Distribution Agreement

In presenting this thesis or dissertation as a partial fulfillment of the requirements for an advanced degree from Emory University, I hereby grant to Emory University and its agents the non-exclusive license to archive, make accessible, and display my thesis or dissertation in whole or in part in all forms of media, nor or hereafter known, including display on the world wide web. I understand that I may select some access restrictions as part of the online submission of this thesis or dissertation. I retain all ownership rights to the copyright of the thesis or dissertation. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.

Signature:

Jennifer L. Kriss	Date

Prevention of Infant Pertussis Through Maternal Vaccination Strategies

By
Jennifer Lara Kriss
Doctor of Philosophy
Epidemiology

Saad B. Omer, Ph.D., M.B.B.S., M.P.H.
Advisor

Paula Frew, Ph.D., M.P.H.
Committee Member

Penelope Howards, Ph.D., M.S.
Committee Member

Walter A. Orenstein, M.D.
Committee Member

Jennifer Liang, D.V.M.
Committee Member

Accepted:

Lisa A. Tedesco, Ph.D.
Dean of the James T. Laney School of Graduate Studies

Date

Prevention of Infant Pertussis Through Maternal Vaccination Strategies

By

Jennifer Lara Kriss
M.P.H., Columbia University, 2009
B.S.P.H., University of North Carolina at Chapel Hill, 2005

Advisor: Saad B. Omer, Ph.D., M.B.B.S., M.P.H.

An abstract of
a dissertation submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
in Epidemiology
2015

Abstract

Prevention of Infant Pertussis Through Maternal Vaccination Strategies

By Jennifer Lara Kriss

Despite routine childhood vaccination against pertussis and high vaccine coverage, there has been a recent resurgence in pertussis in the U.S. In the last five years (2010-2014) there have been an average of 31,000 reported cases annually. Infants too young to be completely vaccinated are at especially high-risk for pertussis-related complications and death. Tetanus toxoid, reduced diphtheria toxoid, and acellular pertussis vaccine (Tdap) is recommended for pregnant women as a strategy to protect young infants against pertussis before they are fully vaccinated. This dissertation explored maternal vaccination as a method of preventing pertussis in young infants.

Aim 1 evaluated disparities in Tdap vaccination of pregnant women in the U.S. and in factors that inform vaccination decisions. We found that 40% of pregnant women were vaccinated with Tdap. Compared to white non-Hispanics, Hispanic women were more than twice as likely to be vaccinated. Higher income and residing in the western U.S. were independently associated with Tdap vaccination. The most common factor that influenced the vaccination decision was a recommendation from a medical provider.

Aim 2 estimated the prevalence and determinants of obstetrician-gynecologist (ob-gyn) administration of Tdap to pregnant women. We found that 78% of ob-gyns administer Tdap to pregnant patients as part of routine practice, and 20% recommend Tdap but refer their patients elsewhere for vaccination. Residence in western or midwestern states, routine administration of influenza vaccine, and larger practices were associated with Tdap administration.

Aim 3 evaluated whether two educational interventions improve perinatal Tdap vaccination among African American women. Thirty-two percent were vaccinated with Tdap during the perinatal period. The majority were vaccinated immediately postpartum instead of during pregnancy, according to outdated recommendations. An iPad app and an educational video both improved vaccination, although only the iPad app had a statistically significant effect. The observed effects were primarily based on improved Tdap vaccination in the postpartum period, rather than during pregnancy.

Tdap vaccination during pregnancy remains sub-optimal. Maternal vaccination is strongly influenced by recommendations from medical providers and knowledge of the risks and benefits of vaccination, so identifying strategies to improve these factors are key to increasing maternal Tdap coverage.

Prevention of Infant Pertussis Through Maternal Vaccination Strategies

By

Jennifer Lara Kriss
M.P.H., Columbia University, 2009
B.S.P.H., University of North Carolina at Chapel Hill, 2005

Advisor: Saad B. Omer, Ph.D., M.B.B.S., M.P.H.

A dissertation submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
in Epidemiology
2015

TABLE OF CONTENTS

TABLES

FIGURES

CHAPTER 1: OVERVIEW AND RATIONALE

Introduction and Public Health Importance

Pertussis.

Pertussis is an infectious bacterial disease that is caused by the bacterium *Bordetella pertussis* and results in acute respiratory disease. During a pertussis illness with typical presentation, coughing is severe, paroxysmal and episodic, and is followed by a long inspiratory high-pitched "whoop", vomiting, and exhaustion. Because of the characteristic whoop sound that accompanies coughing episodes, pertussis is commonly called "whooping cough." Paroxysmal episodes may result in cyanosis (1). Before vaccination against pertussis became widespread in the 1940s, pertussis caused more deaths in the first 2 years of life than measles, diphtheria, polio, and scarlet fever combined (2). Prior to widespread use of pertussis vaccine, there were an average of 175,000 cases per year in the United States (an incidence of 150 per 100,000 population) (1).

Following the start of large-scale routine pertussis vaccination during childhood in the 1950s and 1960s, yearly reported pertussis cases decreased by more than 90% in the U.S., with the lowest number of cases ever in the U.S. reported in 1976 (1,010 cases) (3). During the 1980s, pertussis incidence in the U.S. was approximately 1 per 100,000 population, but incidence has been gradually increasing in the U.S. since the 1980s.

Epidemiology of pertussis.

Worldwide, although pertussis has been preventable by vaccination for several decades, it remains one of the top 10 causes of death in childhood, primarily among

unvaccinated children (4). The World Health Organization (WHO) estimates that there are about 16 million cases of pertussis each year globally (5). Despite an established childhood vaccination program and high coverage in the U.S. and in many other developed countries, since the 1980s there has been a resurgence of pertussis. Pertussis is now considered to be a poorly controlled vaccine-preventable disease. In 2010-2013, several states reported large outbreaks of pertussis, including California, Colorado, Minnesota, Vermont, Washington, and Wisconsin (6). In 2012, 48,277 pertussis cases were reported in the United States (an incidence of 15.2 per 100,000 population); the highest number of reported pertussis cases since 1955 (3), including 20 deaths and hundreds of hospitalizations among infants younger than 12 months (7). Pertussis remains a concern in the U.S., with an average of about 31,000 cases per year during the last 5 years (2010-2014). In 2014, there were 9 pertussis-related deaths, including 7 infants <3 months, and 1 infant 3-11 months (8).

Pertussis in infants.

The recent resurgence in pertussis is especially concerning for young children, since infants, particularly those in the first 6 months of life are at greatest risk for complications from the disease. During the peak incidence year of 2012, the highest incidence was among infants younger than 1 year (127 cases per 100,000 population), and 16 of the 20 deaths occurred in infants younger than 1 year (7). During the 2010 California pertussis epidemic, incidence rates among infants <6 months of age reached 446 cases per 100,000 persons (9). The incidence of pertussis in infants <6 months has been estimated to be up to 19 times greater than pertussis incidence in the general population (10).

Severe pertussis-related disease and death occur mainly among infants in their first weeks and months of life (11), and rates of pertussis-related complications in infants <6 months are estimated to be up to 4 times higher than complication rates in older children (12, 13). Risk of pertussis-related death is inversely proportional to infant age, and deaths occur almost exclusively in infants who are too young to be completely vaccinated (13-18).

Prevention of pertussis through vaccination.

A whole-cell pertussis vaccine using killed whole *B. pertussis* organisms was combined with diphtheria and tetanus toxoids (DTP) in the 1940s (11, 19), and large-scale vaccination began in the 1950s. Because of concerns about safety and adverse events associated with the whole cell vaccine, an acellular pertussis vaccine (DTaP) was developed in the 1970s, which used highly purified, selected components of the *B. pertussis* organism. The World Health Organization's Expanded Programme on Immunization (EPI) has included pertussis vaccine since its inception in 1974 (11). A 3-dose primary pertussis immunization series begins at age 6 weeks to 3 months, and is completed by 6 months, according to WHO's recommendation (11). The EPI schedule used in most developing countries recommends pertussis vaccine at 6, 10, and 14 weeks, while the schedule used in most industrialized countries, including the U.S., recommends pertussis vaccine at 2, 4, and 6 months. Booster doses are typically given at age 15-18 months and 4-6 years (20, 21).

In the U.S. in 2014, coverage of children 19-35 months for ≥3 doses of DTaP was 94.7%, and for ≥4 doses of DTaP was 84.2% (22, 23). This varied by region, ranging from 72.8% (in Wyoming, for ≥4 doses of DTaP) to 93.1% (in Maine). Globally, 86% of

all infants worldwide received 3 doses of pertussis vaccine (DTP3) (2014, the most recent year for which pertussis vaccination coverage data are available from WHO) (24). WHO estimates that global vaccination against pertussis prevents 687,000 deaths annually (2008 numbers) (11), but that 22.6 million children under 1 year of age remain incompletely vaccinated against pertussis (25).

Short duration of immunity.

Protective immunity against pertussis wanes 4-12 years after the last childhood booster dose of pertussis vaccine (26-30). However, some evidence indicates that duration of immunity may be even shorter: a significant proportion of children may be susceptible to typical pertussis within 1–3 years after vaccination, particularly with acellular pertussis vaccines (31), and pertussis incidence rates have been shown to rise in each of the 6 years following receipt of the 5th dose of DTaP vaccine, with risk ratios increased up to 8.9 in year 6 compared to year 1 (32). This waning immunity leaves older children, adolescents, and adults vulnerable to pertussis infection, and in turn puts unprotected infants at risk for transmission of disease.

Transmission to infants.

Pertussis is a highly communicable disease. It has a basic reproduction ratio (R_0) of 12-17, meaning that in a 100% susceptible population on average, each case will infect 12-17 other people during the infectious period (33). The percent of the population that must have immunity either from vaccination or from infection in order to prevent further spread of disease is calculated as $1 – 1/R_0$. In the case of pertussis, 92-94% of the population must have sustained immunity in order to halt transmission of disease (9). Because neither immunization nor disease results in lifelong immunity to pertussis, it is

particularly challenging to reach and sustain the required levels of population immunity to prevent pertussis outbreaks.

Protection of infants through maternal immunization.

Before babies are protected from infectious diseases through active immunity from their own immunization, they are protected through passive immunity from maternal antibodies. Antibodies against pathogens to which the mother has been exposed or immunized in her lifetime are transferred through the placenta to the fetus, providing passive immunity to the infant after birth and before an infant begins the primary series of vaccinations (34). Several studies have shown evidence of efficient placental transfer of pertussis antibodies after maternal receipt of a pertussis booster vaccine (35-37). Most maternal antibodies are transferred across the placenta in the 3rd trimester, and diminish rapidly, mostly within 2 months, in the infant (18, 35, 37, 38). Influenza vaccine has been recommended for pregnant women in the U.S. since 1967 (39), and several studies have estimated that maternal immunization is effective in preventing influenza disease and influenza-related hospitalizations in young infants (40, 41). More recent studies have found that maternal immunization is 91% effective in preventing pertussis disease in young infants (42, 43).

Tdap vaccine.

A combination tetanus-diphtheria-acellular pertussis booster vaccine (Tdap) was licensed in the U.S. in 2005 as a one-time single dose booster for adolescents and adults. In the U.S., a routine Tdap booster dose is recommended for adolescents at age 11-18 years and for all adults age 19 years and older who have not previously received a dose of

Tdap (20), with the intended purpose of boosting the waning immunity in adolescents and adults.

Cocooning, postpartum vaccination, pregnancy vaccination.

Infants typically do not have protective immunity and remain vulnerable to pertussis until they have received all 3 doses of the primary series of pertussis vaccine, usually by 6 months of age. Several vaccination strategies for protecting vulnerable infants from pertussis have been examined in recent years, including vaccination of all people in contact with a newborn ("cocooning"), vaccination of pregnant women both during pregnancy and immediately postpartum, and vaccinating newborns with a birth dose of pertussis vaccine to provide protection prior to the beginning of the primary series.

Because multiple studies have shown that the majority of infant pertussis cases have acquired disease from a family member or contact, cocooning, which requires immunization of all family members and close contacts of newborns, has been recommended as a way to protect newborns (44). Cocooning protects infants by preventing disease among their contacts, and thus prevents transmission to the infant. However, full cocoon coverage can be difficult to achieve, and a major drawback to cocooning as a protective strategy is that it leaves infants without any endogenous protective antibody until they begin the primary DTaP vaccine series at 2 months of age. Without endogenous protective antibody, infants remain solely dependent on the immunity of those around them for pertussis protection (45).

Vaccinating mothers immediately postpartum (after giving birth and before hospital discharge) is another strategy intended to prevent pertussis transmission to young

infants and was recommended by the CDC in 2005 (46). This strategy has drawbacks, the most important of which is that boosted pertussis antibody levels do not peak until about 2 weeks after pertussis vaccination (47-49), so vaccination that is administered after delivery leaves a 2-week window of risk during which the mother could become infected with pertussis and transmit it to the infant in the first weeks of life (47, 50). Maternal pertussis vaccination during pregnancy provides indirect protection starting at birth by preventing mothers from becoming infected with pertussis and transmitting it to the infant, passive immunity by way of maternal pertussis antibodies passing by transplacental transfer to the fetus (50), and direct protection from maternal antibodies passing through the breast milk by way of breastfeeding to the newborn.

CDC recommendations.

In October 2012, the U.S. Advisory Committee on Immunization Practices (ACIP) recommended that pregnant women be vaccinated with Tdap during *every* pregnancy, regardless of immunization history (51). The recommended optimal timing for Tdap administration is at 27-36 weeks gestation, to maximize maternal antibody response and antibody transfer to the fetus. Secondarily, women who are not vaccinated with Tdap during pregnancy and who have never been vaccinated with Tdap should receive it immediately postpartum. ACIP also recommended that adolescents and adults who have close contact with an infant aged <12 months should receive a single dose of Tdap if they have not received Tdap previously (51). The recommendation for women to be vaccinated with Tdap at *every* pregnancy is supported by data showing a rapid decay of pertussis antibodies in adults after vaccination (20).

American Congress of Obstetricians and Gynecologists (ACOG) recommendations.

Following ACIP's recommendations in October 2012, in June 2013 ACOG published recommendations for Tdap use in pregnancy that essentially mirrored ACIP's recommendations: one dose of Tdap should be administered to all women during pregnancy, irrespective of the patient's Tdap history, with optimal timing of vaccination between 27 and 36 weeks gestation, and 1 dose of Tdap administered immediately after delivery if not received during pregnancy (52). Additionally, ACOG recommended sustained efforts at cocooning, with other family members and direct caregivers receiving Tdap at least 2 weeks before planned infant contact.

Maternal immunization coverage.

In 2011-2012, Tdap coverage among pregnant women was estimated from a CDC country-wide internet panel survey as 2.6% (n=1,231) (53, 54). Since then, Tdap coverage among pregnant women has been estimated from several data sources, including the Pregnancy Risk Assessment Monitoring System (PRAMS) (55), Medicaid data (56), Vaccine Safety Datalink sites (57), other health insurance claims data (58), and cross-sectional surveys (59, 60). In general, there has been an increasing trend in Tdap vaccination during pregnancy, although estimates vary by location and data source.

Efforts to increase maternal vaccination in the Kaiser Permanente Northwest health system showed that patient reminders, inclusion on prenatal visit checklists, and clinician reminders in the electronic medical record were associated with improvement in influenza vaccination coverage (61).

Immunization-related disparities.

In general, there are greater racial disparities in adult immunization than in childhood immunization (62). Black and Hispanic adults have lower coverage of several vaccines compared to white adults, including tetanus vaccine (63), pneumococcal vaccine among elderly adults (64), and influenza vaccine among elderly adults (64). Even after adjustment for personal/health characteristics, socioeconomic factors, and measures of access to and utilization of care, black and Hispanic adults are less likely than whites to be vaccinated (65). Although Tdap coverage has improved among all race/ethnicity groups in the years since its introduction (66, 67), coverage remains low overall, and a similar pattern is seen in disparities in Tdap coverage among adults. Black and Hispanic adults 19-64 years had significantly lower coverage of Tdap vaccine during 2005-2013 than white adults (63).

Most data on disparities in vaccine coverage of pregnant women come from studies of influenza vaccine coverage, since influenza vaccine has been recommended for pregnant women for almost 5 decades. Among a Kaiser Permanente Northwest health plan population, black pregnant women had significantly lower influenza vaccination coverage than white women for both seasonal influenza vaccine in 2008-09 and monovalent H1N1 influenza vaccine in 2009-2010 (61). In 2008-09 Hispanics had significantly lower coverage than non-Hispanics. Between 2008-09 and 2011-12, influenza vaccination coverage increased for all racial/ethnic groups, with the largest increases among Hispanics (33% to 69%) and blacks (32% to 60%). By 2011-12, Hispanics had higher influenza vaccine coverage than non-Hispanics. Preliminary studies have shown that disparities exist for Tdap vaccine as well: among Medicaid beneficiaries,

black women have lower coverage than whites ($p<.05$ compared to whites), but Hispanics may not face the same disparities (56). Pregnancy Risk Assessment Monitoring System (PRAMS) data from 16 states and New York City from 2011 indicated similar patterns based on race/ethnicity, and also found that Tdap vaccination during pregnancy fell as maternal age increased (55).

Limitations to Current Knowledge

Tdap was first licensed by the FDA in 2005, and is still a relatively new vaccine. Thus, there is limited evidence on uptake of this vaccine in the populations that are targeted to receive it. The recommendation for Tdap vaccination of pregnant women occurred even more recently, and there is little evidence on uptake of the vaccine in this particular population subgroup.

Disparities by race/ethnicity and other characteristics have been demonstrated for many other vaccines, and often persist after adjustment for socioeconomic status and access to health care. Disparities in Tdap vaccination among pregnant and postpartum women have not been evaluated. Previous studies have evaluated heterogeneity in attitudes, knowledge, and sources of influence by race/ethnicity when adults are deciding whether to get vaccinated (primarily influenza vaccine), but no studies have assessed this with regards to being vaccinated with Tdap during pregnancy.

Some interventions have been tested to improve coverage of Tdap vaccination among pregnant women, such as standing orders in the hospital at the time of delivery, and reminders in the electronic medical record for the physician to offer Tdap vaccine at a prenatal appointment. However, many of these have focused on increasing provider

offers of vaccination, and have not focused on improving a woman's involvement in the decision to be vaccinated with Tdap during pregnancy. Given that many pregnant women decide not to get vaccinated because of fear (they fear that vaccines will cause them or the fetus harm or will cause adverse events) or because they do not have enough information, targeted interventions that educate patients about the facts and importance of vaccines, and include patients in a meaningful way in this educational process, need to be tested.

Specific Study Aims

The overarching goal of this dissertation is to explore maternal vaccination strategies as a method of preventing pertussis in young infants. The primary objective of *Study Aim 1* is to evaluate disparities in uptake or intended uptake of Tdap vaccine among women during pregnancy and the postpartum period in the U.S. This study utilizes a cross-sectional sample of pregnant women in the U.S. to assess disparities based on race/ethnicity, maternal status (e.g., primigravida), geographic region, socioeconomic status, and age. It also assesses how these characteristics are associated with factors that inform a pregnant woman's decision about Tdap vaccination.

In *Study Aim 2* we evaluate whether there are determinants of obstetrician-gynecologist (ob-gyn) administration or recommendation of Tdap vaccine to their pregnant patients among a sample of ACOG members. We evaluate individual and practice characteristics as determinants of administration of Tdap vaccine. We also estimate the prevalence of ob-gyn administration and recommendation of Tdap to pregnant women, and describe reasons for non-administration by ob-gyns.

In *Study Aim 3* we evaluate whether 2 vaccine education interventions improve Tdap vaccination among minority women during pregnancy and the postpartum period using a randomized controlled trial pilot study. We assess whether the 2 interventions based on the Elaboration Likelihood Model framework administered during the prenatal period improve Tdap uptake, and affect the reasons women report for not getting vaccinated with Tdap during pregnancy. We also assess whether ob-gyn recommendation is associated with Tdap vaccination during pregnancy among this sub-population.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

Epidemiology of Pertussis in Infants

Before a vaccine against pertussis became available in the 1940s, more than 200,000 cases were reported annually in the United States (1). Pertussis was an endemic disease that almost always occurred in children and was a major cause of childhood mortality (50). Annual pertussis-attributable morbidity and mortality were reduced by 92% and 99%, respectively, in the U.S. after widespread introduction and administration of pertussis vaccine in childhood (68).

Morbidity.

Young infants are particularly vulnerable to severe morbidity and mortality resulting from pertussis. In the U.S., approximately two-thirds of infants under 6 months of age with reported pertussis are hospitalized (69, 70). During recent pertussis epidemics in California, most of the hospitalizations were infants <6 months of age (9, 60, 71). The hospitalization rate among infants <6 months was 46% (9); length of hospital stay is longer for infants <6 months (9.3 days) compared with children 6 months or older (4.9 days, $p<.001$) and intensive care is more frequently required for infants <6 months (19% of those hospitalized) compared to children 6 months or older (5%, $p<.01$) (72).

The most common pertussis-related complication experienced by young infants is secondary bacterial pneumonia. Among infants <3 months of age with pertussis, as many as 5.2% acquire secondary bacterial pneumonia, and among infants <6 months of age with pertussis, up to 11.8% acquire secondary bacterial pneumonia, more than double the incidence in older children and adults (1). In the U.S. between 1993 and 2004, 95% of

pertussis-infected infants who required mechanical ventilation and all of those who died were aged 3 months or younger (13).

Mortality.

Risk of pertussis-related death is inversely proportional to infant age, and deaths occur almost exclusively in infants who are too young to be completely vaccinated (13-18). A study in England found that among all pertussis-related deaths, 88% of the deaths were in infants <4 months, and the median age at death was 1.7 months (range: 2 weeks – 17 months) (15).

