remains low in this population.

Table 3
Risk and risk difference predictions of hepatitis B vaccination of infants within 3 days of birth from logistic regression models by receipt of prenatal vaccination among mothers who delivered at a safety net hospital in southeast Texas (2014–2016).

	Influenza vaccine receipt, EMR (95% confidence interval)[a]	No influenza vaccine receipt, EMR (95% confidence interval)[a]	Risk difference (95% confidence interval)[a]	n for model
2014–2015 influenza season				
Hepatitis B birth dose, proportion				
Unadjusted	0.952 (0.945–0.960)	0.914 (0.904–0.923)	0.039 (0.026–0.051)	6180
Adjusted[b]	0.947 (0.939–0.956)	0.919 (0.910–0.929)	0.028 (0.015–0.041)	5913
2015–2016 influenza season				
Hepatitis B birth dose, proportion				
Unadjusted	0.944 (0.937–0.952)	0.910 (0.900–0.920)	0.035 (0.022–0.047)	6392
Adjusted[b]	0.939 (0.931–0.948)	0.917 (0.908–0.927)	0.022 (0.009–0.035)	6392
	Tdap vaccine receipt, EMR (95% confidence interval)	**No Tdap vaccine receipt, EMR (95% confidence interval)**	**Risk difference (95% confidence interval)**	**n for model**
Hepatitis B birth dose, proportion				
Unadjusted – eligible only[c]	0.949 (0.945–0.953)	0.845 (0.833–0.858)	0.104 (0.091–0.117)	14,289
Adjusted – eligible only[d]	0.948 (0.944–0.952)	0.857 (0.843–0.871)	0.091 (0.076–0.105)	12,501

EMR = Electronic medical record.
Tdap = Tetanus, diphtheria, and acellular pertussis.
[a] All models include robust variance estimates to account for clustering of births within mother.
[b] Model adjusted for race/ethnicity, insurance, maternal age, year of delivery, parity, and gravidity.
[c] Model includes only those who were eligible (initiated prenatal care prior to delivery and delivered at ≥27 weeks) to receive prenatal Tdap vaccination.
[d] Model adjusted for race/ethnicity, insurance, maternal age, year of delivery, parity, and gravidity, includes only those who were eligible to receive prenatal Tdap vaccination.

The purpose of prenatal vaccination is to protect both the mother and the infant from pertussis and influenza until the infant can receive their own vaccines to protect against pertussis and influenza starting at the ages of 2 and 6 months, respectively (Centers for Disease Control and Prevention, 2018). Influenza vaccination may be given at any time during pregnancy based upon availability due to the influenza season (American College of Obstetricians and Gynecologists, 2018b), but some women will not need an influenza vaccination during pregnancy. In contract, the ideal time for prenatal Tdap vaccination is from 27 to 36 weeks gestation (American College of Obstetricians and Gynecologists, 2017; Liang et al., 2018). However, the most recent national estimates show that only 54% of women received a prenatal influenza vaccine and only 49% of women received a prenatal Tdap vaccine (Kahn et al., 2018).

Even though prenatal vaccination in this study predicted the uptake of neonatal hepatitis B vaccine, the low proportion of mothers who received prenatal vaccination is concerning. The mothers in this study had higher prenatal Tdap vaccination, but lower prenatal influenza vaccination than national estimates. Since prenatal Tdap vaccination is intended to occur during a particular window in the third trimester of each pregnancy, it may be a feasible intervention point for both prenatal and childhood vaccination. If a pregnant woman declines or expresses hesitation about prenatal Tdap vaccination, this may present an ideal opportunity for a targeted intervention addressing both prenatal and childhood vaccination. Strong provider recommendation remains one of the most important predictors of both prenatal and childhood vaccination (Larson et al., 2014; Smith et al., 2017; Strassberg et al., 2018; Yuen and Tarrant, 2014). While providers underestimate maternal knowledge of prenatal vaccine recommendations, women are likely to accept prenatal vaccination if they receive a strong provider recommendation (Healy et al., 2015). Future research should examine how to best support obstetric providers in increasing prenatal vaccination by giving strong recommendations, like those made by pediatric care providers, while maintaining high levels of childhood vaccination.