As the number of reported deaths from pertussis in young infants has increased (14), the case fatality ratio has remained fairly constant (73). The average case fatality rate in developed countries is 0.2% (11). An analysis of U.S. surveillance data (1990-2009) estimated an age-specific case fatality ratio among infants younger than one year of age to be 0.77%, 4.3 times higher than the overall case fatality ratio (74). During the 2010 California outbreak, the case-fatality rate among infants <3 months of age was 1.3% (9, 75). Estimates of the case fatality rate for infants <3 months in England averaged 2.5% for 2008-2013 (43). The average case-fatality rate for pertussis in developing countries is much higher, and is estimated at nearly 4% in infants aged <1 year and 1% in children aged 1–4 years (11), but may be as high as 15% (76).

Pertussis-related disparities.

Several studies in the U.S. have shown that there are disparities in pertussis-related morbidity and mortality. Hispanic infants are consistently overrepresented in pertussis incidence and mortality rates. Based on enhanced pertussis surveillance conducted in 4 states, average annual pertussis incidence was estimated to be 1.7-fold

higher among Hispanic infants <1 year (59.9/100,000) compared to non-Hispanic infants <1 year (35.6/100,000) ($p<.001$) (77). In California's 2010 and 2014 outbreaks, the highest incidence rates were among Hispanic infants (9, 60). Based on pooled data from 1990-1999, Hispanic infants have about 2 times the rate of pertussis-related death compared to non-Hispanic infants (14). In the U.S. in 2007, 70% of pertussis-related deaths were among infants of Hispanic ethnicity (10). There is speculation that Hispanic infants might have a greater risk of exposure to pertussis than non-Hispanic infants due to larger household size and increased number of contacts, which result in more opportunities for exposures (16, 60).

There is also heterogeneity in pertussis-related mortality among infants by maternal education and marital status (16). There is not strong evidence of disproportionate pertussis infection or mortality among African American infants, although African American children have been disproportionately affected by other infectious diseases in the U.S. (78).

Transmission of Pertussis

Transmission to infants.

Pertussis is highly transmissible in the early catarrhal stage, during the first 2 weeks after cough onset and typically before a diagnosis has been made. Following the onset of coughing attacks, untreated patients may be contagious for 3 weeks or more (1, 11). The R_0 (basic reproduction ratio) for pertussis is one of the highest R_0 values among infectious diseases (12-17), and is similar to that for measles. In a fully susceptible population, this means that each case will on average infect 12-17 other people during the

infectious period (33). For pertussis, 92-94% of the population must have immunity either from vaccination or from previous infection in order to terminate transmission (calculated as $1 - 1/R_0$) (9). Unlike measles, however, neither immunization against pertussis nor pertussis disease results in lifelong immunity. This waning immunity makes it virtually impossible to achieve and sustain the required levels of population immunity to eliminate pertussis.

Pertussis has a secondary attack rate of up to 80-90% among non-immune household contacts (1, 11, 79-81). There is conflicting evidence as to whether asymptomatic infections contribute to transmission of the disease. Traditionally, asymptomatic infections were considered to contribute little, if anything, to pertussis transmission (82). However, a 2007 study of pertussis transmission patterns found that for 16.5% of infant index cases, asymptomatic individuals with lab-confirmed infection were the only cases among close contacts (83), indicating that asymptomatic carriers may transmit infection. Seroepidemiologic studies suggest that *B. pertussis* infections, which may be symptomatic, asymptomatic, or with atypical clinical presentations, occur in the general population at an annual rate of 1% to 5% (84).

Adolescents and adults serve as the major source of transmission of pertussis to infants (85). Because pertussis infection often goes unrecognized and undiagnosed in adolescents and adults due to uncharacteristic symptoms and mild disease, they may have a long period of infectiousness during which they can transmit the disease to other susceptible persons with whom they have contact, particularly infants who have not yet been fully immunized against pertussis (86). Several studies have attempted to identify the transmission source of pertussis to infants. These studies are typically able to identify

a source of infection for about half of infant cases. Sources of infection for infants include household contacts, other close family and friend contacts, and more casual non-household contacts. In a multi-country study conducted in Canada, France, Germany, and the U.S., household contacts – particularly parents – were the source of pertussis in 76-83% of infant pertussis cases (87). Another study in Australia found that for infant cases with a coughing contact identified, 68% of those were adults, usually one of the infant's parents (88).

Several studies conducted across different places and times have found that mothers are most often responsible for transmitting pertussis infection to infants, followed by fathers, siblings, and health care workers (77, 83, 88, 89). Among infant pertussis cases for whom a source could be identified (typically about half of cases have an identified source), 15-63% of the infection sources were the mother, and 9-18% were the father. Siblings are another important source of transmission to infants; 16-53% of identified infection sources were a sibling. A prospective stochastic modeling study conducted in the Netherlands estimated that mothers are the most infectious to infants, with an estimated risk of infant infection of approximately 40% if the mother is the primary case in a household, and 10-20% if the father or a sibling is the primary case (90).

Tdap Vaccine

Two combination tetanus-diphtheria-acellular pertussis booster vaccines (Tdap, ADACEL®, Sanofi Pasteur, and Boostrix®, GSK) were licensed by the U.S. Food and Drug Administration (FDA) in 2005 as one-time single dose boosters. Boostrix® is

currently licensed for persons aged 10 years and older, and Adacel® is licensed for persons aged 10-64 years.

Vaccination of adolescents and adults.

A routine Tdap booster dose is recommended in the U.S. for adolescents at age 11-18 years in order to boost immunity to pertussis, preferably at age 11 or 12 (20). Tdap is also recommended by ACIP for all adults age 19 years and older who have not previously received a dose of Tdap, and for all women in every pregnancy, regardless of previous receipt of Tdap (51). The intended purpose of immunization of pregnant women is to promote transplacental transfer of maternal antibodies to the fetus, resulting in protection of the infant from disease after post-natal exposure but before vaccination can induce active immunity (51).

Coverage.

Between 2006 and 2014, Tdap coverage among adolescents age 13-17 years in the U.S. increased from 10.8% to 87.6% (91-93). Preliminary data on Tdap coverage of adults age 19-64 show that coverage has increased year after year since 2008, from 5.9% in 2008 (66) to 18.4% in 2013 (63). In 2011-2012, Tdap coverage among pregnant women was estimated from a CDC country-wide internet panel survey as 2.6% (n=1,231) (53, 54). Since then, Tdap coverage among pregnant women has been estimated from several data sources, including the Pregnancy Risk Assessment Monitoring System (PRAMS), Medicaid data, Vaccine Safety Datalink sites, other health insurance claims data, and cross-sectional surveys. In general, there has been an increasing trend in Tdap vaccination during pregnancy, although estimates vary by location and data source.

Table 2.1. Coverage estimates of Tdap vaccine during pregnancy.

During pregnancy	Postpartum	Location	Year(s)	Population
9.9%	30.5%	16 states & NYC	2011	PRAMS
2.6%		U.S.	2011-12	Internet panel survey
14.3%		Michigan	2011-13	Medicaid enrollees
19.5%		California	2012	Vaccine Safety Datalink sites
25.0%	44.0%	California	2013	Birthing hospitals survey
13.8%		Wisconsin	2013	Health insurance claims for 49% of births
51.0%		Wisconsin	2014	Health insurance claims for 49% of births
26.0%		London, U.K.	2013-14	Cross-sectional survey
55.9%	3.8%	Houston, TX	2013-14	Metropolitan tertiary care center
84.0%		California	2014	Northern CA Kaiser patients

Efficacy and effectiveness.

Immunogenicity studies have shown significant antibody responses in individuals after a Tdap booster dose. By 2 weeks after Tdap vaccination, 88%-94% of vaccinated persons demonstrate a boosted antibody response (48), and 83% of women of childbearing age achieved a ≥4-fold increase in IgG to 3 pertussis antibodies (pertussis toxin, filamentous hemagglutinin, and pertactin) (47). Efficacy of a Tdap booster to prevent pertussis among adolescents and adults was demonstrated by the Adult Pertussis Trial, which found direct vaccine protection of up to 92% (49, 94). In non-trial conditions, effectiveness of an adolescent Tdap booster vaccine was estimated at 66% (95% CI 52-76%) (95, 96). However, Tdap vaccine effectiveness among adolescents

wanes rapidly with increasing time since receipt, so that effectiveness may be as low as 34.5% for receipt 3 years previously, and 11.9% for receipt 4-5 years previously (58).

Duration of immunity.

Evidence suggests that in healthy, non-pregnant adults, there is substantial antibody decay as little as 1 year after Tdap booster vaccination (97-99). Pertussis-specific antibodies similarly decline in pregnant women following pertussis immunization after the 20th week of pregnancy, with significant decreases by 9-15 months post-delivery (100). Vaccine effectiveness declines to 41% (95% CI 7-63%) at 2 or more years post-vaccination (95). Because antibody levels drop so quickly after Tdap vaccination, coverage of adults with Tdap booster vaccines of higher than 85% would be needed to effectively reduce the number of cases of infant pertussis, based on a simulation model (101).

Immunization-related disparities.

Disparities based on race/ethnicity exist in adult immunization, and are typically greater than disparities in childhood immunization. Black and Hispanic adults have lower coverage of several vaccines compared to white adults: tetanus vaccine (54% and 51%, versus 66%, respectively) (66), pneumococcal vaccine among elderly adults (39% and 42%, versus 64%, respectively) (64), and influenza vaccine among elderly adults (48% and 55%, versus 67%, respectively) (64). Black and Hispanic adults are less likely than whites to be vaccinated even after adjustment for personal/health characteristics, socioeconomic factors, and measures of access to and utilization of care (65). Although Tdap coverage remains low for all racial/ethnic groups, data from 2013 showed a significant disparity: 21.6% of white adults aged 19-64 years had received a Tdap

vaccination in the past 8 years, compared with 13.6% of blacks and 10.5% of Hispanics (63).

Data on disparities in vaccine coverage of pregnant women come primarily from studies of influenza vaccine. Similar disparate patterns have been seen, with black and Hispanic women having lower coverage during pregnancy. A study among Kaiser Permanente Northwest found that in 2008-09, 32% of black women compared with 39% of white women received influenza vaccine during pregnancy; in 2009-2010 54% of black women compared with 62% of white women received the monovalent H1N1 influenza vaccine during pregnancy (61). Hispanic women had significantly lower coverage in 2008-09 compared to non-Hispanics (33% vs. 41%, respectively). Between the 2008-09 season and the 2011-12 season, influenza vaccination coverage increased for all racial/ethnic groups, with the largest increases among Hispanics (33% to 69%) and blacks (32% to 60%). This improvement was concurrent with efforts to increase influenza vaccination during pregnancy, including patient reminders, inclusion on prenatal visit checklists, and clinician reminders in the electronic medical record. Recently, Hispanics have reversed the disparity and improved vaccination during pregnancy. By 2011-12, Hispanics had higher influenza vaccine coverage than non-Hispanics (69% vs. 63%, respectively).

A study of Medicaid beneficiaries in Michigan during November 2011–February 2013 found that although Tdap coverage during pregnancy was low overall (14.3%), disparities exist: white non-Hispanic women had the highest coverage (17.6%), and black women had the lowest coverage (8.4%, $p<.05$ compared to whites) (56). Hispanics did not have significantly different Tdap coverage than whites. Another localized study in a

Texas hospital women's center found that black women were less likely to be vaccinated with Tdap during pregnancy than women of other race/ethnicities (OR=0.44, 95% CI 0.38-0.51; 41% vs. 59%) (102).

Strategies to Prevent Pertussis in Infants

Infants typically do not have protective immunity and remain vulnerable to pertussis until they have received all 3 doses of the primary series of pertussis vaccine, usually by 7 months of age (allowing for induction of immunity if vaccine is administered at age 6 months). Several vaccination strategies for protecting vulnerable infants from pertussis have been examined in recent years, including vaccination of all people in contact with a newborn ("cocooning"), vaccination of pregnant women during pregnancy or immediately postpartum, and vaccinating newborns with a birth dose of pertussis vaccine prior to the beginning of the infant's primary vaccination series.

Cocooning.

Cocooning was recommended by the Global Pertussis Initiative (GPI) in 2005 as a strategy to prevent pertussis in young infants before they have been fully vaccinated. The GPI is a scientific forum that includes 37 multidisciplinary experts from 17 countries, and was organized in 2001 to analyze the increase in pertussis globally and enhance existing immunization strategies to reduce the burden of disease (44). In 2002, the GPI made the first cocooning recommendation – that all countries should consider expanding pertussis vaccination to include adults who have the highest risk of transmitting pertussis infection to vulnerable infants (44).

Cocooning is formally defined by GPI as “immunization of family members and close contacts of newborns” (44). The rationale for the cocooning strategy is that multiple studies have shown that the majority of infants with pertussis acquired it from a family member. If immunity to pertussis in close contacts of infants is maintained by booster vaccination, many infant cases could be prevented. The cocoon strategy was recommended in the U.S. and in many developed countries (44), but cocoon coverage can be difficult to achieve. In France, 2 years after the launch of a pertussis cocoon strategy in 2004, just 2% of parents of young infants had received a pertussis-containing vaccine within the previous 3 years (103). More recently in 2008-2010, after initiation of standing orders for postpartum Tdap vaccination in a predominantly Hispanic, medically underserved, uninsured population in the U.S., 75%-86% of mothers received Tdap before leaving the hospital, and a median of 2 other contacts per infant were vaccinated with Tdap (104). A cocooning strategy can be successful in inducing a complete cocoon of vaccinated family members around an infant, but intensive efforts are required, and logistical issues such as timing and vaccine cost must be considered (105). A study of a cocooning program in Australia found that when both parents are immunized, pertussis risk among <4-month-olds is reduced by 51% (95% CI 10%-73%) (106).

A major drawback to cocooning as a protective strategy is that it leaves infants without any endogenous protective antibody until they begin the pertussis primary vaccine series at 2 months of age. Without endogenous protective antibody, infants remain solely dependent on the immunity of those around them for pertussis protection (45). Additionally, all contacts ideally must be vaccinated at least 2 weeks before contact with the infant to allow time for an adequate immune response. While ACIP supports

vaccination with Tdap for persons who anticipate close contact with an infant, they concluded that cocooning with a dose of Tdap given to mothers post-partum is not a sufficient strategy to prevent pertussis morbidity and mortality in young infants (107).

Postpartum maternal vaccination.

Vaccinating mothers after giving birth and before hospital discharge was another strategy to prevent pertussis transmission to young infants. This strategy was recommended by ACIP in 2005 (46), and has been used for several years in the U.S. and in other countries. The most important disadvantage of this strategy is that there is an approximately 14-day window between maternal vaccination and when a sufficient antibody response is attained, leaving a window of risk during which the mother could become infected with pertussis and transmit pertussis to the infant in the first few weeks of life (47, 50). Evaluation of a hospital-based postpartum Tdap immunization program among a predominantly Hispanic, medically-underserved population did not result in a decrease in infant pertussis infection (108).

Maternal vaccination during pregnancy.

The ways in which Tdap vaccination of women during pregnancy protects infants are three-fold: 1) provides indirect protection by preventing mothers from becoming infected with pertussis and transmitting it to the infant; 2) maternal pertussis antibodies pass through the placenta to the fetus, resulting in passive immunity (50); 3) maternal antibodies pass through the breast milk by way of breastfeeding to the newborn, likely providing direct protection to the baby before he/she is protected by active vaccination.

Maternal Tdap vaccination during pregnancy is more protective than postpartum vaccination for the newborn because it provides passive immunity to the newborn starting

at birth from transplacental transfer of maternal pertussis antibodies, and does not leave open the window of risk associated with vaccination only in the postpartum period (50). An analytic comparison of the impact of Tdap vaccination during pregnancy compared to postpartum vaccination estimated that vaccination during pregnancy would prevent more infant cases, hospitalizations, and deaths at lower cost than Tdap administered postpartum, even when postpartum vaccination is combined with additional cocooning of close infant contacts (109). Based on modeling estimates, immunizing parents ≥2 weeks before delivery would have a larger impact than vaccination before delivery or at the time of delivery, with pertussis hospitalizations among infants 0-4 months reduced by 29-50%; if only mothers were vaccinated before delivery, infant pertussis hospitalizations could be reduced by 15-37% (110).

Maternal Tdap Vaccination During Pregnancy: Immunologic Basis and Evidence

Maternal-fetal transmission of antibodies.

Neonates are protected from many infectious diseases by maternal antibodies during the first few weeks and months of life. Antibodies against pathogens to which the mother has been exposed or immunized in her lifetime are transferred through the placenta to the fetus, providing passive immunity to the infant after birth and before an infant begins to acquire active immunity from the primary series of vaccinations (34). Most maternal antibodies are transferred across the placenta in the third trimester, and diminish rapidly, mostly within 2 months, in the infant (18).

Several studies provide evidence of efficient placental transfer of pertussis antibodies. Among mother-baby pairs (n=64 pairs) with detectable levels of antibodies in

both mother and baby, cord geometric mean concentrations for 3 pertussis antigens were >100% of maternal delivery values (35), and mean ratios of infant to maternal antibodies for pertussis antigens were >1.0 (37). As evidenced by titers in cord blood among infants born after maternal Tdap booster, compared to their siblings who were born before maternal Tdap booster, there is efficient transplacental antibody transfer of pertussis antigens (36). However, in more recent years, 2 studies have found that moms and babies have low levels of pertussis-specific antibody (35, 37) – just 21% of mothers and 26% of infants had levels of pertussis antibodies that may potentially be protective at the time of birth.

In the absence of maternal Tdap vaccination, infant protection from maternal antibodies appears to be short-lived. IgG antibody levels for each pertussis antigen decay to below the level of detection by the time the infant is 2 to 4 months old (35, 38); by 6 weeks of age, only 11% of infants had levels of antibodies that might be protective. Thus, the remaining 89% without any detectable antibodies are likely susceptible, most likely because the level of maternal antibodies was too low preventing effective transfer of antibodies to the fetus (37). The half-life of transferred maternal pertussis antibodies is estimated at approximately 6 weeks (38). This rapid decay in maternally-derived infant antibodies leaves infants with little protection beyond the first weeks of life if the initial levels at birth start out low.

Correlation between maternal Tdap vaccination and infant antibodies.

The strategy of boosting maternal pertussis antibody levels to protect infants from pertussis was first investigated by researchers in the 1930s and 1940s. Several studies independently found an association between active immunization of pregnant women

with whole-cell pertussis vaccine and infant titers, with the titers of infants of immunized mothers higher than the titers of infants of unimmunized mothers (2, 111, 112). Several recent studies have also found significant correlation between maternal acellular pertussis (Tdap) vaccination and newborn serum antibody levels. Cord blood from newborn infants whose mothers received Tdap during pregnancy or before pregnancy had up to 11 times higher concentrations of pertussis antibodies compared to cord blood from newborn infants of unvaccinated mothers (113), and this difference persisted at age 1 month (36). Because boosted antibody levels peak several weeks after a Tdap immunization, then decline over several months (48, 49), timing of Tdap vaccination is important in transfer of antibodies to infants. Maternal Tdap vaccination later in pregnancy results in adequate levels of antibody in the infant to protect against pertussis through 2-3 months of age, but because of the short half-life of maternally acquired pertussis antibodies, pre- or early pregnancy maternal vaccination may not result in sufficient pertussis-specific antibodies to protect against infant infection (38, 114).

Maternal Tdap vaccination is also correlated with measurable amounts of pertussis antibodies being transferred to the infant by way of breast milk, although for shorter durations. After Tdap vaccination among women of childbearing age and postpartum women, levels of pertussis antigens in breast milk are first detectable at day 7, peak by day 10, then slowly decrease through day 28 (47).

Efficacy of maternal immunization against infant disease.

A study in 1946 that investigated the incidence of pertussis in infants born to mothers who had received whole-cell pertussis vaccine during pregnancy provided some of the first evidence that maternal vaccination may have an effect on infant disease (115).

This study found no cases after recognized pertussis exposures for 8 infants of vaccinated mothers, while 3 of 6 exposed infants born to unvaccinated mothers developed clinical pertussis. A case-control study in England and Wales in 2012-2013 estimated effectiveness of 91% (95% CI 77%-97%) for protecting infants aged <8 weeks from pertussis (42). Another observational study in England using 2008-2013 data estimated maternal pertussis vaccination as 91% effective against infant pertussis in those <3 months (95% CI 84%-95%) (43).

Current Recommendations on Tdap Vaccination of Pregnant Women

Advisory Committee on Immunization Practices (ACIP) recommendations.

The California Department of Public Health (CDPH) was the first state in the U.S. to recommend Tdap vaccine to pregnant women during the 2010 California outbreak (9). CDPH advised that no minimum interval was needed between tetanus-diphtheria and Tdap vaccines. CDPH also provided doses of Tdap free to hospitals, community health centers, and tribal clinics to immunize pregnant and postpartum women and other contacts of newborn infants (9).

In October 2011, ACIP made its first recommendation for one dose of Tdap during pregnancy to any woman who has never received Tdap. Tdap was recommended immediately after delivery if it was not received during pregnancy (107). In October 2012, ACIP voted to recommend that pregnant women be vaccinated with Tdap during *every* pregnancy, regardless of immunization history (51). The recommended optimal timing for Tdap administration is at 27-36 weeks gestation, to maximize maternal antibody response and antibody transfer to the fetus. Women who are not vaccinated with

Tdap during pregnancy and who have never been vaccinated with Tdap should receive it immediately postpartum. ACIP also recommends that adolescents and adults who have close contact with an infant aged <12 months should receive a single dose of Tdap if they have not received Tdap previously (51).

American Congress of Obstetricians and Gynecologists (ACOG) recommendations.

Following ACIP's recommendations in October 2012, in June 2013 ACOG published recommendations for Tdap use in pregnancy that essentially mirrored ACIP's recommendations: 1 dose of Tdap should be administered to all women during pregnancy, irrespective of the patient's Tdap history, with optimal timing of vaccination between 27 and 36 weeks gestation, and 1 dose of Tdap administered immediately after delivery if not received during pregnancy (116). Additionally, ACOG recommended sustained efforts at cocooning, with other family members and direct caregivers receiving Tdap at least 2 weeks before planned infant contact.

Interventions to improve Tdap vaccination of pregnant women.

Studies have evaluated different methods to improve Tdap vaccination of pregnant women. A standing order approach tested in a hospital setting in which all women had a standing order for Tdap vaccination before discharge improved postpartum Tdap vaccination from 0% to 69% (implemented in 2009, prior to the ACIP's recommendation for Tdap during pregnancy) (117). This strategy resulted in no significant disparities in postpartum vaccination by race/ethnicity, insurance, age, or parity. A randomized trial of a promotion package to improve antenatal influenza and

Tdap vaccination found that the intervention package did not significantly improve Tdap vaccine coverage (118).

The Elaboration Likelihood Model.

Tailored messaging based on the Elaboration Likelihood Model (ELM) framework has been successful in improving human papillomavirus (HPV) vaccine uptake (119) and breast cancer screening (120), and may be useful in improving uptake of pertussis vaccine among pregnant minority women. The ELM features 2 routes of persuasive influence – central and peripheral – by which individuals receive and process information, and which result in differences in persuasive impact. Information-based messages that are personally relevant evoke central processing, which results in stronger and less modifiable behavioral changes, whereas simplistic messages evoke peripheral processing, which results in behavioral changes that may be more subject to change and less enduring (121).

The 2 education interventions used in this study were based on the ELM, and provided information in a way that was tailored specifically to pregnant women. The ELM explains that when involvement and elaboration are high, such as when messages that are personally relevant and contain ample information and logical reasons, the central persuasive route is used, and tends to result in behavioral changes that are considered to be stronger and less likely to be modified or undergo revision (121, 122). Conversely, elaboration is low when messages rely on simplistic associations of negative and positive attributes to some object, action or situation, and may not seem as personally relevant to the viewer, resulting in processing by the peripheral route and behavioral changes that may be more subject to change (121).

The ELM suggests that for thorough elaboration via the high-involvement central route to occur, individuals must be involved and motivated to process the relevant information in order for behavior change to occur. Information that is presented in a high-elaboration, interactive way provides individuals with increased motivation and the ability to acquire and process the information as it is relevant to them, leading to critical evaluation and decision making. Conversely, when information is presented to an individual that is low interaction and not specifically targeted to that individual's needs and characteristics – like the CDC vaccine information statements used in the control group – he or she is more likely to process it via the peripheral route, leading to decisions that are based on short cut cues, and which may result in behavioral changes that are more short-term and modifiable (120-123).

Limitations to Current Knowledge

Tdap was first licensed by the FDA in 2005, and is still a relatively new vaccine. Thus, there is limited evidence on uptake of this vaccine in targeted populations that are recommended to receive it. The recommendations for Tdap vaccination of pregnant (2011, 2013) women occurred even more recently, and there is little evidence on uptake of the vaccine in this particular population subgroup.

Disparities by race/ethnicity and other characteristics have been demonstrated for many other vaccines, and often persist after adjustment for socioeconomic status and access to health care. Disparities in Tdap vaccination among pregnant and postpartum women have not been evaluated. Previous studies have evaluated heterogeneity in attitudes, knowledge, and sources of influence by race/ethnicity when adults are deciding

whether to get vaccinated (primarily influenza vaccine), but no studies have assessed this with regards to being vaccinated with Tdap during pregnancy.

Some interventions have been tested to improve coverage of Tdap vaccination among pregnant women, such as reminders in the electronic medical record for the physician to offer Tdap vaccine at a prenatal appointment. However, many of these have focused on increasing provider offers of vaccination, and have not focused on improving a woman's involvement in the decision to be vaccinated with Tdap during pregnancy. Given that many pregnant women decide not to get vaccinated because of fear (they fear that vaccines will cause them or the fetus harm) or because they do not have enough information, targeted interventions that educate patients about the facts and importance of vaccines need to be developed and tested.

CHAPTER 3: Disparities in Uptake of Tdap Vaccine and Vaccine Information Needs among Pregnant Women in the United States

Jennifer L. Kriss[1], Alison Albert[2], Victoria Carter[3], Angela J. Jiles[2], Jennifer L. Liang[2], Jennifer Mullen[3], Leslie Rodriguez[3], Penelope P. Howards[4], Walter A. Orenstein[5], Saad B. Omer[6], Allison Fisher[3]

[1] Emory University, Department of Epidemiology and Laney Graduate School, Atlanta, GA.
[2] Centers for Disease Control and Prevention, National Center for Immunization and Respiratory Diseases, Division of Bacterial Diseases, Atlanta, GA.
[3] Centers for Disease Control and Prevention, National Center for Immunization and Respiratory Diseases, Atlanta, GA.
[4] Emory University, Rollins School of Public Health, Department of Epidemiology, Atlanta, GA.
[5] Emory University, Emory Vaccine Center and School of Medicine, Atlanta, GA.
[6] Emory University, Rollins School of Public Health, Hubert Department of Global Health and Department of Epidemiology, Atlanta, GA.

Running Title: Disparities in Tdap Uptake among Pregnant Women

Keywords: Tdap, Vaccine, Pregnancy, Pertussis, Whooping cough

ABSTRACT

Objective: The Advisory Committee on Immunization Practices and the American Congress of Obstetricians and Gynecologists recommend that pregnant women receive Tdap vaccine during every pregnancy. However, Tdap vaccination of pregnant women remains low. The objectives of this paper are to evaluate disparities in uptake or intended uptake of Tdap vaccine among pregnant women in the U.S., and to assess whether race/ethnicity and other characteristics are associated with factors that inform pregnant women's decision about Tdap vaccination.

Study Design: We conducted a nationwide cross-sectional web-based survey of pregnant women in the U.S. during June–July 2014. The primary outcome was self-reported vaccination status with Tdap during pregnancy, categorized as vaccinated, unvaccinated with intent to be vaccinated during current pregnancy, and unvaccinated with no intent to be vaccinated during current pregnancy. Secondary outcomes included factors that influenced women's decision to get vaccinated or not and information needs on Tdap specifically for pregnant women. We used multivariable logistic regression models to estimate odds ratios for associations between race/ethnicity and the outcomes.

Results: Among all pregnant women who completed the survey, 40% (95% CI 36%-45%) reported that they had received Tdap vaccine during the current pregnancy. Hispanics had higher Tdap coverage than whites (52%, $p<.05$, compared with 38% among white non-Hispanics); black non-Hispanics did not have significantly different coverage (35%). In logistic regression models adjusting for maternal age, geographic region, education, and income, Hispanics were more than twice as likely to have been vaccinated with Tdap compared to white non-Hispanics (aOR=2.29, 95% CI 1.20-4.37).

Tdap vaccination was also independently associated with higher income and residing in the western U.S. Twenty-six percent of women had not been vaccinated with Tdap yet but intended to receive the vaccine during the current pregnancy; this did not differ by race/ethnicity. The most common factor that influenced women to get vaccinated was a provider recommendation, followed by knowledge that babies can die from whooping cough and recommendations by family or friends. The most common reasons for not getting vaccinated were safety concerns.

Conclusion: Tdap vaccination of pregnant women in the U.S. is increasing, but disparities exist by Hispanic ethnicity and household income. It is important that information about the maternal Tdap recommendation is available to pregnant women, who use this information to make vaccination decisions.

INTRODUCTION

The incidence of pertussis, pertussis-related complications, and mortality are highest among infants who are too young to be fully vaccinated (12, 13, 69, 70, 124-128). In the United States, infants receive their first dose of pertussis vaccine at 2 months of age, but do not achieve high levels of protection until their third dose at age 6 months (129). The tetanus toxoid, reduced diphtheria toxoid, and acellular pertussis (Tdap) vaccine was licensed in 2005 as a booster vaccine, and is recommended to women during pregnancy as a strategy to help prevent pertussis infection in young infants before they can develop active immunity against pertussis through receipt of their own pertussis vaccine series. In 2012, the U.S. Advisory Committee on Immunization Practices (ACIP) recommended that pregnant women receive Tdap vaccine during every pregnancy, regardless of their immunization history (51). Vaccination is optimally recommended at 27-36 weeks gestation to maximize antibody response and transfer of antibodies to the fetus. The following year, the American Congress of Obstetricians and Gynecologists (ACOG) also recommended Tdap vaccination for all pregnant women (52).

To date, uptake of Tdap vaccination in pregnant women remains low. At the time that these recommendations were made, Tdap coverage estimates among pregnant women were between 3% and 16% (2011-2012) (18, 54, 57, 130). Some state-specific estimates were higher, with between 16% and 30% vaccinated in California (57). More recent estimates indicate that coverage is increasing incrementally (23% of pregnant women received Tdap during the 2014–2015 influenza season) but still remains low (131).

Although coverage with Tdap vaccine as a booster dose for adults in general has increased in recent years (116, 132), improvements have varied by race/ethnicity, and disparities in Tdap coverage in the non-pregnant population remain. The objectives of this paper are to update prevalence estimates of self-reported Tdap uptake and intent among pregnant women, to evaluate disparities in self-reported uptake or intended uptake of Tdap vaccine among pregnant women in the U.S., and to assess whether race/ethnicity and other characteristics are associated with factors that inform pregnant women's decisions about Tdap vaccination.

METHODS

We conducted a nationwide cross-sectional web-based survey of pregnant women in the United States. The survey was conducted as part of efforts to inform development of communication materials to increase uptake of the Tdap recommendation among ob-gyns and pregnant women. Potential survey participants were recruited by a professional recruiting firm, which used its national database of individuals who have previously agreed to be a member of a survey panel. Emails inviting women to complete a web-based survey on whooping cough and the whooping cough vaccine were sent to 253,993 women ages 18-45, and included a weblink to the survey. A total of 2,522 individuals began the survey, and 487 of these met the screening criteria (currently pregnant, at least 18 years of age, and resided in the U.S.). All surveys were completed between June 27, 2014 and July 3, 2014 using NOVI electronic survey software. An incentive of $20 in gift cards was given to survey participants. Informed consent was obtained electronically at

the beginning of the survey. The study protocol was approved by the CDC Institutional Review Board.

The web-based survey was designed to be completed in approximately 10 minutes, and was conducted in English only. There was no additional follow-up with pregnant women after they completed the one-time survey. An incentive of $20 in gift cards was paid to the survey participants for participating in this study.

Information was collected on demographics and characteristics of the pregnant women. These included maternal age, education, household income, geographic region of the country, health insurance status, primigravida (whether the current pregnancy was the woman's first pregnancy), and estimated gestation at the time the survey was completed. The primary exposure for this analysis was race/ethnicity, categorized as white non-Hispanic, black non-Hispanic, and Hispanic. The survey also asked about pregnant women's knowledge of Tdap and pertussis in infants, reasons for getting vaccinated or refusing vaccination with Tdap, and sources of information used in decision making.

The primary outcome for this analysis was the pregnant woman's self-reported vaccination status with Tdap. This outcome was based on the question "Have you gotten the whooping cough vaccine (Tdap) during your current pregnancy?" We subsequently categorized response options as follows: 1) Received Tdap vaccine during current pregnancy; 2) Intent to receive Tdap vaccine during current pregnancy but has not done so yet; and 3) Has not received Tdap vaccine during current pregnancy and does not intend to receive vaccine during pregnancy. Secondary outcomes were factors that influenced women's decision to get vaccinated or not, whether women looked for

information on Tdap specifically for pregnant women, what type of information they looked for, and where they looked for this information.

We used chi-square tests to determine whether there were statistically significant differences in proportions. Logistic regression models were used to estimate odds ratios (ORs) for associations. Polytomous models were used to estimate associations for the primary outcome, which had 3 nominal categories. We used multivariable models to estimate adjusted ORs, with covariates chosen from variables that were on a causal path with the outcome based on directed acyclic graphs (DAGs) or associated with the outcome in bivariate analysis at $p<0.20$. We conducted secondary analyses using inverse probability weights to weight our sample of pregnant women to the distribution of all pregnancies among white, black, and Hispanic women in the U.S. in 2013 based on maternal age and race/ethnicity (133). SAS version 9.4 was used for all analyses (SAS Institute, Inc., Cary, NC).

RESULTS

There were a total of 486 women who were currently pregnant who completed the survey. Fourteen were excluded from this analysis because they did not report their race or ethnicity, and 4 were excluded because they did not report their age. Among the respondents, the majority were white non-Hispanic (64%), 11% were black non-Hispanic, 19% were Hispanic, and 6% categorized themselves as 'Other' (Table 3.1). The category 'Other' included only 27 women so were excluded from analyses presented in this paper. Respondents were distributed relatively equally by geographic area, with a slightly higher proportion (33%) in the south, and a slightly lower proportion (19%) in

the Midwest. The majority of respondents were between the ages of 30 and 39 (57%). Slightly more than half had a 4-year college degree or more (59%), 75% reported a household income of at least $50,000 per year, and just 3% were uninsured. For 43% of respondents, the current pregnancy was their first time being pregnant. Most were in their second trimester (42%) or third trimester (41%), but 17% were in their first trimester.

Among all pregnant women who completed the survey, 40% (95% CI 36%-45%) reported that they had received Tdap vaccine during the current pregnancy (Figure 3.1). Coverage increased from first to second to third trimester of pregnancy, with 30% of women in the first trimester reporting Tdap vaccination during the current pregnancy, 39% in the second trimester, and 51% in the third trimester ($p<.05$ compared to first trimester). White non-Hispanics had 38% coverage, and black non-Hispanics had 36% coverage. However, Hispanics had significantly higher coverage than whites (53%, $p<.05$). Coverage was lowest in the South (32%) and highest in the West (51%). Women in their first pregnancy were slightly more likely to have been vaccinated with Tdap (45%) compared to those in a second or higher pregnancy (37%), but not significantly so.

In polytomous logistic regression models we adjusted for maternal age, geographic region, education, and household income. Black non-Hispanics did not vary from white non-Hispanics in either Tdap vaccination or intent to be vaccinated during the current pregnancy. Hispanics were more than twice as likely to have been vaccinated with Tdap compared to white non-Hispanics (aOR=2.29, 95% CI 1.20-4.37) (Table 3.2).

Compared to women in the Northeast, those in the West were more likely to have been vaccinated with Tdap (aOR=2.08, 95% CI 1.03-4.20). Women in the highest household income category ($75,000 or more per year) were 3 times as likely to have

received Tdap during the current pregnancy compared to those with low incomes (aOR=2.99, 95% CI 1.04-8.59). Those in middle income categories ($25,000-$49,999 and $50,000-$74,999) did not have different Tdap coverage compared to low income. Women who were 40 and older were less likely to have Tdap (aOR=0.68, 95% CI 0.24-1.97). In adjusted models, there were no differences in Tdap vaccination by education, health insurance status, or primigravida. We also assessed associations with intent to receive Tdap vaccine during the current pregnancy, for women who had not yet been vaccinated at the time of the survey. Women in the $50,000-$74,999 and the $75,000 or more income categories were both about 4 times more likely to plan to get a Tdap vaccine compared to the lowest income category (aOR=3.86, 95% CI 1.14-12.99 and aOR=4.00, 95% CI 1.18-13.53, respectively). Hispanic women and those in the Western U.S. also had elevated likelihood of Tdap intent.

In secondary analyses, we weighted our sample using inverse probability weights based on the age and race/ethnicity distribution of all pregnancies in the U.S. in 2013. We did not find significant differences in the results in weighted analysis: Tdap coverage among women during pregnancy was 43% (compared with 40% in unweighted analysis), and 25% planned to get vaccinated (compared with 26% in unweighted analysis). Results of multivariable models did not change meaningfully in the weighted analysis. However, in weighted analysis primigravida women were almost twice as likely to be vaccinated with Tdap compared to women who were non-primigravida (aOR=1.92, 95% CI 1.13-3.28), and were also more likely to plan to get a vaccination before the end of their pregnancy (aOR=1.80, 95% CI 1.03-3.16).

Among pregnant women who have received Tdap vaccine or who intend to receive it during the current pregnancy, the most common factor that influenced their decision to get vaccinated was a recommendation by their doctor, nurse, or midwife (62%) (Table 3.3). This was followed by knowledge that babies can die from whooping cough (48%) and recommendations by family or friends (42%). In unadjusted models, Hispanic women were more likely to report that their decision to get vaccinated was influenced by seeing or hearing a commercial that recommended Tdap (OR=1.93, 95% CI 1.11-3.37) or seeing a website that recommended Tdap (OR=1.76, 95% CI 1.01-3.08), compared to white non-Hispanics. However, these differences were not significant in adjusted models. Black non-Hispanics were more likely to say they read in a magazine that Tdap is recommended (aOR=2.96, 95% CI 1.16-7.57).

There were 31 pregnant women (6%) who said they had not received the Tdap vaccine and did not plan to get it during pregnancy. The remainder (n=135, 28%) were not sure if they would get it during their current pregnancy. Among those who definitely did not plan to get it, the most common reasons were that they don't think it is safe for themselves (48%) or for their babies (45%) to get the vaccine during pregnancy. Thirty-five percent said they did not plan to get vaccinated because their doctor, nurse, or midwife didn't tell them about the vaccine.

The majority of respondents (61%) said they had looked for information on Tdap vaccine specifically for pregnant women, and Hispanic women were more likely to have done so compared to white non-Hispanics (aOR=2.67, 95% CI 1.44-4.93) (Table 3.4). Among the women who looked for information on Tdap, the most common information they looked for was information about the vaccine's safety (71%), potential side effects

(64%), whooping cough disease (63%), the vaccine's effectiveness (63%), when to get Tdap (56%), and who else should get Tdap (51%). There were no differences in type of information looked for by race/ethnicity except that Hispanic women were about half as likely to look for information about who else should get Tdap (aOR=0.51, 95% CI 0.27-0.96, compared to white non-Hispanics). The most common places that women looked for information were the internet (76%) and health care professionals (64%). Friends and family were also common sources for information (45% and 40%, respectively). There were no differences in source of information by race/ethnicity except that Hispanic women were more than twice as likely to look to their insurance company for information about Tdap (aOR=2.13, 95% CI 1.07-4.25, compared to white non-Hispanics).

DISCUSSION

Most estimates of Tdap uptake and coverage among pregnant women are from shortly after ACIP first made the recommendation for pregnant women to be vaccinated with Tdap in 2011; more recent estimates have indicated that Tdap uptake is low but improving both in the general population and among pregnant women. Thus far, few studies have assessed how racial/ethnic disparities and other sources of disparity have contributed to low coverage among pregnant women. We found that non-Hispanic blacks and whites did not vary in either self-reported Tdap vaccination or intent to be vaccinated during the current pregnancy, but Hispanics were more than twice as likely to have been vaccinated with Tdap compared to white non-Hispanics. Some other studies have found lower pregnancy Tdap coverage among black women than white women (134), and similar patterns for postpartum Tdap coverage (135).

Other demographics that were associated with improved Tdap uptake were residence in the Western U.S. and higher household income; intent to receive Tdap during the current pregnancy was also associated with higher incomes. Our finding of higher coverage among Hispanics contrasts with data from the National Health Interview Survey (NHIS), which found that Hispanic ethnicity was associated with lower likelihood of Tdap vaccination (63). Other studies using the NHIS have found some other demographics that were associated with improved Tdap coverage that we did not find, including younger age and higher level of education (136). However, the NHIS findings may not be directly comparable to our study, since the study population was not limited to pregnant women only but was all adults in the U.S.

We also found that women were most likely to get vaccinated because of a recommendation by their doctor, nurse, or midwife, which did not differ by race/ethnicity. Other researchers have found that physician recommendation of vaccination is an important factor in individuals deciding to get vaccinated (137). Evidence from Medicare beneficiaries shows that among individuals who have negative attitudes towards vaccination, a provider recommendation can improve influenza vaccination rates by 2 to 3 times compared to those without a provider recommendation; and provider recommendations are especially important for African Americans (138). Conversely, survey respondents reported that not being told about the Tdap vaccine by a doctor, nurse, or midwife was an important factor in not getting vaccinated.

The results of this study should be considered in light of its limitations. First, respondents to this survey may not be representative of all pregnant women in the U.S. The women who were invited to participate in this study had already agreed to be

members of a survey group, and they are probably different from the U.S. population as a whole with respect to some important characteristics. We tried to address this by conducting secondary analyses in which we weighted our sample using inverse probability weights based on the age and race/ethnicity distribution of all births in the U.S. in 2013. We did not find significant differences in the weighted analysis compared with the unweighted analysis. However, our results might be subject to selection bias even after adjustment with inverse probability weights because there may be unmeasured factors which we do not adjust for. Second, the Hispanic respondents to our survey had a higher socioeconomic status (SES) than Hispanics in the U.S. generally (139). We conducted our survey only in English, which may have contributed to this higher Hispanic SES by selecting for English speakers. It is likely that non-English-speaking Hispanics have lower SES, and also have more barriers to prenatal care and Tdap vaccination. Additionally, 24% of the Hispanic respondents resided in California, which has had several large pertussis outbreaks in recent years. This is compared to 15% of the total survey sample residing in California. Because Hispanic respondents were more likely to live in California, this may have resulted in increased Tdap vaccination among Hispanics. Additionally, this survey was conducted via internet, so women had to have access to a computer or mobile device with high speed Internet access that would allow them to complete the web survey. This may have contributed to limitations on external validity; women with lower incomes, education, or who live in remote areas are probably under-represented in this study sample. Therefore, findings from this study of pregnant women may not be generalizable to all U.S. pregnant women.