4.1. Study limitations and strengths

This study has numerous strengths. This study relies on electronic medical records to examine uptake of prenatal vaccination which may be less prone to bias than self-report and adds to evidence from previous studies, for example, a large historical cohort examining Tdap uptake among privately insured women using claims data (Butler et al., 2017) and estimates of prenatal influenza vaccination relying upon self-report (Centers for Disease Control and Prevention, 2016). Additionally, the electronic medical record includes vaccination records from the state Immunization Information System when participants have consented to the data exchange, capturing vaccinations that occur elsewhere in the state or that were recorded by other providers in the state. Importantly, this study relies on the electronic medical record rather than processed claims that are commonly used in retrospective research. Additionally, the present studies examines prenatal and neonatal vaccination in a generally low-income, racially diverse population and includes a large number of births covered by Medicaid.

There are several limitations to this study. This study was conducted in one geographic location and may not be generalizable to other areas of the state or country. Hepatitis B vaccination was higher in this population than national estimates even among those mothers who did not receive prenatal vaccination. The population served by this hospital system is predominantly low-income and the results may not be generalizable to higher income populations. Few socioeconomic variables were available for analysis. There may still be substantial confounding with Medicaid use as the only socioeconomic variable available for analysis (Casey et al., 2018). Influenza vaccinations may have occurred at locations outside of the health system, like employee health fairs, community events, retail clinics, or pharmacies. Whether prenatal Tdap vaccinations are routinely given in these contexts is unknown. Reasons for lack of vaccination were not explored here.

5. Conclusion

Prenatal vaccination is significantly associated with the uptake of infant hepatitis B vaccine. Though the proportion of infants who received the first dose of the hepatitis B vaccine in this population was high, prenatal vaccination remains low. Interventions aiming to increase prenatal vaccination to ideal levels are needed. Whether interventions aiming to increase prenatal vaccination also impact infant vaccination is unknown.

Conflicts of interest

None.

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References

American College of Obstetricians and Gynecologists, 2004. Influenza vaccination and treatment during pregnancy. ACOG committee opinion number 305. Obstet. Gynecol. 104.

American College of Obstetricians and Gynecologists, 2017. Update on immunization and pregnancy: tetanus, diphtheria, and pertussis vaccination. Committee opinion no. 718. Obstet. Gynecol. 130, 153–157.

American College of Obstetricians and Gynecologists, 2018a. Maternal immunization. ACOG committee opinion, no. 741. Obstet. Gynecol. 131, e214–e217.

American College of Obstetricians and Gynecologists, 2018b. Influenza vaccination during pregnancy. ACOG committee opinion no. 732. Obstet. Gynecol. 131, e109–e114.

Butler, A.M., Layton, J.B., Li, D., Hudgens, M.G., Boggess, K.A., McGrath, L.J., Weber, D.J., Becker-Dreps, S., 2017. Predictors of low uptake of prenatal tetanus toxoid, reduced diphtheria toxoid, and acellular pertussis immunization in privately insured women in the United States. Obstet. Gynecol. 129, 629–637. https://doi.org/10.1097/AOG.0000000000001927.

Casey, J.A., Pollak, J., Glymour, M.M., Mayeda, E.R., Hirsch, A.G., Schwartz, B.S., 2018. Measures of SES for electronic health record-based research. Am. J. Prev. Med. 54, 430–439. https://doi.org/10.1016/j.amepre.2017.10.004.

Centers for Disease Control and Prevention, 2008. Prevention and control of influenza — recommendations of the advisory committee on immunization practices (ACIP), 2008. MMWR 57.

Centers for Disease Control and Prevention, 2011. Updated recommendations for use of tetanus toxoid, reduced diphtheria toxoid and acellular pertussis vaccine (Tdap) in pregnant women and persons who have or anticipate having close contact with an infant aged < 12 months - ACIP, 2011. MMWR 60, 1424–1426.

Centers for Disease Control and Prevention, 2016. Pregnant women and Tdap vaccination, Internet Panel Survey, United States, April 2016 [WWW Document]. URL. https://www.cdc.gov/vaccines/imz-managers/coverage/adultvaxview/tdap-report-2016.html, Accessed date: 30 July 2018.

Centers for Disease Control and Prevention, 2018. Recommended immunization schedule for children and adolescents aged 18 years or younger, United States, 2018 [WWW Document]. URL. https://www.cdc.gov/vaccines/schedules/downloads/child/0-18yrs-child-combined-schedule.pdf, Accessed date: 30 July 2018.

Dubé, E., Gagnon, D., MacDonald, N.E., the SAGE Working Group on Vaccine Hesitancy, 2015. Strategies intended to address vaccine hesitancy: review of published reviews. Vaccine 33, 4191–4203. https://doi.org/10.1016/j.vaccine.2015.04.041.