Third, our primary outcome of Tdap vaccination during pregnancy was self-reported by respondents, and was not verified by medical record review. There is a potential for misclassification of this outcome variable because of the self-report. Fourth, pregnant women were not followed throughout their pregnancies as a part of this study; there was no further contact after the one-time completion of the survey during pregnancy. Therefore, we were not able to assess if the women who reported that they intended to be vaccinated with Tdap actually were vaccinated during this pregnancy, and if women who said they did not intend to be vaccinated with Tdap actually did not get vaccinated. It is probable that there is imperfect correlation between intention to be vaccinated in the future and actual vaccination, particularly among women who are surveyed early in pregnancy. Although not in a pregnant population, previous research on the association between intent to receive a vaccine and actually receiving one (based on influenza vaccination) found sensitivity of 85% and specificity of 83% (140).

Finally, because of the inclusion criteria for the study, any woman who was currently pregnant was eligible to complete the survey, regardless of their current gestation. Thus, women were surveyed at a range of gestational ages, and many of them had not yet reached the time in pregnancy when Tdap is recommended (the third trimester). We attempted to address this by the way we defined our Tdap uptake outcome measure, with 2 outcome categories: 1) Have been vaccinated with Tdap during current pregnancy, and 2) Intend to be vaccinated with Tdap during current pregnancy but have not been vaccinated yet. The category of intent to be vaccinated with Tdap during the current pregnancy takes into account the fact that women may intend to receive Tdap, but have not yet at the time of the survey been vaccinated because they are earlier in their

pregnancy. We observed a surprisingly high proportion of women in the first trimester reporting that they had been vaccinated with Tdap (31%). Since vaccination is recommended in the third trimester, this high vaccination rate so early in pregnancy was unexpected, and this finding needs further study. Women may be receiving vaccine at the wrong time during pregnancy, or they may be inaccurately reporting their Tdap vaccination status.

We identified characteristics of pregnant women that are associated with receipt of Tdap vaccine during pregnancy. Although we hypothesized that there would be disparities in vaccination by race/ethnicity, we found differences only for Hispanics (higher Tdap coverage) and not for black non-Hispanics when we controlled for other socioeconomic variables. Disparities in Tdap were more related to sociodemographic characteristics including household income and geographic region. We found that physician recommendation is one of the most important factors in improved Tdap coverage, and accordingly women's physicians, including ob-gyns, should be used as a method to improve coverage with Tdap vaccine during pregnancy.

Figure 3.1. Receipt of Tdap vaccine during the current pregnancy (percent)

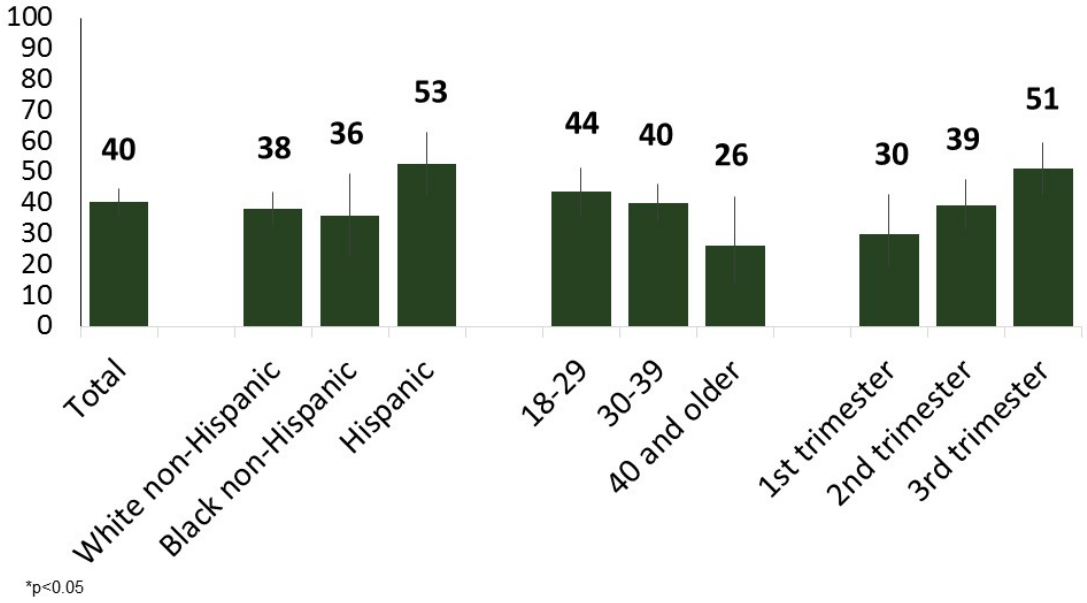


Table 3.1. Demographic characteristics of pregnant women, by race/ethnicity

		White[a] (n=300)	Black (n=53)		Hispanic (n=89)	
	n (%)	%	%	p-value	%	p-value
Total	442	68%	12%		20%	
Region[a]						
Northeast	110 (24)	26%	18%	0.09	22%	0.06
South	149 (33)	32%	49%		26%	
Midwest	84 (19)	20%	20%		15%	
West	107 (24)	22%	14%		37%	
Age group						
18-29	165 (35)	32%	34%	<0.01	44%	0.09
30-39	265 (57)	61%	45%		53%	
40 and older	38 (8)	7%	21%		3%	
College degree						
No	192 (41)	37%	64%	<0.01	43%	0.53
Yes	276 (59)	63%	36%		57%	
Household income						
<$25,000	31 (7)	6%	20%	<0.01	2%	0.21
$25,000-$49,999	83 (19)	16%	41%		14%	
$50,000-$74,999	115 (26)	25%	16%		36%	
$75,000+	218 (49)	53%	24%		48%	
Health insurance						
Uninsured	14 (3)	3%	2%	0.70	3%	0.87
Insured	444 (97)	97%	98%		97%	
Primigravida						
Yes	197 (43)	42%	29%	0.07	54%	
No	262 (57)	58%	71%		46%	
Gestation[b]						
1st trimester	57 (17)	16%	37%	<0.01	11%	0.31
2nd trimester	140 (42)	42%	26%		53%	
3rd trimester	135 (41)	42%	37%		37%	

Information missing for the following variables (n): region (16), household income (19), health insurance status (10), primigravida (8), gestation (128).

[a] 26 reported 'Other' race and were excluded from these analyses.

[b] 136 women did not report their due date, so trimester was unknown.

Table 3.2. Estimated associations between demographic characteristics and uptake of pertussis vaccine during current pregnancy

	Crude OR (95% CI)	p-value	Adjusted OR[b] (95% CI)	p-value
Received Tdap vaccine during current pregnancy				
Race/ethnicity				
White non-Hispanic	Ref		Ref	
Black non-Hispanic	0.79 (0.40-1.54)	0.49	1.54 (0.69-3.41)	0.29
Hispanic	2.04 (1.14-3.64)	0.02	2.29 (1.20-4.37)	0.01
Region[d]				
Northeast	Ref		Ref	
Midwest	0.81 (0.42-1.55)	0.52	0.97 (0.47-2.01)	0.94
South	0.73 (0.41-1.31)	0.29	1.03 (0.54-1.97)	0.93
West	1.88 (0.99-3.54)	0.05	2.08 (1.03-4.20)	0.04
Age group				
18-29	Ref		Ref	
30-39	0.79 (0.50-1.25)	0.32	0.78 (0.46-1.31)	0.35
40 and older	0.46 (0.19-1.11)	0.09	0.68 (0.24-1.97)	0.48
College degree				
No	Ref		Ref	
Yes	1.66 (1.08-2.57)	0.02	0.93 (0.51-1.70)	0.82
Household income				
<$25,000	Ref		Ref	
$25,000-$49,999	0.82 (0.31-2.15)	0.68	0.55 (0.19-1.60)	0.27
$50,000-$74,999	2.66 (1.05-6.71)	0.04	2.23 (0.77-6.47)	0.14
$75,000+	3.41 (1.43-8.15)	0.01	2.99 (1.04-8.59)	0.04
Health insurance				
Uninsured	Ref		Ref	
Insured	3.58 (0.71-17.97)	0.18	4.82 (0.49-47.19)	0.18
Primigravida				
No	Ref		Ref	
Yes	1.52 (0.98-2.35)	0.06	1.57 (0.93-2.66)	0.09
Intends to receive Tdap vaccine[a]				
Race/ethnicity				
White non-Hispanic	Ref		Ref	
Black non-Hispanic	0.69 (0.32-1.48)	0.34	0.99 (0.42-2.29)	0.97
Hispanic	1.27 (0.65-2.48)	0.49	1.14 (0.54-2.40)	0.73
Region[d]				
Northeast	Ref		Ref	
Midwest	0.92 (0.44-1.92)	0.82	1.16 (0.53-2.54)	0.72
South	1.07 (0.57-2.01)	0.83	1.40 (0.70-2.80)	0.35
West	1.45 (0.70-3.01)	0.33	1.70 (0.77-3.76)	0.19
Age group				

18-29	Ref		Ref	
30-39	0.83 (0.49-1.38)	0.47	0.75 (0.43-1.31)	0.31
40 and older	1.01 (0.43-2.35)	0.99	1.27 (0.47-3.39)	0.64
College degree				
No	Ref		Ref	
Yes	1.05 (0.65-1.68)	0.85	0.62 (0.33-1.16)	0.13
Household income				
<$25,000	Ref		Ref	
$25,000-$49,999	1.55 (0.50-4.78)	0.45	1.19 (0.36-3.90)	0.78
$50,000-$74,999	4.04 (1.34-12.16)	0.01	3.86 (1.14-12.99)	0.03
$75,000+	3.46 (1.20-10.01)	0.02	4.00 (1.18-13.53)	0.03
Health insurance				
Uninsured	Ref		Ref	
Insured	0.75 (0.24-2.38)	0.62	0.46 (0.13-1.70)	0.24
Primigravida				
No	Ref		Ref	
Yes	1.21 (0.74-1.96)	0.45	1.48 (0.84-2.60)	0.17

[a] But has not been vaccinated with Tdap yet in current pregnancy.
[b] Adjusted for race/ethnicity, geographic region, maternal age, education, and household income.

Table 3.3. Associations between race/ethnicity and factors that influenced pregnant women's decision on Tdap vaccination (Ref=White non-Hispanic)

		Black (n=31)		Hispanic (n=70)	
	Overall n (%)	Adjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Women who received Tdap vaccine or intend to receive it during current pregnancy: Factors that influenced their decision to get vaccinated (n=311)					
Provider recommendation	194 (62)	1.0 (0.4-2.6)	0.93	0.8 (0.4-1.4)	0.36
Heard babies can die from pertussis	150 (48)	1.6 (0.7-3.9)	0.29	0.6 (0.3-1.2)	0.16
Family or friends recommendation	131 (42)	0.8 (0.3-2.0)	0.58	1.4 (0.7-2.5)	0.35
Prenatal class/hospital tour recommendation	117 (38)	1.3 (0.5-3.5)	0.57	1.5 (0.8-2.9)	0.22
News report recommendation	115 (37)	0.8 (0.3-2.2)	0.70	1.3 (0.7-2.4)	0.40
Cases of pertussis in my state	113 (36)	1.2 (0.5-3.0)	0.73	1.1 (0.6-2.1)	0.79
Commercial recommendation	112 (36)	1.8 (0.7-4.5)	0.21	1.7 (0.9-3.2)	0.09
Website recommendation	110 (35)	2.4 (0.9-6.3)	0.09	1.4 (0.8-2.7)	0.29
Book recommendation	105 (34)	1.5 (0.6-3.6)	0.41	1.3 (0.7-2.4)	0.44
Magazine recommendation	103 (33)	3.0 (1.2-7.6)	0.02	0.7 (0.4-1.4)	0.35
App recommendation	50 (16)	1.3 (0.4-4.7)	0.69	1.6 (0.7-3.4)	0.24
Women who did not receive Tdap vaccine and do not plan to receive it during current pregnancy: Factors that influenced their decision not to get vaccinated (n=31)					
Unsafe for mother	15 (48)				
Unsafe for baby	14 (45)				
No provider recommendation	11 (35)				
Don’t know about the vaccine	9 (29)				

Table 3.4. Associations between race/ethnicity and information seeking about Tdap vaccine for pregnant women

		Black (n=54)		Hispanic (n=91)	
	Overall n (%)	Adjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Looked for information on Tdap for pregnant women	286 (61)	1.3 (0.7-2.7)	0.41	2.7 (1.4-4.9)	<0.01
Among women who looked for information, what information did they look for:					
Vaccine's safety	203 (71)	0.4 (0.2-1.1)	0.07	0.7 (0.3-1.3)	0.24
Potential side effects	183 (64)	0.7 (0.3-1.8)	0.48	1.0 (0.5-1.9)	0.96
Whooping cough disease (such as symptoms or complications)	181 (63)	1.1 (0.5-2.8)	0.82	1.0 (0.6-1.9)	0.91
Effectiveness	180 (63)	0.6 (0.3-1.5)	0.28	0.7 (0.4-1.3)	0.22
When to get this vaccine	161 (56)	1.1 (0.4-2.6)	0.90	0.9 (0.5-1.6)	0.67
Who else should get this vaccine	147 (51)	1.2 (0.5-2.9)	0.74	0.5 (0.3-0.9)	0.04
Vaccine's ingredients	137 (48)	0.8 (0.3-1.9)	0.55	1.2 (0.6-2.2)	0.61
Insurance coverage for this vaccine	126 (44)	1.1 (0.4-3.0)	0.80	1.0 (0.5-1.9)	0.92
Where to get this vaccine	120 (42)	0.7 (0.3-1.9)	0.51	0.9 (0.5-1.8)	0.83
Cost of this vaccine	117 (41)	0.5 (0.2-1.4)	0.17	1.2 (0.6-2.2)	0.60
Where did they look for this information?					
Internet or social media	216 (76)	1.8 (0.6-6.0)	0.33	0.6 (0.3-1.2)	0.12
Healthcare professional (doctor, nurse, or midwife)	183 (64)	0.8 (0.3-1.9)	0.54	1.0 (0.5-1.9)	0.96
Friends	128 (45)	0.9 (0.3-2.4)	0.77	0.8 (0.4-1.6)	0.54
Family	115 (40)	1.2 (0.5-3.1)	0.72	1.7 (0.9-3.2)	0.10
Pharmacy or pharmacist	98 (34)	1.1 (0.4-2.9)	0.84	1.1 (0.6-2.2)	0.69
Books	97 (34)	1.6 (0.6-4.2)	0.33	0.6 (0.3-1.3)	0.19
Insurance company	96 (34)	0.5 (0.1-1.6)	0.22	2.1 (1.1-4.3)	0.03
Magazines	89 (31)	2.3 (0.9-6.1)	0.09	0.7 (0.3-1.4)	0.27
Television	83 (29)	1.9 (0.6-5.9)	0.28	1.5 (0.8-2.9)	0.25
Newspapers	63 (22)	0.3 (0.1-1.4)	0.12	0.5 (0.2-1.0)	0.06
Apps	53 (19)	1.4 (0.4-4.5)	0.58	1.2 (0.6-2.5)	0.65
Radio	40 (14)	2.2 (0.6-8.6)	0.26	1.6 (0.7-3.6)	0.29

CHAPTER 4: Characteristics Associated with Obstetrician-Gynecologist Recommendation and Administration of Pertussis Vaccine for Pregnant Patients in the United States: Findings from a National Survey

Jennifer L. Kriss[1], Alison Albert[2], Victoria Carter[2], Angela J. Jiles[2], Jennifer L. Liang[2], Jennifer Mullen[2], Leslie Rodriguez[2], Saad B. Omer[3], Walter A. Orenstein[4], Penelope P. Howards[5], Allison Fisher[6]

[1] Emory University, Rollins School of Public Health, Department of Epidemiology, and Laney Graduate School, Atlanta, GA.
[2] Centers for Disease Control and Prevention, National Center for Immunization and Respiratory Diseases, Division of Bacterial Diseases, Atlanta, GA.
[3] Emory University, Rollins School of Public Health, Hubert Department of Global Health and Department of Epidemiology, Atlanta, GA.
[4] Emory University, Emory Vaccine Center and School of Medicine, Atlanta, GA.
[5] Emory University, Rollins School of Public Health, Department of Epidemiology, Atlanta, GA.
[6] Centers for Disease Control and Prevention, National Center for Immunization and Respiratory Diseases, Atlanta, GA.

Running Title: Ob-Gyns and Pertussis Vaccine for Pregnant Women

Keywords: Ob-Gyn, Tdap, Vaccine, Pregnancy, Pertussis, Whooping cough

ABSTRACT

Objective: In the United States, current guidelines recommend that pregnant women be vaccinated with Tdap during each pregnancy, but vaccination remains low. The objectives of this paper are to estimate the prevalence of Tdap administration and recommendation to pregnant women by obstetrician-gynecologists (ob-gyns) and to evaluate individual and practice characteristics as determinants of administration of Tdap to pregnant women.

Methods: We conducted a nationwide cross-sectional web-based survey of licensed members of ACOG in the United States. All current members of ACOG who provide prenatal care as part of their routine practice and who practice primarily in the United States were eligible for the study. Our primary outcome was physician administration of Tdap to pregnant patients. Secondary outcomes included recommendation of Tdap, correct recommendation based on current guidelines, and reasons for not stocking Tdap vaccine. We used multivariable logistic regression models to estimate odds ratios for associations between physician characteristics and the outcomes.

Results: Among 2,230 physicians who completed the web-based survey, 78% administer Tdap to pregnant patients as part of routine practice, and another 20% recommend Tdap but refer their patients elsewhere for vaccination. Administration of Tdap was associated with larger practice size (≥10 practitioners aOR=2.44, 95% CI 1.21-4.90, compared to one practitioner), being part of a larger health system (aOR=2.19, 95% CI 1.68-2.85), administration of influenza vaccine (aOR=23.94, 95% CI 16.86-33.99), and residence in the West and Midwest (aOR=1.55, 95% CI 1.08-2.22 and aOR=1.46, 95% CI 1.03-2.09, respectively, compared to Northeast). Ob-gyn knowledge of Tdap recommendations and

recent pertussis cases in their state were also associated with increased Tdap administration. Twenty-two percent of ob-gyns reported that their offices do not stock Tdap vaccine at all, and the most common barriers to stocking vaccine are financial and the relative ease of referring patients elsewhere for vaccination.

Conclusion: The majority of ob-gyns administer Tdap to their pregnant patients as a part of routine practice, in accordance with current guidelines that all women should be vaccinated with Tdap during each pregnancy. Administration of Tdap is associated with several characteristics including practice size, influenza vaccine administration, and region.

INTRODUCTION

Infants who are too young to be fully vaccinated against pertussis are particularly vulnerable to pertussis-related morbidity and mortality. In the United States, infants receive their first dose of pertussis vaccine at 2 months, but do not achieve high levels of protection until their third dose at 6 months (141). The estimated incidence of pertussis among infants younger than 6 months of age is 169 cases per 100,000, compared to 44 per 100,000 for infants 6-11 months, and 10 per 100,000 for all ages (8). Pertussis-related hospitalizations, complications, and mortality are also highest among infants who are too young to be fully vaccinated (12, 13, 69, 70, 124-127). A booster pertussis vaccine – tetanus toxoid, reduced diphtheria toxoid, and acellular pertussis (Tdap) – was licensed in 2005, and vaccinating women during pregnancy is a strategy to help protect young infants from pertussis before they can begin getting their own pertussis vaccine.

The U.S. Centers for Disease Control and Prevention (CDC) recommended in 2005 that pregnant women be vaccinated with Tdap in the immediate postpartum period before discharge from the hospital (142). In 2012, CDC made a recommendation that pregnant women be vaccinated with Tdap during every pregnancy, regardless of their immunization history (51), optimally at 27-36 weeks gestation to maximize antibody response and transfer of antibodies to the fetus. In 2013, the American Congress of Obstetricians and Gynecologists (ACOG) published recommendations for Tdap vaccination of pregnant women based upon CDC 2012 recommendations (52). After the implementation of CDC and ACOG recommendations, uptake of Tdap vaccine among pregnant women remained low. Early estimates of Tdap coverage among pregnant women in the United States indicated that between 3% and 16% were vaccinated in 2011-

2012 (53, 54, 57, 130). Some state-specific estimates were higher, with between 16% and 30% vaccinated during 2010-2012 in California (57).

Physician recommendation of vaccination is an important factor in helping individuals to decide whether to get vaccinated or not (137, 143). Among individuals who have negative attitudes towards vaccination, a provider recommendation can improve vaccination rates by 2 to 3 times compared to those without a provider recommendation (138). Prior to the CDC recommendation for postpartum Tdap vaccination of mothers, a 2005 survey of obstetricians in the United States found that 78% agreed or strongly agreed that they would recommend Tdap for women immediately after delivery if recommended by CDC and/or ACOG (144). However, evidence from California in 2010 showed that healthcare providers were slow to implement policies to vaccinate postpartum women with Tdap – only 23% of birth hospitals had policies to offer Tdap to postpartum women, even though this was recommended in the state at the time (9). After implementation of the CDC recommendation for Tdap vaccination in the third trimester, a survey of obstetric providers in New York state found that among physicians, mid-level practitioners, and nurses, although 92% knew of the CDC recommendations, only 67% provided Tdap to pregnant women in their offices (145).

There have been no national level studies of obstetrician-gynecologist (ob-gyn) administration or recommendation of Tdap vaccine to pregnant women. The objectives of this paper are to estimate the prevalence of ob-gyn administration and recommendation of Tdap to pregnant women, to evaluate individual and practice characteristics as determinants of administration of Tdap vaccine to pregnant women, and to assess reasons for non-administration.

METHODS

We conducted a nationwide cross-sectional web-based survey of licensed members of ACOG in the United States. The survey was conducted as part of efforts to inform development of communication materials to increase uptake of the Tdap recommendation among ob-gyns and pregnant women. Invitations to complete the web-based survey were emailed to the more than 32,000 physician members of ACOG. ACOG sent an initial email invitation for physicians to take the web survey in February 2014. An email reminder was sent 2 weeks later. All practicing ob-gyns who were current members of ACOG were eligible to complete the survey if they specialized in obstetrics or gynecology, provided prenatal care as part of their routine practice, and practiced primarily in the United States. Informed consent was obtained electronically at the beginning of the survey. The study protocol was approved by the CDC Institutional Review Board.

The web-based survey was designed to be completed in approximately 10 minutes. NOVI Systems online survey software was used to collect the survey results. The survey was conducted in English only. There was no additional follow-up with physicians after they completed the one-time survey. No incentives were paid to the survey participants or ACOG for participating in this study.

The survey included questions about awareness of pertussis and the Tdap vaccine, perceived responsibilities toward recommending Tdap, barriers to and concerns about Tdap vaccination, provider and patient information needs, and physicians' current practices regarding recommending and administering Tdap vaccine to their patients

during pregnancy. The primary outcome for this analysis was whether the physician administers Tdap vaccine to pregnant patients. This outcome was based on the question: "Which of the following best describes your approach to recommending the Tdap vaccine for your pregnant patients?", with the following possible responses: "I recommend Tdap vaccine to my pregnant patients and vaccinate them in my office"; "I recommend Tdap vaccine to my pregnant patients but refer them elsewhere to receive the vaccine"; "I discuss Tdap vaccine with my pregnant patients but do not offer a recommendation for or against vaccination"; "I do not routinely discuss Tdap vaccine with my pregnant patients"; or "I recommend against Tdap vaccine for my pregnant patients". Secondary outcomes of interest were whether physicians recommended Tdap correctly based on current guidelines and reasons for not stocking Tdap vaccine. Physicians who reported that they recommend Tdap to their pregnant patients were asked when they typically recommend pregnant women be vaccinated with Tdap and how many doses of Tdap they recommend for pregnant patients. Physicians who reported that their offices did not stock Tdap vaccine were asked for the main reason they do not stock the vaccine.

Information was collected on demographics and characteristics of the physician and his/her medical practice. These included age and sex of the physician, geographic region of the country, urban/suburban/rural, size and type of practice (e.g., solo, small group, large group, hospital), percent of patients that are Spanish-speaking, percent of patients with Medicaid insurance, and administration of other vaccines (influenza, human papillomavirus (HPV)) to patients as part of routine practice.

Chi-square tests were used to determine whether there were statistically significant differences in proportions. Logistic regression models were used to estimate

odds ratios (ORs) for associations between characteristics and the outcomes. We first estimated unadjusted ORs using bivariate models for each of the characteristics of interest. We then used multivariable models to estimate adjusted ORs, with covariates chosen from variables that were on a causal path with the outcome based on directed acyclic graphs (DAGs) or associated with the outcome in bivariate analysis at $p<0.20$. For models of the outcome ob-gyn administration of Tdap vaccine, the referent group was ob-gyns who do not administer Tdap. For models of the outcome ob-gyns who recommend Tdap but refer patients elsewhere for vaccination, we wanted to be able to make comparisons to providers who administer Tdap vaccine; thus the reference group is ob-gyns who administer Tdap to pregnant patients. We conducted secondary analyses using inverse probability weights to weight our sample of ob-gyns to the distribution of all ACOG members based on age and sex. SAS version 9.4 was used for all analyses (SAS Institute, Inc., Cary, NC).

RESULTS

Of the 2,568 physicians who began the screening questions for the survey, 6 were excluded because they did not specialize in obstetrics and gynecology, and 197 were excluded because they did not provide prenatal care as part of their routine practice. A total of 2,365 physicians began the main part of the survey. Another 135 were excluded from this analysis because they did not complete the survey (n=42), did not answer the question upon which the primary outcomes were based (n=22), were missing all demographic information (n=70), or reported that they only practice medicine outside the United States (n=1). A total of 2,230 physicians were included in this analysis. The

geographic distribution of survey participants was compared to that of all ACOG members, and was found to be similar, but the physicians who responded to our survey were younger and more female, on average, compared with all ACOG members.

Among the respondents to the survey, the majority were female (72%) (Table 4.1). Almost half characterized the type of practice in which they worked as a private practice with 2-3 or 4 or more practitioners (9% and 38%), 8% were in private solo practice, 26% practiced in a hospital, and 19% worked in some other practice type, which included academic medical centers, community health clinics, and large multispecialty or hospital-owned practices. A large majority (86%) administered influenza vaccine to their patients as part of routine practice. Ob-gyns were distributed relatively equally by geographic area, with a slightly higher proportion (31%) in the south. Most practiced in urban (44%) or suburban (43%) areas. Most ob-gyns had at least some patients who were insured through Medicaid, with 60% having 1-50% Medicaid patients. Three-quarters of ob-gyns reported that 1-25% of their patients spoke Spanish as their primary language.

Among all ob-gyns, 78% reported that they administer Tdap to their pregnant patients. In secondary analyses, we weighted our sample using inverse probability weights based on the age and sex distribution of all ACOG members, and did not find significant differences in the results. In weighted analysis, 76% of ob-gyns overall administered Tdap to pregnant patients, only slightly lower than the proportion found in unweighted results. Results of multivariable models did not change in the weighted analysis. The proportion who reported administering Tdap was higher among younger physicians (83% among those younger than 40), providers who practice in a hospital (89%) or practice type identified as “other” (87%), larger practices (90% in practices with

10 or more practitioners), part of a larger health system (87%), and providers who administer influenza vaccine (87%). Those who were least likely to report administering Tdap to their pregnant patients were ob-gyns in private solo practices or in small private group practices (2-3 practitioners) (42% and 52%, respectively), and those who do not administer influenza vaccine (21%). One in 5 ob-gyns (20%) recommended Tdap vaccine to their pregnant patients, but refer them elsewhere for vaccination (Table 4.1). Ob-gyns in older age groups, in smaller practices, who do not administer influenza vaccine, and with smaller proportions of Medicaid and Spanish-speaking patients were more likely to refer patients somewhere else to be vaccinated.

In logistic regression models we adjusted for ob-gyn age, practice type, practice size, larger health system, region, and urban/suburban/rural setting. Ob-gyns in private group practices with 4 or more practitioners were more than twice as likely to administer Tdap vaccine compared to private solo practices (aOR=2.90, 95% CI 1.66-5.07) (Table 4.2). Ob-gyns in hospitals and other practice types were 3.68 and 3.99 times more likely, respectively, to administer Tdap compared to those in solo practices. Ob-gyns who were part of a larger health system were also twice as likely as those who were not part of a larger health system to administer Tdap (aOR=2.19, 95% CI 1.68-2.85). Administration of influenza vaccine was associated with administration of Tdap vaccine (aOR=23.94, 95% CI 16.86-33.99). Physicians in the West and Midwest were about 1.5 times more likely to administer Tdap compared to physicians in the Northeast (aOR=1.55, 95% CI 1.08-2.22 and aOR=1.46, 95% CI 1.03-2.09, respectively), but no other geographic areas were different from the northeast. In unadjusted models, physicians who worked in practices with larger proportions of Medicaid patients were more likely to administer

Tdap; however, in models adjusting for covariates, larger proportions of Medicaid patients were associated with reduced Tdap vaccination. There were no differences by urban/suburban/rural setting or proportion of Spanish-speaking patients.

Ob-gyns who worked in larger practices, hospitals, or larger health systems were less likely to refer their patients elsewhere to receive Tdap (compared to administering it themselves) (Table 4.2). Ob-gyns who administer influenza vaccine were less likely to refer their patients elsewhere to receive Tdap (aOR=0.04, 95% CI 0.03-0.06), and those with larger proportions of Medicaid patients were more likely to refer their patients elsewhere to receive Tdap (51-75% Medicaid patients aOR=1.71, 95% CI 1.08-2.71; >75% Medicaid patients aOR=1.89, 95% CI 1.08-3.33).

Physicians who reported that there had been cases of pertussis in the past 12 months in the state where they practice were almost twice as likely to administer Tdap to their pregnant patients, even in adjusted models (aOR=1.83, 95% CI 1.09-3.08) (Table 4.3). Knowledge of the CDC/ACOG recommendations was associated with Tdap administration (aOR=3.49, 95% CI 1.68-7.26). However, knowledge that household contacts are the most common source of pertussis infection for infants was not associated with Tdap administration. No measures of a physician's personal experience with pertussis – including had pertussis, knew someone who had pertussis, treated a patient with pertussis, or delivered a baby who was later diagnosed with pertussis – were associated with Tdap administration.

Twenty-two percent of ob-gyns reported that their offices do not stock Tdap vaccine at all, and gave a variety of reasons for not doing so (Figure 1). The most common reason was the expense to maintain a stock of Tdap (57%). Many said it was

easier to refer patients elsewhere for Tdap (33%), they do not stock any vaccines in the office (28%), and it is too time consuming to maintain a stock of Tdap (20%). Only 9% said there was not enough demand for Tdap vaccine.

The majority (81%) of ob-gyns recommended Tdap to their pregnant patients according to current CDC recommendations (i.e., recommend one dose of Tdap vaccine during each pregnancy, administered between 27 and 36 weeks of pregnancy) (Table 4.4). Among those who did not correctly recommend Tdap, 47% gave the wrong recommendation for dose and timing of Tdap, 21% recommended the incorrect dose only, and 3% recommended the incorrect timing only. Male ob-gyns had 29% reduced odds of correctly recommending Tdap to pregnant patients compared to female ob-gyns (aOR=0.71, 95% CI 0.55-0.93). Physicians age 50 and older were also less likely than those younger than 40 to correctly recommend Tdap (for age 50-59 aOR=0.61, 95% CI 0.45-0.83; for age 60+ aOR=0.53, 95% CI 0.36-0.78). Ob-gyns in private group practice with 4 or more practitioners were roughly twice as likely to correctly recommend Tdap compared to those in solo practice; the same pattern was seen for practices with 10 or more practitioners compared to practices with one practitioner, and those in practices that were part of a larger health system. Administration of influenza vaccine and West/Midwest region were also associated with correct recommendation of Tdap according to CDC guidelines. Ob-gyns with larger proportions of Medicaid or Spanish-speaking patients were less likely to correctly recommend Tdap – those with more than 50% Medicaid patients were only about one-third as likely to correctly recommend Tdap, and those with more than 50% Spanish-speaking patients were about half as likely.

DISCUSSION

To our knowledge, this is the first study to estimate prevalence and assess determinants of Tdap administration and recommendation by ob-gyns to pregnant patients. We found that a majority (78%) of ob-gyns do administer Tdap to their pregnant patients as a part of routine practice, in accordance with CDC and ACOG's guidelines that all women should be vaccinated with Tdap during each pregnancy. Another 20% recommend Tdap but refer their pregnant patients elsewhere for vaccination. This study is the first to examine whether ob-gyns nationally are recommending and administering Tdap vaccine since CDC/ACOG began recommending Tdap in every pregnancy. Prior to the 2012 CDC recommendation on Tdap vaccination in every pregnancy, a study by Clark et al. found that 78% of obstetricians in the United States agreed or strongly agreed that they would recommend Tdap for women immediately after delivery if it was recommended by CDC/ACOG (144), and 69% agreed or strongly agreed that they would recommend Tdap for women during pregnancy if recommended by CDC/ACOG. Even with commitment from physicians, implementing routine vaccination during pregnancy has been challenging, and these challenges are not limited to Tdap vaccine. Although influenza vaccine has been recommended during pregnancy for almost 50 years (39), only about half of pregnant women in the United States receive the influenza vaccine either before or during pregnancy, based on an internet panel survey and self-report of vaccination (143). A provider recommendation to be vaccinated is important in improving vaccine uptake. Ding et al. found that among pregnant women who received a clinician recommendation and were offered an influenza vaccine, 71% were vaccinated, compared to 10% of those whose clinician did not recommend or offer it (143).

In adjusted analysis, we found that administration of Tdap vaccine was associated with larger practice size and association with a larger health system, administration of influenza vaccine, and practicing in the West/Midwest. Concurrently, ob-gyns who work in smaller practices and those who do not administer influenza vaccine were more likely to refer their patients elsewhere to receive Tdap. A study of HPV vaccine previously found that physicians in larger practices are more likely to offer vaccine than those in solo practices (146), and practices with fewer numbers of providers have reported greater financial barriers to delivering adult vaccines (147). The strongest association we found was that between administration of influenza vaccine and Tdap (aOR = 23.97), which is similar to findings from a recent survey of obstetric providers in New York state (145). Physicians in West/Midwest states were more likely to administer Tdap, perhaps reflecting a greater level of awareness or perception of risk since some states in those regions have recently experienced epidemic levels of pertussis (8).

In unadjusted models, Tdap vaccination is associated with higher proportions of Medicaid patients, but in models adjusting for covariates, Tdap vaccination is associated with lower proportions of Medicaid patients. The covariates that we controlled for are more likely confounders of the association between proportion of Medicaid patients and Tdap vaccination than intermediates, so the adjusted models estimate the association when provider and facility characteristics are held constant.

Twenty-two percent of ob-gyns reported that their offices do not stock Tdap vaccine at all, and the reasons for this varied. The most common reasons were related to expense, issues with time spent stocking vaccines, and ease of referring patients elsewhere for vaccination. Previous studies of physicians have found similar barriers to

stocking vaccines (145, 147, 148). Open-ended responses to our survey emphasized difficulties with insurance reimbursement, high up-front costs, and problems with vaccine supply as barriers to stocking Tdap vaccine.

This study has a few limitations. First, we were not able to fully assess representativeness of the ob-gyns who completed the survey to all ob-gyns who are members of ACOG. We compared survey responders' geographic location (the state in which participants worked) to the distribution of all ACOG members' geographic locations, and found that the distribution across states closely matched the ACOG membership distribution. The respondents for this survey were also younger and more likely to be female compared to the overall ACOG membership. Second, the survey had a relatively low response rate, and it is possible that the small proportion of ACOG members who completed the survey were the physicians who were most interested in vaccination and Tdap, or those who have implemented a vaccination program in their office. If this is the case, our estimates of the prevalence of Tdap administration by ob-gyns would overestimate the true prevalence. In secondary analyses, we weighted our sample using inverse probability weights based on the age and sex distribution of all ACOG members, and did not find significant differences in the results. In weighted analysis, 76% of ob-gyns overall administered Tdap to pregnant patients, only slightly lower than the proportion found in unweighted results. Results of multivariable models did not change in the weighted analysis. Third, it is possible that there is reporting bias, if physicians who do not always administer Tdap reported that they vaccinate women because they know that ACOG recommends it. This would result in an overestimation of

Tdap vaccination, and if over-reporting is associated with physician characteristics, may result in biased estimates in multivariable models.

We identified characteristics of ob-gyns that are associated with not administering Tdap to pregnant patients, and found that the most common barriers to stocking Tdap vaccine are financial challenges and the relative ease of referring patients elsewhere for vaccination. Specific characteristics that could be targeted for improvement in administration of Tdap vaccine to pregnant patients are practices that are smaller and not associated with larger health systems. Ob-gyn practices could partner with nearby general practitioners– who tend to have a well-established vaccine program because of their wider patient population (102) – or hospitals to reduce financial risk of up-front vaccine purchasing, storage, and personnel costs. Additionally, free educational materials are available to aid ob-gyns and other prenatal healthcare professionals in administering or recommending and referring for Tdap. Developed by CDC, ACOG, the American College of Nurse-Midwives, the American Academy of Pediatrics, and the American Academy of Family Physicians, these materials can be found at www.cdc.gov/pertussis/pregnant.

The majority of ob-gyns administer Tdap to their pregnant patients as a part of routine practice, in accordance with current guidelines that all women should be vaccinated with Tdap during each pregnancy, but removing barriers for those providers that do not currently administer Tdap will result in improved access to an important vaccine for pregnant women and enhanced prevention of pertussis among newborns.

Figure 4.1. Among ob-gyns whose office does not stock Tdap vaccine, reasons for not stocking Tdap

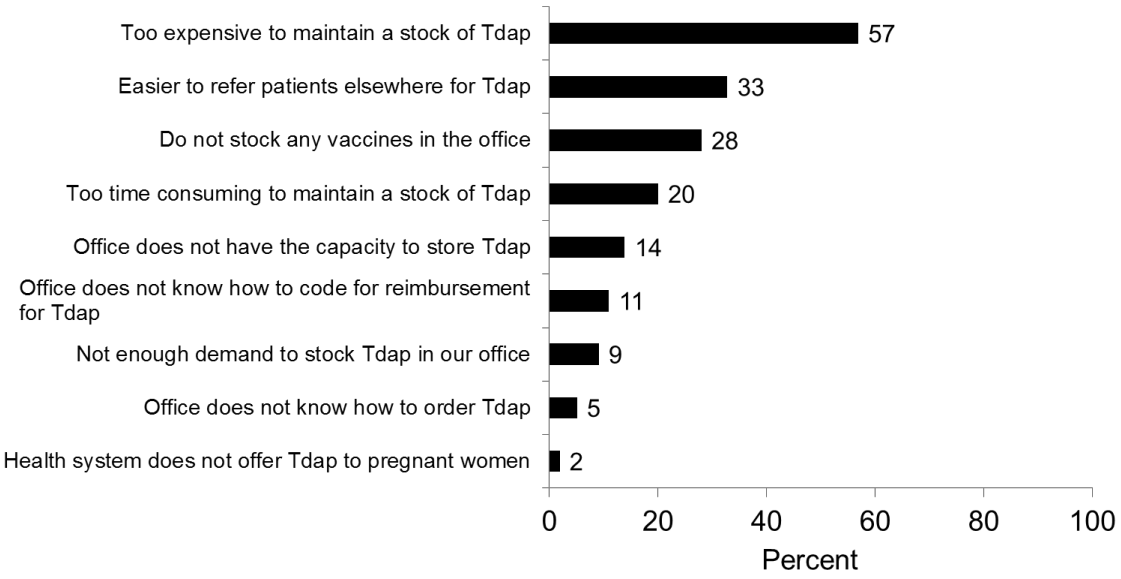


Table 4.1. Demographic and practice characteristics of ob-gyns, in relation to administration and recommendation of Tdap vaccine to their pregnant patients

	Total n (%)	Administers Tdap n (%)	Recommends Tdap[a] n (%)	Does not administer or recommend Tdap n (%)
Total	2,230 (100)	1,733 (78)	453 (20)	44 (2)
Sex				
Female	1,599 (72)	1,272 (80)	303 (19)	24 (2)
Male	631 (28)	461 (73)	150 (24)	20 (3)
Age group				
<40	836 (37)	694 (83)	132 (16)	10 (1)
40-49	583 (26)	454 (78)	116 (20)	13 (2)
50-59	563 (25)	417 (74)	135 (24)	11 (2)
60+	248 (11)	168 (68)	70 (28)	10 (4)
Practice type				
Private solo	170 (8)	71 (42)	90 (53)	9 (5)
Private, 2-3 practitioners	209 (9)	108 (52)	91 (44)	10 (5)
Private, 4+ practitioners	843 (38)	665(79)	170 (20)	8 (1)
Hospital	588 (26)	526 (89)	53 (9)	9 (2)
Other type[b]	412 (19)	357 (87)	47 (11)	8 (2)
Number of practitioners in practice[c]				
1	129 (6)	58 (45)	67 (52)	4 (3)
2-5	587 (27)	377 (64)	188 (32)	22 (4)
6-9	493 (23)	392 (80)	95 (19)	6 (1)
10 or more	953 (44)	854 (90)	91 (10)	8 (1)
Part of a larger health system				
No	890 (40)	575 (65)	292 (33)	23 (3)
Yes	1,317 (60)	1,141 (87)	156 (12)	20 (2)
Administration of influenza vaccine				
Does not administer	317 (14)	66 (21)	237 (75)	14 (4)
Administers	1,904 (86)	1,664 (87)	215 (11)	25 (1)
Region				
Northeast	444 (20)	342 (77)	93 (21)	9 (2)
Midwest	527 (24)	437 (83)	78 (15)	12 (2)
South	673 (31)	479 (71)	176 (26)	18 (3)
West	520 (24)	432 (83)	84 (16)	4 (1)
Other territory	14 (1)	9 (64)	5 (36)	0 (0)
Practice area				
Urban	969 (44)	789 (81)	156 (16)	24 (2)
Suburban	956 (43)	708 (74)	234 (24)	14 (1)
Rural	291 (13)	229 (79)	57 (20)	5 (2)
Proportion of patients with Medicaid				
None	296 (13)	207 (70)	87 (29)	2 (1)
1-25%	779 (35)	620 (80)	153 (20)	6 (1)
26-50%	549 (25)	433 (79)	105 (19)	11 (2)
51-75%	342 (16)	259 (76)	69 (20)	14 (4)
>75%	239 (11)	197 (82)	32 (13)	10 (4)

Proportion of Spanish-speaking patients				
None	176 (8)	122 (69)	52 (30)	2 (1)
1-25%	1,642 (74)	1,277 (78)	337 (21)	28 (2)
26-50%	243 (11)	201 (83)	37 (15)	5 (2)
51-75%	96 (4)	76 (79)	16 (17)	4 (4)
>75%	64 (3)	53 (83)	8 (13)	3 (5)

[a] But refers them elsewhere for Tdap vaccination.