Eberg, M., Platt, R.W., Filion, K.B., 2017. The estimation of gestational age at birth in database studies. Epidemiology 28, 854–862. https://doi.org/10.1097/EDE.0000000000000713.

Fuchs, E.L., 2016. Self-reported prenatal influenza vaccination and early childhood vaccine series completion. Prev. Med. 88, 8–12. https://doi.org/10.1016/j.ypmed.2016.03.012. (Baltim).

Harvey, H., Reissland, N., Mason, J., 2015. Parental reminder, recall and educational interventions to improve early childhood immunisation uptake: a systematic review and meta-analysis. Vaccine 33, 2862–2880. https://doi.org/10.1016/j.vaccine.2015.04.085.

Healy, C.M., Rench, M.A., Montesinos, D.P., Ng, N., Swaim, L.S., 2015. Knowledge and attitudes of pregnant women and their providers towards recommendations for immunization during pregnancy. Vaccine 33, 5445–5451. https://doi.org/10.1016/j.vaccine.2015.08.028.

Kahn, K.E., Black, C.L., Ding, H., Williams, W.W., Lu, P.-J., Fiebelkorn, A.P., Havers, F., D'Angelo, D.V., Ball, S., Fink, R.V., Devlin, R., 2018. Influenza and Tdap vaccination coverage among pregnant women — United States, April 2018. Morb. Mortal. Wkly Rep. 67, 1055–1059.

Larson, H.J., Jarrett, C., Eckersberger, E., Smith, D.M.D., Paterson, P., 2014.

Understanding vaccine hesitancy around vaccines and vaccination from a global perspective: a systematic review of published literature, 2007-2012. Vaccine 32, 2150–2159. https://doi.org/10.1016/j.vaccine.2014.01.081.

Liang, J., Tiwari, T., Moro, P., Messonnier, N.E., Reingold, A., Sawyer, M., Clark, T.A., 2018. Prevention of pertussis, tetanus, and diphtheria with vaccines in the United States: recommendations of the advisory committee on immunization practices (ACIP). MMWR Recomm. Rep. 67, 1–44. https://doi.org/10.15585/mmwr.rr6702a1.

Robison, S.G., Osborn, A.W., 2017. The concordance of parent and child immunization. Pediatrics 139, e20162883. https://doi.org/10.1542/peds.2016-2883.

Schillie, S., Vellozzi, C., Reingold, A., Harris, A., Haber, P., Ward, J.W., Nelson, N.P., 2018. Prevention of hepatitis B virus infection in the United States: recommendations of the advisory committee on immunization practices. MMWR Recomm. Rep. 67, 1–31. https://doi.org/10.15585/mmwr.rr6701a1.

Smith, L.E., Amlôt, R., Weinman, J., Yiend, J., Rubin, G.J., 2017. A systematic review of factors affecting vaccine uptake in young children. Vaccine 35, 6059–6069. https://doi.org/10.1016/j.vaccine.2017.09.046.

StataCorp, 2017. Stata Statistical Software: Release 15.

Strassberg, E.R., Power, M., Schulkin, J., Stark, L.M., Mackeen, A.D., Murtough, K.L., Paglia, M.J., 2018. Patient attitudes toward influenza and tetanus, diphtheria and acellular pertussis vaccination in pregnancy. Vaccine 36, 4548–4554. https://doi.org/10.1016/j.vaccine.2018.05.121.

U.S. Department of Health and Human Services, 2018. State-level data, children receiving a birth dose of HepB vaccine within 3 days of birth (percent) [WWW Document]. URL. https://www.healthypeople.gov/2020/data/map/4721?year=2013-15, Accessed date: 30 July 2018.

Vannice, K.S., Salmon, D.A., Shui, I., Omer, S.B., Kissner, J., Edwards, K.M., Sparks, R., Dekker, C.L., Klein, N.P., Gust, D.A., 2011. Attitudes and beliefs of parents concerned about vaccines: impact of timing of immunization information. Pediatrics 127 (Suppl), S120–S126. https://doi.org/10.1542/peds.2010-1722R.

Wu, A.C., Wisler-Sher, D.J., Griswold, K., Colson, E., Shapiro, E.D., Holmboe, E.S., Benin, A.L., 2008. Postpartum mothers' attitudes, knowledge, and trust regarding vaccination. Matern. Child Health J. 12, 766–773. https://doi.org/10.1007/s10995-007-0302-4.

Yuen, C.Y.S., Tarrant, M., 2014. Determinants of uptake of influenza vaccination among pregnant women - a systematic review. Vaccine 32, 4602–4613. https://doi.org/10.1016/j.vaccine.2014.06.067.