Table 4.2. Associations between characteristics of ob-gyns and administration/recommendation of Tdap vaccine to their pregnant patients

	Administers Tdap to pregnant patients[a]		Recommends Tdap but refers patients elsewhere[b]	
	Crude OR (95% CI)	Adjusted OR[c] (95% CI)	Crude OR (95% CI)	Adjusted OR[c] (95% CI)
Sex				
Female	Ref	Ref	Ref	Ref
Male	0.7 (0.6-0.9)	1.0 (0.8-1.4)	1.4 (1.1-1.7)	0.9 (0.7-1.3)
Age group				
<40	Ref	Ref	Ref	Ref
40-49	0.7 (0.6-0.9)	1.1 (0.8-1.5)	1.3 (1.0-1.8)	0.8 (0.6-1.2)
50-59	0.6 (0.5-0.8)	1.0 (0.8-1.4)	1.7 (1.3-2.2)	0.9 (0.7-1.3)
60+	0.4 (0.3-0.6)	0.9 (0.6-1.3)	2.2 (1.6-3.1)	1.1 (0.7-1.7)
Practice type				
Private solo	Ref	Ref	Ref	Ref
Private, 2-3 practitioners	1.5 (1.0-2.2)	1.6 (0.9-2.8)	0.7 (0.4-1.0)	0.8 (0.4-1.6)
Private, 4+ practitioners	5.2 (3.7-7.4)	2.9 (1.7-5.1)	0.2 (0.1-0.3)	0.4 (0.2-0.8)
Hospital	11.8 (7.9-17.7)	3.7 (2.0-6.9)	0.1 (0.1-0.1)	0.3 (0.1-0.5)
Other type[d]	9.1 (6.0-13.7)	4.0 (2.1-7.6)	0.1 (0.1-0.2)	0.3 (0.2-0.7)
Number of practitioners in practice[e]				
1	Ref	Ref	Ref	Ref
2-5	2.2 (1.5-3.2)	0.9 (0.5-1.7)	0.4 (0.3-0.6)	0.9 (0.5-1.4)
6-9	4.8 (3.2-7.2)	1.4 (0.7-2.8)	0.2 (0.1-0.3)	0.6 (0.4-1.1)
10 or more	10.6 (7.1-15.8)	2.4 (1.2-4.9)	0.1 (0.1-0.1)	0.4 (0.2-0.6)
Part of a larger health system				
No	Ref	Ref	Ref	Ref
Yes	3.6 (2.9-4.4)	2.2 (1.7-2.9)	0.3 (0.2-0.3)	0.5 (0.3-0.6)
Administers influenza vaccine				
No	Ref	Ref	Ref	Ref
Yes	26.4 (19.5-35.7)	23.9 (16.9-34.0)	0.04 (0.03-0.05)	0.04 (0.03-0.06)
Region				
Northeast	Ref	Ref	Ref	Ref
Midwest	1.4 (1.1-2.0)	1.5 (1.0-2.1)	0.7 (0.5-0.9)	0.7 (0.5-0.9)
South	0.7 (0.6-1.0)	0.9 (0.7-1.3)	1.4 (1.0-1.8)	1.1 (0.8-1.6)
West	1.5 (1.1-2.0)	1.6 (1.1-2.2)	0.7 (0.5-0.9)	0.7 (0.5-1.0)
Other territory	0.5 (0.2-1.6)	1.4 (0.3-6.0)	2.0 (0.7-6.2)	0.8 (0.2-3.6)
Practice area				
Urban	Ref	Ref	Ref	Ref
Suburban	0.7 (0.5-0.8)	1.0 (0.8-1.3)	1.7 (1.3-2.1)	1.1 (0.8-1.4)
Rural	0.8 (0.6-1.2)	1.4 (0.9-2.0)	1.3 (0.9-1.8)	0.8 (0.5-1.1)
Proportion of patients with Medicaid				
None	Ref	Ref	Ref	Ref
1-25%	1.7 (1.2-2.3)	0.9 (0.7-1.3)	0.6 (0.4-0.8)	1.1 (0.7-1.5)
26-50%	1.6 (1.2-2.2)	0.7 (0.5-1.0)	0.6 (0.4-0.8)	1.3 (0.9-2.0)
51-75%	1.3 (0.9-1.9)	0.5 (0.3-0.8)	0.6 (0.4-0.9)	1.7 (1.1-2.7)
>75%	2.0 (1.3-3.1)	0.4 (0.3-0.7)	0.4 (0.3-0.6)	1.9 (1.1-3.3)
Proportion of Spanish-speaking patients				
None	Ref	Ref	Ref	Ref
1-25%	1.6 (1.1-2.2)	1.1 (0.8-1.7)	0.6 (0.4-0.9)	0.8 (0.6-1.2)
26-50%	2.1 (1.3-3.4)	1.1 (0.6-1.9)	0.4 (0.3-0.7)	0.9 (0.5-1.5)
51-75%	1.7 (0.9-3.0)	0.7 (0.4-1.4)	0.5 (0.3-0.9)	1.2 (0.6-2.4)
>75%	2.1 (1.0-4.4)	1.3 (0.5-3.3)	0.4 (0.2-0.8)	0.6 (0.2-1.6)

[a] Compared to 'Does not administer Tdap to pregnant patients'.
[b] Compared to 'Administers Tdap to pregnant patients.'
[c] Adjusted for provider age, practice type, practice size, larger health system, region, and urban/suburban/rural.
[d] Includes academic medical centers, community health clinics, and multispecialty practices.
[e] Number of doctors, nurse practitioners, physician assistants, and midwives in the practice.

Table 4.3. Associations between knowledge of and personal experience with Tdap vaccine and pertussis and Ob-Gyn administration of Tdap vaccine to their pregnant patients

	Administers Tdap n (%)	Crude OR[a] (95% CI)	Adjusted OR[b] (95% CI)
Knowledge			
Have there been cases of pertussis in past year in the state where you practice			
No	64 (65)	Ref	Ref
Yes	1,291 (80)	2.1 (1.3-3.2)	1.8 (1.1-3.1)
Household contacts are the most common source of pertussis infection for infants			
False	10 (71)	Ref	Ref
True	1,655 (78)	1.5 (0.5-4.7)	1.8 (0.5-7.1)
The CDC and ACOG recommend that women receive Tdap vaccine during every pregnancy			
False	22 (49)	Ref	Ref
True	1,671 (79)	4.0 (2.2-7.3)	3.5 (1.7-7.3)
Personal Experience			
Had pertussis	85 (77)	0.9 (0.6-1.5)	1.0 (0.6-1.7)
Know someone who had pertussis	393 (79)	1.1 (0.9-1.4)	1.0 (0.8-1.4)
Personally treated patients with pertussis	156 (82)	1.3 (0.9-1.9)	1.1 (0.7-1.7)
Personally treated patients exposed to pertussis	132 (80)	1.1 (0.8-1.6)	1.1 (0.7-1.7)
Delivered a baby who was diagnosed with pertussis	62 (70)	0.7 (0.4-1.1)	0.8 (0.5-1.3)

Information missing for the following variables (n): cases in the state (10), household contacts (11), CDC recommend (8), all personal experience variables (10)

[a] Compared to 'Does not administer Tdap to pregnant patients'.

[b] Adjusted for provider age, practice type, practice size, larger health system, region, and urban/suburban/rural.

Table 4.4. Associations between characteristics of ob-gyns and correct recommendations for administration of Tdap vaccine for pregnant patients

	Recommends Tdap correctly[a] n (%)	Crude OR[b] (95% CI)	Adjusted OR[c] (95% CI)
Total	1,811 (81)		
Sex			
Female	1,345 (84)	Ref	Ref
Male	466 (74)	0.5 (0.4-0.7)	0.7 (0.6-0.9)
Age group			
<40	726 (87)	Ref	Ref
40-49	472 (81)	0.6 (0.5-0.9)	0.8 (0.6-1.1)
50-59	436 (77)	0.5 (0.4-0.7)	0.6 (0.-0.8)
60+	177 (71)	0.4 (0.3-0.5)	0.5 (0.4-0.8)
Practice type			
Private solo	102 (60)	Ref	Ref
Private, 2-3 practitioners	143 (68)	1.4 (0.9-2.2)	1.3 (0.7-2.4)
Private, 4+ practitioners	716 (85)	3.8 (2.6-5.4)	2.1 (1.1-3.9)
Hospital	497 (85)	3.6 (2.5-5.3)	1.3 (0.7-2.4)
Other type[d]	347 (84)	3.6 (2.4-5.3)	1.5 (0.8-2.8)
Number of practitioners in practice[e]			
1	80 (62)	Ref	Ref
2-5	431 (73)	1.7 (1.1-2.5)	1.1 (0.7-1.7)
6-9	408 (83)	2.9 (1.9-4.5)	1.5 (0.8-2.5)
10 or more	836 (88)	4.4 (2.9-6.6)	2.2 (1.2-3.7)
Part of a larger health system			
No	665 (75)	Ref	Ref
Yes	1,128 (86)	2.0 (1.6-2.5)	1.7 (1.3-2.3)
Administration of influenza vaccine			
Does not administer	211 (67)	Ref	Ref
Administers	1,597 (84)	2.6 (2.0-3.4)	2.1 (1.6-2.8)
Region			
Northeast	350 (79)	Ref	Ref
Midwest	457 (87)	1.8 (1.3-2.5)	1.6 (1.1-2.3)
South	507 (75)	0.8 (0.6-1.1)	0.8 (0.6-1.1)
West	445 (86)	1.6 (1.1-2.2)	1. (1.1-2.2)
Other territory	12 (86)	1.6 (0.4-7.3)	4.1 (0.5-33.4)
Practice area			
Urban	792 (82)	Ref	Ref
Suburban	775 (81)	0.9 (0.8-1.2)	1.2 (0.9-1.6)
Rural	234 (80)	0.9 (0.7-1.3)	1.3 (0.9-1.9)
Proportion of patients with Medicaid			
None	244 (82)	Ref	Ref
1-25%	671 (86)	1.3 (0.9-1.9)	0.9 (0.6-1.3)
26-50%	436 (79)	0.8 (0.6-1.2)	0.5 (0.3-0.7)
51-75%	251 (73)	0.6 (0.4-0.9)	0.3 (0.2-0.5)
>75%	191 (80)	0.9 (0.6-1.3)	0.4 (0.2-0.6)
Proportion of Spanish-speaking patients			
None	147 (84)	Ref	Ref

1-25%	1,349 (82)	0.9 (0.6-1.4)	0.6 (0.4-1.0)
26-50%	180 (74)	0.6 (0.4-0.9)	0.3 (0.2-0.6)
51-75%	76 (79)	0.8 (0.4-1.4)	0.5 (0.2-0.9)
>75%	53 (83)	0.9 (0.4-2.0)	0.5 (0.2-1.2)

[a] According to current recommendations: one dose of Tdap vaccine during each pregnancy AND recommends pregnant patients receive Tdap between 27 and 36 weeks of pregnancy.
[b] Compared to 'Does not recommend Tdap according to current CDC recommendation for pregnant women'.
[c] Adjusted for provider age, practice type, practice size, larger health system, region, and urban/suburban/rural.
[d] Includes academic medical centers, community health clinics, and multispecialty practices.
[e] Number of doctors, nurse practitioners, physician assistants, and midwives in the practice.

CHAPTER 5: Evaluation of Two Vaccine Education Interventions to Improve Pertussis Vaccination among Pregnant African American Women: A Randomized Controlled Trial

Jennifer L. Kriss[1], Paula M. Frew[2,3], Marielysse Cortes[3], Fauzia A. Malik[3], Allison T. Chamberlain[4], Katy Seib[3], Robert L. Davis[5], Lisa Flowers[6], Kevin A. Ault[7], Penelope P. Howards[4], Walter A. Orenstein[8], Saad B. Omer[9]

[1] Department of Epidemiology and Laney Graduate School, Emory University, Atlanta, GA.
[2] Department of Behavioral Sciences and Health Education, Rollins School of Public Health, and Department of Medicine, Division of Infectious Diseases, Emory University, Atlanta, GA.
[3] Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, GA.
[4] Department of Epidemiology, Rollins School of Public Health, Emory University, Atlanta, GA.
[5] Center in Biomedical Informatics, University of Tennessee Health Science Center, Memphis, TN.
[6] Department of Gynecology and Obstetrics, School of Medicine, Emory University, Atlanta, GA.
[7] Department of Obstetrics and Gynecology, University of Kansas, Kansas City, KS.
[8] Emory Vaccine Center and School of Medicine, Emory University, Atlanta, GA.
[9] Hubert Department of Global Health and Department of Epidemiology, Emory University, Atlanta, GA.

Running Title: Educational Interventions and Pertussis Vaccination Among Pregnant Women
Keywords: Tdap, Vaccine, Pregnancy, Pertussis, Whooping cough

ABSTRACT

Objective: Tailored messaging based on the Elaboration Likelihood Model (ELM) framework has been successful in improving human papillomavirus vaccine uptake and breast cancer screening. The objectives of this paper are to evaluate whether two vaccine education interventions based on the ELM framework improved Tdap uptake during pregnancy or affect the reasons women report for not getting vaccinated with Tdap, and assess women's engagement with the interventions.

Study Design, Setting, and Participants: We conducted a prospective randomized controlled trial among pregnant African American women recruited during routine prenatal care visits at ob-gyn offices in the Atlanta, GA metropolitan area.

Interventions: Two ELM-based vaccine education interventions – an affectively-based video titled "Pregnant Pause" and a cognitively-based iPad app titled "MOMVAX", both based on the ELM central processing persuasive route.

Main Outcomes and Measures: The primary outcome for this study was uptake of Tdap vaccine during the perinatal period, including during pregnancy and immediately postpartum. Secondary outcomes included intention to be vaccinated with Tdap in a future pregnancy and reasons for not being vaccinated with Tdap.

Results: Among women who completed follow-up (n=95), 32% were vaccinated with Tdap during the perinatal period, including 6 vaccinated during pregnancy and 24 vaccinated immediately postpartum. In the iPad app arm, 50% (95% CI 33%-67%) of women were vaccinated with Tdap in the perinatal period, compared with 29% in the video arm and 18% in the control arm. From baseline to follow-up, women's reported intention to receive Tdap vaccine in the future improved in all 3 arms of the study, and

the education interventions did not have statistically significant effects compared to the control arm. Participant engagement was higher for the video intervention than for the iPad app intervention.

Conclusions and Relevance: Among our sample of pregnant African American women, most who received Tdap in the perinatal period received it immediately postpartum; only a small number were vaccinated during pregnancy in alignment with current recommendations. Education interventions that provide targeted information for pregnant women in an interactive manner may be important in improving Tdap vaccination during pregnancy among racially and ethnically diverse women.

Trial Registration: clinicaltrials.gov Identifier: NCT01740310

INTRODUCTION

Although recommendations have been issued for routine childhood vaccination against pertussis that have resulted in high vaccine coverage, there has been a recent resurgence in pertussis in the U.S. and in many other countries throughout the world. From 1965 until 2002, there were fewer than 10,000 cases of pertussis per year in the U.S. Reported cases have increased since then, with a peak of 48,277 in 2012, the highest number of reported cases since 1955 (149). Infants too young to be completely vaccinated are at especially high-risk for acquiring pertussis; the incidence of pertussis in infants aged <6 months has been estimated to be up to 19 times greater than pertussis incidence in the general population (10). The majority of pertussis-related hospitalizations in the U.S. occur in infants who are too young to be fully vaccinated (1, 11, 17, 18, 69, 70). Rates of pertussis-related complications in infants <6 months may be up to 4 times higher than complication rates in older children (12). Pertussis-related deaths occur almost exclusively in infants who are too young to be completely vaccinated, and risk of death is inversely proportional to infant age (13-16, 18).

A 3-dose primary pertussis immunization series begins at age 2 months, and is completed by 6 months in the U.S. (141). There is some evidence that 2 doses of acellular pertussis vaccine confers some protection against pertussis (73, 150), and 1 dose of vaccine protects against pertussis-related death (151), but infants typically do not have full protective immunity and remain vulnerable to pertussis until they have received all 3 doses of the primary series of pertussis vaccine. Infants who have not been fully vaccinated rely on other mechanisms of protection, including passively acquired maternal antibodies and herd immunity (27).

Immunization with tetanus toxoid, reduced diphtheria toxoid, and acellular pertussis (Tdap) vaccine of mothers and others with infant contact is a potential strategy to protect young infants from pertussis before they are fully vaccinated. In 2005, the U.S. Advisory Committee on Immunization Practices (ACIP) recommended vaccinating mothers after giving birth and before hospital discharge to prevent pertussis transmission to young infants (46). This strategy has drawbacks, the most important of which is the fact that although there is a sufficient antibody response by 14 days after maternal vaccination, this leaves a 2-week window of risk during which the mother could become infected with pertussis and transmit it to the infant in the first weeks of life (47, 50). In June 2011, ACIP recommended that pregnant women who have not previously been vaccinated with Tdap should receive the vaccine during the third or late second trimester, or immediately postpartum if not administered during pregnancy (152). In October 2012, ACIP recommended that pregnant women be vaccinated with Tdap during *every* pregnancy, regardless of immunization history (116).

Tailored messaging based on the Elaboration Likelihood Model (ELM) framework has been successful in improving human papillomavirus (HPV) vaccine uptake (119) and breast cancer screening (120), and may be useful in improving uptake of pertussis vaccine among pregnant minority women. The ELM features 2 routes of persuasive influence – central and peripheral – by which individuals receive and process information, and which result in differences in persuasive impact. Information-based messages that are personally relevant evoke central processing, which results in stronger and less modifiable behavioral changes, whereas simplistic messages evoke peripheral

processing, which results in behavioral changes that may be more subject to change and less enduring (121).

This study was designed to: 1) evaluate whether 2 vaccine education interventions based on the ELM framework administered during the prenatal period improved Tdap uptake, 2) evaluate whether the education interventions affect the reasons women report for not getting vaccinated with Tdap during pregnancy, and 3) assess women's engagement with the interventions. This study has important implications for minority women for whom distrust, a lack of information, and fear of vaccination may result in less vaccine uptake compared to other groups (61, 64, 65, 152).

METHODS

Study design

This study was a prospective, randomized, controlled trial that was designed to be a pilot study. The study population consisted of African American pregnant women between the ages of 18 and 50 in Atlanta, Georgia. Women were recruited into the study during routine prenatal care visits at their ob-gyn offices. Four antenatal clinics in metro Atlanta participated as enrollment sites.

Recruitment

Recruitment occurred during the 2013 influenza season (January 30-April 3, 2013). This time period was chosen for recruitment because one of the outcomes of interest was reported influenza vaccination. Inclusion criteria were the following: currently pregnant with an expected delivery date between January 30, 2013 and June 30,

2013. Women were not eligible for the study if they had already received the influenza or Tdap vaccine during the current pregnancy.

Women were approached by trained study personnel in the waiting rooms of antenatal clinics if they appeared to be eligible for the study (based on pregnancy status, age, and race). They were asked if they would participate in an interview on women's health education. A recruitment script was used and a screening checklist was completed for each participant approached. If the participant was eligible and interested in participating, the informed consent document was read to the participant and written informed consent was obtained. Enrolled women completed a baseline questionnaire to assess attitudes regarding vaccination before randomization.

Randomization and Interventions

A master randomization database which provided randomization assignments was generated by non-study personnel. Randomization lists were produced separately for each of the 4 study sites. Participants were randomly assigned to one of 2 vaccine education interventions based on the ELM central processing persuasive route (an affectively-based video titled "Pregnant Pause" or a cognitively-based iPad app titled "MOMVAX") or a control arm based on the ELM peripheral processing route (Figure 5.1). The vaccine education interventions were completed on a handheld electronic tablet device and were designed to take no longer than 20 minutes, to enable patients to complete them during the time they were waiting for their appointments.

Women randomized to the video arm watched a video targeted specifically to pregnant women in which physicians provided detailed vaccine-related information on Tdap and influenza vaccine for pregnant women. It provided information on the severity

of pertussis and influenza for pregnant women and their newborns, how the vaccines work to protect pregnant women and newborns, safety information, and information on the current ACIP recommendations. Women randomized to the iPad app arm were given an interactive educational tutorial that provided information through a question and answer format on Tdap, influenza vaccine, whooping cough and influenza among pregnant women and infants, and information on the current ACIP recommendations for vaccination during pregnancy. Women could choose the topic(s) that they were most interested in and complete each tutorial section separately. The video and iPad app were given to the women in the waiting room, and if not completed before the woman was called back for her appointment, the woman was allowed to take the iPad to her examination room to complete. Women randomized to the control arm received the standard CDC vaccine information statements on Tdap and influenza vaccines. These statements are paper-based, text-only, non-interactive, and are not targeted specifically to pregnant women. Those who were randomized to the 2 intervention arms completed a brief post-intervention questionnaire which asked about women's reactions to the video/iPad app such as whether they learned something, their confidence in the evidence presented, the complexity of the information, and whether they could clearly understand the information. Women in the control arm did not complete a post-intervention questionnaire, in order to replicate the current strategy in which women are provided with text-based information statements on the vaccines which they must read and process themselves.

Outcomes

The primary outcome for this study was uptake of Tdap vaccine during the perinatal period, including during pregnancy and immediately postpartum (receipt before discharge from the hospital after delivery). This was based on self-report during the follow-up survey. Secondary outcomes included immunization intention with Tdap in a future pregnancy and reasons for not being vaccinated with Tdap. Outcomes were assessed via a follow-up survey conducted approximately one to 2 months (mean=47 days) after the expected delivery date. Follow-up was conducted primarily via telephone, with a small number of contact attempts made by email or Facebook for women who had given consent for this type of contact. The follow-up questionnaire asked about the general health of the mother and infant, immunization status for receipt of influenza vaccine during pregnancy and Tdap during pregnancy or immediately postpartum, recommendation by ob-gyn or nurse midwife for Tdap vaccine, attitudes and beliefs regarding vaccination, perceived seriousness of whooping cough and influenza, intent to be vaccinated in future pregnancies, and plans for vaccination of infants. Participants received grocery store gift cards after completion of the baseline questionnaire ($35) and the follow-up questionnaire ($50).

Study power and sample size

Power and sample size calculations were based on ensuring adequate power for the outcome of influenza vaccination during pregnancy; in order to have 80% power to detect a 20 percentage point increase in influenza vaccine coverage in each of the intervention arms compared to the control arm, we planned to enroll 162 women, or 54 women in each study arm.

Statistical methods

Descriptive analyses were conducted to characterize the study population. We used chi-square tests and t-tests to test for differences in proportions and means between the randomization arms. We assessed the success of randomization with respect to maternal age, education, gravidity, health insurance, health seeking behavior, pregnancy complications, and recommendation of Tdap/influenza vaccine by ob-gyn. Risk ratios (RRs) were calculated for the study outcomes from log-binomial regression models. All analyses were based on intention-to-treat. All analyses were conducted using SAS version 9.4 (SAS Institute, Inc., Cary, NC). This study was approved by the institutional review board of Emory University.

RESULTS

A total of 106 women who met the inclusion criteria agreed to participate and were enrolled in the study between January 30 and April 3, 2013. Ninety-five (90%) of the women completed a follow-up survey after giving birth, of which 34 were in the control arm, 31 were in the video arm, and 30 were in the iPad app arm (Figure 5.2). All follow-up surveys were completed between April 2 and October 16, 2013; the mean time between birth and follow-up was 47 days. The remaining 11 women were lost to follow-up due to incorrect phone numbers or inability to contact them.

The average age of women who completed follow-up was 26 years (Table 5.1). There were no significant differences in demographic characteristics by randomization arm, although women in the control arm were less educated than women in the iPad app arm, and the distribution of women in the 4 practices differed slightly between study

arms. The majority had less than a college degree (91%), and the average number of current children (not including the current pregnancy) was 1.2 (SD 1.4). Most women (92%) had health insurance, primarily Medicaid (88%). Most women had not received an influenza vaccine in the last 5 years (63%) or did not know if they had (12%) (Table 5.2). Only 10% received an influenza vaccine in at least 2 of the last 5 years; women in the video arm were more likely to have had an influenza vaccine at least once in the last 5 years (35%), and women in the iPad app arm were less likely to have had at least one influenza vaccine (10%). Women were moderately hesitant about getting vaccines that their doctor recommended getting during pregnancy (4.5 on a scale of 0-10, where 0 was "not hesitant" and 10 was "very hesitant"). Women in the iPad app arm were less hesitant than the others (3.8). Most women planned to vaccinate their babies with all recommended childhood vaccines (8.2 on the 10-point scale), and this did not vary by study arm.

Overall, 32% of the women who completed follow-up were vaccinated with Tdap during the perinatal period (Table 5.3). This included 6% (n=6) vaccinated during pregnancy, and an additional 25% (n=24) vaccinated immediately postpartum. No women reported that they were vaccinated with Tdap both during pregnancy and immediately postpartum.

In the control arm, 18% (95% CI 7%-33%) of women were vaccinated with Tdap – 6% during pregnancy and 12% immediately postpartum (Table 5.3). In the iPad app arm, 50% of women (95% CI 33%-67%) were vaccinated with Tdap – 7% during pregnancy and 43% immediately postpartum. The iPad app was associated with improved Tdap vaccination in the total perinatal period (RR=2.83, 95% CI 1.26-6.37) and in the

postpartum period (RR=3.71, 95% CI 1.37-10.09) compared to the control arm. In the video arm, 29% (95% CI 15%-47%) of women received Tdap vaccine during the perinatal period – 6% during pregnancy and 23% immediately postpartum. This was not significantly different from the control arm (RR=1.65, 95% CI 0.66-4.09).

From baseline to follow-up, women's reported intention to receive Tdap vaccine improved in all 3 arms of the study. Women were asked at baseline "On a scale of 0 (definitely will not) to 10 (definitely will), please rank your likelihood of getting the Tdap shot during this pregnancy," and were asked at follow-up "On a scale of 0 (definitely not) to 10 (definitely so), please rank your likelihood of getting the Tdap shot during your next pregnancy." At baseline, among all women in the study the average likelihood of getting Tdap during pregnancy was 3.0 (SD 3.4) (Table 5.2). When asked again at follow-up, the average likelihood of getting Tdap during a future pregnancy was 6.3 (SD 3.6). This increase was evident in all 3 randomization arms. The control arm increased from 2.8 (SD 3.6) to 6.1 (SD 3.9), the video arm increased from 3.2 (SD 3.1) to 6.8 (SD 3.4), and the iPad app arm increased from 2.9 (SD 3.6) to 5.9 (SD 3.5). Improvement in intention to receive Tdap vaccine was not significantly different for the 2 intervention arms compared to the control arm (Table 5.3).

Participant engagement in the intervention, as measured by the observing interviewer, was higher in the video arm (65% very engaged) than in the iPad app arm (23% very engaged) (Table 5.5). More women said they felt they could relate to the educational material in the video arm than in the iPad app arm (68% vs. 37%, p=0.015), and they were likely to believe that there was evidence to support the vaccine information presented (77% vs. 50% said the producers could provide evidence to support vaccine

claims, p=0.026). The video was also easier to understand, with 97% saying they clearly understood it, compared to 77% of iPad app users (p=0.020).

Women who reported that they did not receive Tdap during pregnancy were asked an open-ended question, "What are the main reasons you decided not to get a Tdap shot during your pregnancy?," and responses were coded by interviewers. The 2 most frequent reasons reported by women for not getting the vaccine was that it was not recommended by their doctor (48%) and that they did not know about the Tdap vaccine (44%) (Table 5.4). These reasons did not vary by randomization arm. Other reasons given by a considerable number of women were that they were not sure what the Tdap vaccine was for (25%), they did not think they were at risk for tetanus, diphtheria, or pertussis (19%), and they do not generally take vaccines (14%). A smaller percentage of women in the iPad app arm reported that they were not sure what the Tdap vaccine was for (15%, compared to 28% in the control arm and 31% in the video arm), but differences were not statistically significant.

Ob-gyn or nurse midwife recommendation of Tdap during pregnancy was associated with an increase in Tdap uptake during the perinatal period. In adjusted models that separately adjusted for ob-gyn practice and intervention arm (because of non-convergence in models adjusting for both covariates), women who reported that their ob-gyn recommended they receive Tdap were about 3 times as likely to be vaccinated compared to women who said their ob-gyn did not recommend Tdap to them (practice-adjusted model: aRR=3.45, 95% CI 1.88-6.34; intervention-adjusted model: aRR=3.32, 95% CI 1.85-5.98) (Table 5.6). Cell sizes were too small to analyze Tdap vaccination during pregnancy only, but we found similar results for Tdap vaccination immediately

postpartum. We evaluated whether there was effect modification of the association between provider recommendation and perinatal vaccination by study arm. The association was larger in the video arm (OR=7.35, 95% CI 1.85-29.19) compared with the iPad app arm (OR=2.04, 95% CI 1.07-3.90), but the interaction was not significant (p=0.334).

DISCUSSION

This is the first randomized controlled trial to assess the effect of ELM-based education interventions on vaccine uptake among pregnant women. A small minority of women in this study were vaccinated with Tdap during their pregnancy; most women who received Tdap sometime in the perinatal period received it immediately postpartum. The iPad app – a high-involvement cognitively-based education intervention – was associated with improved Tdap vaccine uptake, with women in this arm more than twice as likely to receive Tdap in the perinatal period compared to the control arm, in both unadjusted and adjusted models. This was mainly driven by vaccination immediately postpartum. Women in the video arm – a high-involvement affectively-based education intervention – had a slight but non-significant increase in Tdap uptake during the perinatal period, also mainly driven by vaccination immediately postpartum. Women's reported intention to receive Tdap in future pregnancies improved in all 3 arms of the study from baseline to follow-up, which may be because of involvement in the study itself resulting in greater awareness of Tdap and pertussis. Recommendation of Tdap by a woman's ob-gyn or nurse midwife during pregnancy improved Tdap uptake: women whose ob-gyn recommended they receive Tdap were more than 3 times as likely to be

vaccinated during the perinatal period, compared to women whose ob-gyn did not recommend Tdap to them. Physician recommendation and offer of vaccine has been found to be associated with improved vaccination coverage for many vaccines, including influenza and pneumococcal vaccination of high-risk adults (153), influenza vaccination of older adults (154), HPV vaccination of adolescents (155), and influenza vaccination of women during pregnancy (156).

The 2 education interventions used in this study were based on the ELM, and provided information in a way that was tailored specifically to pregnant women. The ELM explains that the way a message is designed affects how individuals will change their opinion and behavior based on that message. When messages are personally relevant and contain ample information, the viewer tends to use logical thinking to consider pro and con arguments (by the central persuasive route). This type of decision-making tends to result in behavioral changes that are considered to be stronger and less likely to be modified or undergo revision (121, 122). Conversely, messages that rely on simplistic associations of negative and positive attributes, such as likeability of the speaker, result in decision-making based on more subjective external cues (by the peripheral persuasive route). The resulting behavioral changes tend to be more fleeting and subject to change (121).

The iPad app can be tailored more individually to each woman through her independent choice of which topic(s) to view and spend time on. It was aligned with the high-involvement, central processing route of the ELM, which tends to result in behavioral changes that are stronger and more enduring. However, in our study women were less engaged in the iPad app than in the video, based on interviewers' observation,

and study participants rated the iPad app as less relatable and less easy to understand than the video. Of the 2 interventions, the "MOMVAX" iPad app was associated with higher pertussis vaccine uptake in the perinatal period and immediately postpartum. Conversely, the "Pregnant Pause" short film was designed to evoke an emotional response with its affective edutainment storyline. We found that this approach demonstrated no improvement in uptake of Tdap by pregnant women either during pregnancy or immediately postpartum, despite women seeming to be more engaged with it. Previous research on the use of entertainment-education has found mixed results on its effectiveness in completely transforming behavior (157-160).

The 2 most frequent barriers to vaccination were lack of recommendation by their doctor and lack of knowledge about the Tdap vaccine. These reasons did not vary by arm of the study; even when women were provided with information on Tdap and whooping cough that was tailored to them, it appears that some women did not process the information or remember the messages that were presented. Following a vaccination campaign in England, similar reasons related to feeling uninformed, lack of provider recommendation and encouragement, and uncertainties about risks were given by women who decided not to get vaccinated (59).

This study has a few limitations. This study was designed as a pilot study, and therefore has a small sample size, which may result in limited power to detect effects. The target sample size for the study was calculated based on ensuring adequate power for the outcome of influenza vaccination during pregnancy, which is more common in the population than Tdap vaccination during pregnancy. This study is underpowered for detecting differences in Tdap outcomes, and we were unable to model Tdap during

pregnancy due to small cell sizes. Second, vaccination and provider recommendation were based only on self-report by the women in the study. We did not review medical records to validate vaccination or provider recommendation, and we did not match women's self-reported vaccination against a vaccine registry. Women were not asked about vaccination until on average 1.5 months after delivery, so their reporting of both provider recommendation and vaccination may be subject to poor recall, resulting in non-differential misclassification of the outcome. It is also possible that women confused Tdap vaccine with influenza vaccine, since both are recommended during pregnancy. Additionally, women may not have accurately reported whether their provider recommended Tdap; they may have forgotten that they received a recommendation, or reported the recommendation they got postpartum as a recommendation during pregnancy. Third, we do not have information on the hospital that each woman delivered at and the Tdap vaccination policy there, so we cannot control for this potentially important source of confounding. Fourth, all analyses were conducted based on intention-to-treat, but it is possible that some of the women who were randomized to the 2 education interventions did not have time to complete the entire activity while waiting for their prenatal appointment. If women were unable to complete either the video or the iPad app before they were called back for their appointment, they may have missed important messages or failed to process the information, which would result in biased estimates of effect. We did not collect information on the number of women who were unable to complete the interventions in the available time. Fifth, the population included in this study was African American women in a southeastern metropolitan area.

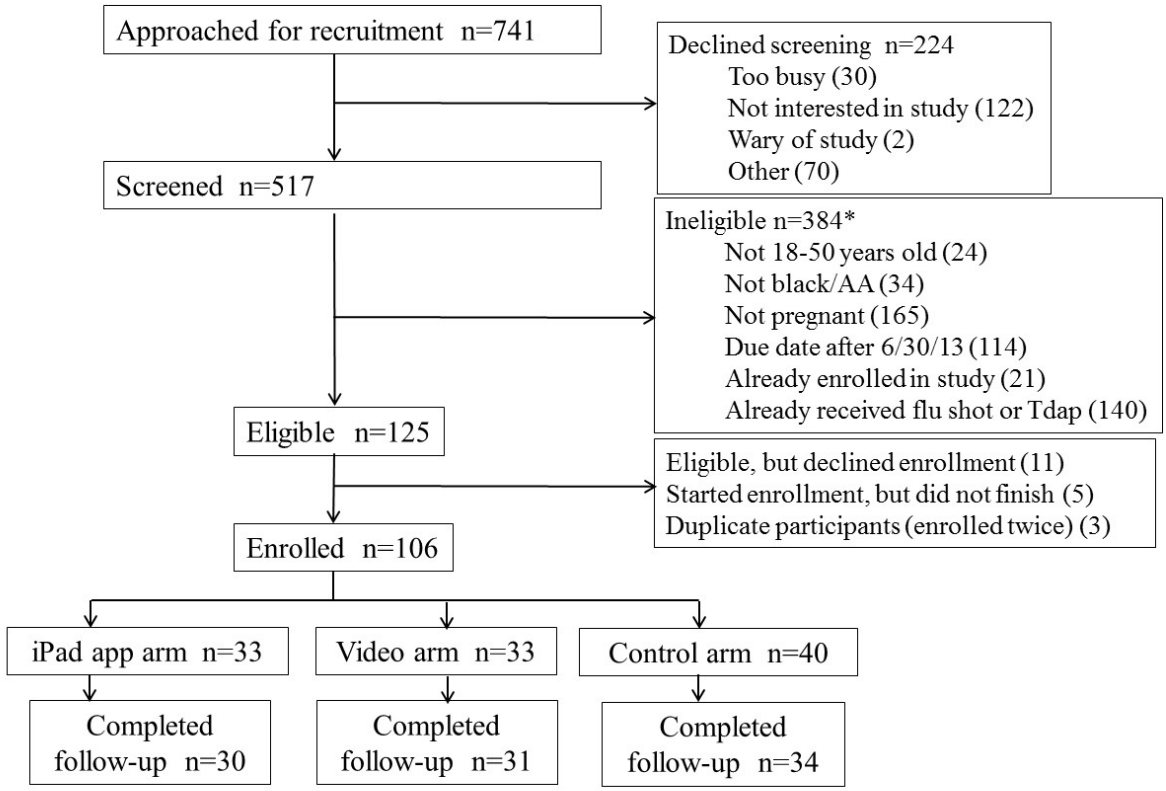
Therefore, findings may not be generalizable to non-African American populations, or to populations outside of the target geographic area.

Among our sample of pregnant African American women, most who received Tdap in the perinatal period received it immediately postpartum; only a small number were vaccinated during pregnancy in alignment with current recommendations. This study showed that education interventions that provide targeted information for pregnant women in an interactive manner may be important in improving Tdap vaccination in the perinatal period.

Figure 5.1. Details of two intervention arms and control arm materials

		Interventions	
	Control Arm	**Cognitively-based iPad App**	**Affectively-based video**
Material	Standard CDC Vaccine Information Statements (VIS)	iPad-based interactive app Detailed vaccine-related information Women selected sections of interest	"Pregnant Pause" educational video viewed on iPad Detailed vaccine-related information 10 minutes
ELM Theory	Not targeted specifically to pregnant women Although contains a lot of information, potentially low/no involvement	Info targeted specifically to pregnant women High involvement Cognitively-based	Info targeted specifically to pregnant women High involvement Affectively-based (emotion)

Figure 5.2. Participant enrollment for ELM study



*Note: people could be ineligible for more than one reason.

Table 5.1. Demographic characteristics of pregnant women who completed follow-up

	Overall (n=95)	**Control Arm (n=34)**	**Video Arm (n=31)**	**iPad App Arm (n=30)**
Mean age, years (SD)	26.1 (5.5)	25.3 (6.0)	25.8 (5.1)	27.4 (5.1)
Education				
Less than high school	13%	15%	13%	10%
High school graduate/GED	47%	50%	48%	43%
Vocational or associates	31%	26%	32%	33%
Bachelor degree	8%	9%	6%	10%
Graduate degree	1%	0%	0%	3%
Children, mean (SD)[a]	1.2 (1.4)	1.0 (1.3)	1.5 (1.5)	1.2 (1.4)
Currently insured	92%	91%	97%	87%
Practice				
1	41%	41%	45%	37%
2	5%	9%	3%	3%
3	19%	24%	13%	20%
4	35%	26%	39%	40%

GED=General Educational Development test.

[a] Not including current pregnancy.

Table 5.2. Baseline health-seeking behavior and health knowledge of pregnant women who completed follow-up

	All Women (n=95)	Control Arm (n=34)	Video Arm (n=31)	iPad App Arm (n=30)
Considers ob-gyn to be primary care doctor[a]	80%	79%	83%	76%
Number of times been treated for an illness or condition by a health care provider in past year				
0	40%	35%	45%	40%
1-4	52%	59%	48%	47%
5-9	2%	0%	3%	3%
10 times or more	4%	3%	3%	7%
Don't know	2%	3%	0%	3%
How many seasonal influenza vaccines received in past 5 years				
5 (every year)	1%	0%	0%	3%
2-4	9%	12%	16%	0%
1	15%	18%	19%	7%
0	63%	62%	52%	77%
Don't know	12%	9%	13%	13%
Baseline likelihood of getting: *(0=definitely will not; 10=definitely will)*				
Tdap vaccine during current pregnancy	3.0 ± 3.4	2.8 ± 3.6	3.2 ± 3.1	2.9 ± 3.6
Influenza vaccine during current pregnancy	2.1 ± 2.8	1.8 ± 2.8	2.6 ± 2.9	1.9 ± 2.9
Baby vaccinated with all recommended childhood vaccines	8.2 ± 2.9	8.3 ± 2.7	8.0 ± 3.2	8.2 ± 2.9
Baseline hesitancy about getting vaccines your doctor recommends that you get during pregnancy (0=not hesitant; 10=very hesitant)	4.5 ± 3.1	4.8 ± 3.2	4.7 ± 3.1	3.8 ± 3.1
I feel knowledgeable about the vaccines my new baby will begin getting after (s)he is born				
Strongly agree	29%	26%	26%	34%
Agree	34%	32%	35%	34%
Not sure	24%	24%	26%	24%
Disagree	7%	12%	3%	7%
Strongly disagree	5%	6%	10%	0%
BASELINE KNOWLEDGE				
Have ever heard of "cocooning" to protect your newborn from infectious diseases?	7%	9%	10%	3%
How serious do you think it would be if your newborn got				

whooping cough?				
Not serious at all	2%	0%	3%	3%
Somewhat serious	2%	3%	3%	0%
Neutral	2%	3%	0%	3%
Serious	13%	15%	10%	14%
Very serious	78%	79%	77%	76%
Don't know	3%	0%	6%	3%

Table 5.3. Associations between vaccine education interventions and Tdap vaccination in the perinatal period

	Video Arm[a]			iPad App Arm[a]		
Outcome	**No. (%)**	**Risk Ratio (95% CI)**	**P-value**	**No. (%)**	**Risk Ratio (95% CI)**	**P-value**
Unadjusted Models						
Tdap vaccine administered during perinatal period	9 (29)	1.7 (0.7-4.1)	0.28	15 (50)	2.8 (1.3-6.4)	0.01
During pregnancy	2 (6)	--	--	2 (7)	--	--
Immediately postpartum[b]	7 (23)	1.9 (0.6-5.9)	0.25	13 (43)	3.7 (1.4-10.1)	0.01
Adjusted Model 1[c]						
Tdap vaccine administered during perinatal period		1.6 (0.7-4.1)	0.29		3.0 (1.4-6.7)	<0.01
Adjusted Model 2[d]						
Tdap vaccine administered during perinatal period		1.3 (0.5-3.1)	0.60		2.5 (1.1-5.8)	0.04
Mother's intention to be vaccinated with Tdap in future pregnancies (scale 0-10)[e]						
Low likelihood (0-3)	6 (19)	Ref		6 (20)	Ref	
Medium likelihood (4-6)	6 (19)	1.1 (0.5-2.5)	0.74	10 (33)	1.4 (0.7-2.8)	0.30
High likelihood (7-10)	19 (61)	1.1 (0.8-1.6)	0.46	14 (47)	1.1 (0.7-1.6)	0.81

[a] Ref=control group.
[b] Postpartum vaccination refers to vaccine administered while in the hospital after delivering baby. These models exclude women who already received Tdap during pregnancy.
[c] Adjusted for education.
[d] Adjusted for education and ob-gyn practice.
[e] Unadjusted models.

Table 5.4. Associations between vaccine education interventions and women's reported reasons for not getting vaccinated with Tdap, among women who did not receive the Tdap vaccine during pregnancy (n=84*)

	Video Arm[a]			iBook Arm[a]		
	No. (%)	**Risk Ratio (95% CI)**	**P-value**	**No. (%)**	**Risk Ratio (95% CI)**	**P-value**
The vaccine was not recommended to me by my doctor	10 (38)	0.8 (0.5-1.5)	0.53	15 (58)	1.2 (0.8-2.0)	0.41
I didn't know about the Tdap vaccine	11 (42)	0.97 (0.5-1.8)	0.91	12 (46)	1.1 (0.6-1.9)	0.86
I wasn't sure what the Tdap vaccine was for	8 (31)	1.1 (0.5-2.4)	0.83	4 (15)	0.6 (0.2-1.6)	0.26
I didn't think I was at risk for tetanus, diphtheria, or pertussis	5 (19)	1.2 (0.4-3.8)	0.72	6 (23)	1.5 (0.5-4.3)	0.47
I don't take vaccines	5 (19)	1.2 (0.4-3.8)	0.72	2 (8)	0.5 (0.1-2.3)	0.37

[a]Referent is control group.

Table 5.5. Time spent and engagement with interventions, among pregnant women in the two intervention arms who completed follow-up (n=61)

	Video Arm (n=31)	iPad App Arm (n=30)	P-value
Time spent in minutes, median (range)	10 (1-20)	8.5 (1-20)[a]	
Level of participant engagement in intervention[b]			
Very engaged	20 (65%)	7 (23%)	
Engaged	7 (23%)	10 (33%)	
Neither engaged nor disengaged	2 (6%)	10 (33%)	
Disengaged	0 (0%)	2 (7%)	
Very disengaged	1 (3%)	1 (3%)	
Percent who strongly agree/agree with following statements about the education intervention:			
I learned something about vaccines	28 (90%)	28 (93%)	0.67
I thought about how vaccines might be useful to me	25 (81%)	19 (63%)	0.13
I could really relate	21 (68%)	11 (37%)	0.02
The producers could provide evidence to support vaccine claims	24 (77%)	15 (50%)	0.03
It did not really hold my attention	4 (13%)	0 (0%)	0.04
It reminded me of some important facts about vaccines	27 (87%)	25 (83%)	0.68
It leaves me with a good feeling about vaccines	21 (68%)	18 (60%)	0.53
I felt as though I was right there in the video experiencing the same thing	16 (52%)	10 (33%)	0.15
I thought of reasons why I would take or not take vaccines recommended	24 (77%)	20 (67%)	0.35
I clearly understood the video	30 (97%)	23 (77%)	0.02

[a]This excludes one participant who was called back for appointment in the middle of viewing the intervention and spent a total of 52 minutes.
[b]Average engagement was calculated for the iPad app using engagement scores for the 5 chapters.

Table 5.6. Associations between ob-gyn recommendation of Tdap and Tdap vaccination in the perinatal period

	Ob-gyn or nurse midwife recommended Tdap during pregnancy[a] (n=27)					
Outcome	**Unadjusted Risk Ratio (95% CI)**	**P-value**	**Adjusted[b] Risk Ratio (95% CI)**	**P-value**	**Adjusted[c] Risk Ratio (95% CI)**	**P-value**
Tdap vaccine administered during perinatal period	3.8 (2.1-6.7)	<0.01	3.5 (1.9-6.3)	<0.01	3.3 (1.9-6.0)	<0.01
During pregnancy	5.0 (0.98-25.9)	0.05	6.9 (1.4-33.9)	0.02	5.0 (0.98-26.1)	0.05
Immediately postpartum[d]	4.0 (2.1-7.8)	<0.01	2.9 (1.5-5.6)	<0.01	3.2 (1.6-6.3)	<0.01

[a] Ref=ob-gyn or nurse midwife did not recommend Tdap during pregnancy.
[b] Adjusted for practice.
[c] Adjusted for intervention arm.
[d] Postpartum vaccination refers to vaccine administered while in the hospital after delivering baby. These models exclude women who already received Tdap during pregnancy.

Chapter 6: CONCLUSIONS AND FUTURE DIRECTIONS

SUMMARY OF FINDINGS

Overall Findings

The overarching goal of this dissertation was to explore how to improve maternal Tdap vaccination strategies in order to prevent pertussis in young infants. The three studies show that there is improvement in Tdap vaccination of women during pregnancy, but there are groups of women who are not being vaccinated, and there are medical providers who are not vaccinating women according to the recommendations. The findings indicate that for both **Aim 1** and **Aim 3** that provider recommendation for Tdap vaccination is one of the most important factors in a woman's decision whether to get vaccinated during pregnancy, as reported by women. **Aim 3** found that women who received a recommendation for Tdap from their physician were up to three times more likely to get vaccinated in the perinatal period compared to those without a recommendation. Physician recommendation of vaccine has been found to be associated with improved vaccination coverage for several other vaccines, including influenza, pneumococcal, and HPV vaccines. These studies provide evidence that physician recommendation is equally important for vaccination of pregnant women with Tdap vaccine.

The findings indicate that the main reasons that women do not get vaccinated with Tdap during pregnancy are concerns about the safety of vaccination during pregnancy for both the mother and the fetus, a lack of recommendation from their doctor, and not knowing about the vaccine. Thorough and clear information that is specifically targeted

to pregnant women is essential in improving women's knowledge of the benefits and importance of Tdap vaccination. **Aim 1** results indicate that many women are looking for information on Tdap vaccination specifically targeted to pregnant women, and the women who received the educational interventions in our **Aim 3** study were interested and engaged in them overall. Since safety concerns are particularly important to pregnant women, information on the safety of Tdap vaccine for both mother and baby must be communicated to women. However, the findings from **Aim 3** reflect that even when educational interventions are used, the reasons for non-vaccination do not necessarily change among women who were not vaccinated. This indicates that women may not be able to fully understand or remember all the information presented in a single viewing, and multiple exposures to vaccination information may be needed.

Providers and women alike continue to rely on postpartum Tdap vaccination to protect infants. In general, most ob-gyns know the current ACIP and ACOG recommendations for Tdap during pregnancy, but a subset continue to not vaccinate patients for various reasons. A substantial proportion of ob-gyns who did not administer or recommend Tdap to their pregnant patients said that women could be vaccinated postpartum (**Aim 2**). Additionally, most women in our intervention trial (**Aim 3**) who did get vaccinated got vaccinated postpartum in the hospital, instead of during their pregnancy as recommended by ACIP and ACOG. Postpartum Tdap vaccination was a former ACIP recommendation, which has been replaced by the current recommendation for Tdap vaccination during every pregnancy. Postpartum vaccination is not as protective for infants as vaccination during pregnancy because it results in a gap immediately after

birth – during which a mothers boosted pertussis antibody levels have not yet peaked – during which the infant is unprotected.

Findings from Aim 1

Aim 1 (**Chapter 3**) evaluated disparities in uptake or intended uptake of Tdap vaccine among women during pregnancy and the postpartum period in the U.S. We used a cross-sectional sample of pregnant women in the U.S. to assess disparities based on race/ethnicity, primigravida, geographic region, socioeconomic status, and maternal age. We also assessed how these characteristics were associated with factors that inform a pregnant woman's decision about Tdap vaccination. This study found that about 40% of pregnant women in our sample had been vaccinated with Tdap during their pregnancy. Hispanic women were more than twice as likely to have been vaccinated with Tdap compared to white non-Hispanic women in adjusted models. Black non-Hispanic women were as likely as white non-Hispanic women to receive Tdap vaccine. Higher income and residing in the western U.S. were independently associated with Tdap vaccination, and in weighted analysis primigravida women were almost twice as likely to be vaccinated with Tdap compared to women who were non-primigravida. An additional 26% of women had not been vaccinated with Tdap yet but intended to receive the vaccine during the current pregnancy; this did not differ by race/ethnicity. Additionally, the most common factor that influenced a woman's decision to get vaccinated was a provider recommendation, followed by knowledge that babies can die from whooping cough and recommendations from family or friends. The most common reasons for not getting vaccinated were safety concerns. Six in 10 respondents had looked for information on Tdap vaccine specifically for pregnant women, and Hispanic women were more than twice as likely to have done

so compared to white non-Hispanics. Women most commonly looked for information on the vaccine's safety, side effects, whooping cough disease, and vaccine effectiveness. The most common places that women looked for information were the internet and health care professionals; friends and family were less common sources for information.

Findings from Aim 2

Aim 2 (**Chapter 4**) evaluated whether there are determinants of obstetrician-gynecologist administration or recommendation of Tdap vaccine to their pregnant patients among a sample of ACOG members. This study also estimated the prevalence of ob-gyn administration and recommendation of Tdap to pregnant women, and described reasons for non-administration by ob-gyns. The findings reveal that a majority of ob-gyns in our survey sample either administer Tdap to pregnant patients as part of routine practice or recommend Tdap but refer their patients elsewhere for vaccination. Ob-gyns who reside in the West or Midwest, administer influenza vaccine, and were in larger practices or part of a larger health system were more likely to administer Tdap to their pregnant patients. Ob-gyns who reported knowledge of Tdap recommendations and recent pertussis cases in their state also had increased Tdap administration, independent of other characteristics. The main reasons given by ob-gyns for not administering Tdap were that they do not stock the vaccine, do not think it is necessary during pregnancy because it is given postpartum, and safety concerns for mother or baby. We found that 2 in 10 ob-gyns do not stock Tdap in their offices, and the most common barriers to stocking vaccine were the expense to maintain a stock of Tdap and the relative ease of referring patients elsewhere for vaccination. Individual physician demographics were not associated with administration of Tdap, but male and older physicians were less likely to

recommend Tdap correctly in line with ACIP's current timing and dose recommendations for one dose of Tdap vaccine during each pregnancy, ideally given at 27-36 weeks gestation.

Findings from Aim 3

Aim 3 (**Chapter 5**) evaluated whether two vaccine education interventions improve Tdap vaccination among minority women during pregnancy and the postpartum period using a randomized controlled trial pilot study. This study assessed whether the two interventions based on the Elaboration Likelihood Model framework administered during the prenatal period improve Tdap uptake, and affect the reasons women report for not getting vaccinated with Tdap during pregnancy. It also assessed whether ob-gyn recommendation is associated with Tdap vaccination during pregnancy among this sub-population.

Among this group of minority pregnant women, 32% were vaccinated with Tdap during the perinatal period, although most (80% of those vaccinated) were vaccinated immediately postpartum instead of during pregnancy, according to outdated recommendations. From baseline to follow-up, women's reported intention to receive Tdap vaccine in the future improved in all three arms of the study. Women given an iPad app-based educational intervention were almost three times more likely to be vaccinated with Tdap in the perinatal period compared to those in the control arm who were only given the standard CDC vaccine information statements. This effect is primarily based on improved Tdap vaccination in the postpartum period, rather than during pregnancy.

Women given a video educational intervention were 1.5 times more likely to be vaccinated with Tdap in the perinatal period compared to those in the control arm,

although this difference was not statistically significant. Although we observed a greater effect on Tdap vaccination associated with the iPad app, observed participant engagement was higher for the video intervention than for the iPad app intervention, and women found the video easier to relate to and easier to understand. The main reasons women gave for non-vaccination were that it was not recommended by their doctor and that they did not know about the vaccine. Women who reported that their ob-gyn recommended they receive Tdap were about three times more likely to be vaccinated compared to women who were not recommended Tdap.

LIMITATIONS

There were some limitations to the studies presented in **Aims 1-3**. First, for **Aims 1** and **2**, the study samples were intended to be nationally representative, but because of sampling designs were in effect convenience samples. The ob-gyn survey was sent to all members of ACOG, but the survey had a low response rate and it is possible that the small proportion of ACOG members who completed the survey were the physicians who were most interested in vaccination and Tdap. In this case our estimates of the prevalence of ob-gyn Tdap administration would likely overestimate the true prevalence.

The women who were invited to participate in the pregnant women survey had previously agreed to be members of a survey group, and are probably different from the U.S. population as a whole with respect to some important characteristics. The study team tried to address this limitation by conducting secondary analyses in which we weighted our samples using inverse probability weights based on the demographic distributions of all ACOG members (for the ob-gyn survey) and all births in the U.S. (for

the pregnant women survey), and did not find significant differences in our conclusions between the weighted and unweighted analyses.

Second data were used from cross-sectional surveys for **Aims 1** and **2**. The cross-sectional design did not allow us to assess causality, and of particular importance did not allow for follow-up of pregnant women through delivery. Consequently, this study was not able to assess if the women who reported that they intended to be vaccinated with Tdap actually were vaccinated during their pregnancy, and if women who said they did not intend to be vaccinated with Tdap actually did not get vaccinated. Seventeen percent of our surveyed women were only in their first trimester of pregnancy, and if we had been able to follow-up with them later in pregnancy, we would have had increased accuracy of Tdap vaccination status. It is probable that there was imperfect correlation between intention to be vaccinated and actual vaccination, particularly among women who were surveyed early in pregnancy.

Third, reporting bias may have been an issue in all three of our studies. Since physicians were recruited for the **Aim 2** study through ACOG, it is possible that physicians over-reported Tdap vaccination of pregnant women because they know that ACOG recommends it. In **Aim 1**, there is potential for misclassification of the primary outcome (Tdap vaccination during pregnancy) because it was self-reported by respondents, and was not verified by medical record review. Women might have over-reported vaccination or future intent for vaccination after reading about Tdap as part of the survey questionnaire. Additionally, women were surveyed at a range of gestational ages, and many of them had not yet reached the time in pregnancy when Tdap is recommended (the third trimester). Thus, many women who were surveyed might not

have had the chance yet to be vaccinated. The study team attempted to address this by the way we defined our Tdap outcome, with two categories (1. Have been vaccinated with Tdap during current pregnancy, and 2. Intend to be vaccinated with Tdap during current pregnancy but have not been vaccinated yet). The study consequently observed a surprisingly high percentage of women in the first trimester reporting that they had been vaccinated with Tdap (31%), which deserves further study. In our **Aim 3** study, the study team also did not review medical records to validate self-reported vaccination, and was unable to match against a vaccine registry. Additionally, women were not asked about vaccination until a few months after delivery, so their reporting of both provider recommendation and vaccination may be subject to recall bias.

Fourth, there is the potential for less than ideal external validity (i.e. generalizability) in all of our studies. The ob-gyns who answered our survey (**Aim 2**) were different with respect to some demographics (age, sex) compared with all ACOG members. Additionally, the survey used for **Aim 1** was conducted via internet, so women had to have access to a computer or mobile device with high speed Internet access that would allow them to complete the web survey. This may have biased our sample toward women with higher incomes, more education, and those who live in less remote areas. Of particular note is the fact that the Hispanic respondents to our survey had a higher socioeconomic status (SES) than Hispanics in the U.S. generally. This may have been due to the fact that the survey was conducted in English only, resulting in only more acculturated Hispanics with higher SES answering our survey. It is likely that English-speaking Hispanics have higher SES and experience less barriers to prenatal care and Tdap vaccination compared with their non-English-speaking counterparts. Additionally, a

larger proportion of the Hispanics than the non-Hispanics resided in California, which has had several large pertussis outbreaks in recent years, which may have resulted in increased Tdap vaccination among Hispanics. In our **Aim 3** study, the population was a very specific demographic group – African American women in the Atlanta, GA metropolitan area. Therefore, this may limit generalizability of the findings from this study to other populations, namely non-African American populations outside of the target geographic area.

CONCLUSIONS AND FUTURE RESEARCH

The recommendation for Tdap vaccination during every pregnancy is relatively new, so it has not been studied extensively. Based upon a comprehensive review of the literature, these are among the first studies to estimate Tdap vaccination of pregnant women and to assess determinants of Tdap vaccination. This body of research has provided important information on a growing field of study, and has indicated areas for future research. Physicians who see women during pregnancy have a unique opportunity to provide education and recommendations for their pregnant patients.

The **Aim 1** study suggested that Hispanic women may have increased Tdap coverage, which is in contrast to other studies that have found lower vaccine coverage among Hispanics. Our finding may be biased by the higher SES and geography (residence in the western U.S.) of the Hispanic respondents in our study. Future studies should evaluate whether this is a valid finding, and if so seek to determine the factors that improve Tdap coverage for Hispanics. Additionally, we observed a surprisingly high percentage of women in the first trimester reporting that they had been vaccinated with

Tdap (31%). Since vaccination is recommended later in pregnancy (in the third trimester, at 27-36 weeks gestation), this high vaccination rate so early in pregnancy was unexpected, and this finding needs further study. Our study was limited by its cross-sectional design and lack of verification by medical record review or vaccine registry. Future research should follow women prospectively through pregnancy to determine if and when they are being vaccinated – and if they are being vaccinated at the recommended time (27-36 weeks gestation).

In addition, the **Aim 2** study indicated some sources of disparity in ob-gyns administering and recommending Tdap to their pregnant patients, and identified financial barriers as the most important challenge to a practice-based Tdap vaccination program. Future research should identify options to aid physicians in implementing Tdap vaccination of their patients by reducing risk and cost to physicians, potentially through partnering with nearby general practitioners or hospitals.

The **Aim 3** study was a pilot study of two vaccine educational interventions, and had a small sample size with limited power to detect associations. The results indicated that at least one of these interventions improves Tdap vaccination in the perinatal period, but we were unable to evaluate Tdap vaccination specifically during pregnancy because of small sample sizes. Therefore, a larger randomized controlled trial should be conducted to test the effects of these interventions, among a population that is more representative of all pregnant women, with oversamples of minority groups to allow for racial/ethnic sub-group analyses. Future research on Tdap vaccination of pregnant women will have important consequences for young infants who are at risk for pertussis that is largely preventable by improved perinatal vaccination.

References

1. Centers for Disease Control and Prevention. Pertussis. In: Atkinson W, Wolfe S, Hamborsky J, editors. Epidemiology and Prevention of Vaccine-Preventable Diseases. 12th ed. Washington, DC: Public Health Foundation; 2012.

2. Cohen P, Scadron SJ. The placental transmission of protective antibodies against whooping cough by inoculation of the pregnant mother. JAMA. 1943;121(9):656-62.

3. Centers for Disease Control and Prevention. Pertussis (whooping cough). Pertussis cases by year (1922-2014). http://www.cdc.gov/pertussis/surv-reporting/cases-by-year.html (Accessed Oct 05 2015).

4. Crowcroft NS, Stein C, Duclos P, Birmingham M. How best to estimate the global burden of pertussis? Lancet Infect Dis. 2003;3(7):413-8.

5. Centers for Disease Control and Prevention. Pertussis (whooping cough). Fast facts. Updated Aug 16, 2012. http://www.cdc.gov/pertussis/fast-facts.html (Accessed Jul 18 2013).

6. Centers for Disease Control and Prevention. Pertussis (whooping cough). Pertussis outbreak trends. http://www.cdc.gov/pertussis/outbreaks/trends.html (Accessed Jul 01 2013).

7. Centers for Disease Control and Prevention. 2012 final pertussis surveillance report. 2013 Aug. 62(33).

8. Centers for Disease Control and Prevention. 2014 Provisional pertussis surveillance report. http://www.cdc.gov/pertussis/downloads/pertuss-surv-report-2014.pdf (Accessed Oct 07 2015).

9. Winter K, Harriman K, Zipprich J, et al. California pertussis epidemic, 2010. J Pediatr. 2012;161(6):1091-6.

10. Healy CM, Rench MA, Castagnini LA, Baker CJ. Pertussis immunization in a high-risk postpartum population. Vaccine. 2009;27(41):5599-602.

11. World Health Organization. Pertussis vaccines: WHO position paper. Weekly Epidemiological Record. 2010;85(40):385-400.

12. Heininger U, Klich K, Stehr K, Cherry JD. Clinical findings in Bordetella pertussis infections: results of a prospective multicenter surveillance study. Pediatrics. 1997;100(6):E10.

13. Cortese MM, Baughman AL, Zhang R, Srivastava PU, Wallace GS. Pertussis hospitalizations among infants in the United States, 1993 to 2004. Pediatrics. 2008;121(3):484-92.

14. Vitek CR, Pascual FB, Baughman AL, Murphy TV. Increase in deaths from pertussis among young infants in the United States in the 1990s. Pediatr Infect Dis J. 2003;22(7):628-34.

15. Crowcroft NS, Andrews N, Rooney C, Brisson M, Miller E. Deaths from pertussis are underestimated in England. Arch Dis Child. 2002;86(5):336-8.

16. Haberling DL, Holman RC, Paddock CD, Murphy TV. Infant and maternal risk factors for pertussis-related infant mortality in the United States, 1999 to 2004. Pediatr Infect Dis J. 2009;28(3):194-8.

17. Cortese MM, Baughman AL, Brown K, Srivastava P. A "new age" in pertussis prevention new opportunities through adult vaccination. Am J Prev Med. 2007;32(3):177-85.

18. Murphy TV, Slade BA, Broder KR, et al, Advisory Committee on Immunization Practices (ACIP), Centers for Disease Control and Prevention (CDC). Prevention of pertussis, tetanus, and diphtheria among pregnant and postpartum women and their infants. Recommendations of the Advisory Committee on Immunization Practices (ACIP). MMWR Recomm Rep. 2008 May 30; 57(RR-4): 1-51. Erratum in: MMWR Morb Mortal Wkly Rep. 2008 Jul 4; 57(26): 723.

19. Plotkin SA, Orenstein WA, Offit PA. Vaccines. 6th ed. Philadelphia, Pa.: Elsevier Saunders; 2013.

20. ACIP Childhood/Adolescent Immunization Work Group, Akinsanya-Beysolow I, Jenkins R, Meissner HC. Advisory Committee on Immunization Practices (ACIP) recommended immunization schedule for persons aged 0 through 18 years -- United States, 2013. MMWR Surveill Summ. 2013 Feb 1; 62 Suppl 1: 2-8.

21. World Health Organization. Summary of WHO position papers - recommended routine immunizations for children. Updated Feb 27 2015. http://www.who.int/immunization/policy/Immunization_routine_table2.pdf (Accessed Oct 27 2015).

22. Centers for Disease Control and Prevention. National, state, and local area vaccination coverage among children aged 19–35 months--United States, 2012. MMWR Morb Mortal Wkly Rep. 2013;62(36):733-40.

23. Hill HA, Elam-Evans LD, Yankey D, Singleton JA, Kolasa M. National, state, and selected local area vaccination coverage among children aged 19-35 months - United States, 2014. MMWR Morb Mortal Wkly Rep. 2015 Aug 28;64(33):889-96.

24. World Health Organization. Global and regional immunization profile. July 2015. http://www.who.int/immunization/monitoring_surveillance/data/gs_gloprofile.pdf?ua=1 (Accessed Oct 10 2015).

25. World Health Organization. Global Immunization Data. July 2013. www.who.int/hpvcentre/Global_Immunization_Data.pdf (Accessed 27 Oct 2013).

26. Cattaneo LA, Reed GW, Haase DH, Wills MJ, Edwards KM. The seroepidemiology of Bordetella pertussis infections: a study of persons ages 1-65 years. J Infect Dis. 1996;173(5):1256-9.

27. Gerbie MV, Tan TQ. Pertussis disease in new mothers: effect on young infants and strategies for prevention. Obstet Gynecol. 2009;113(2 Pt 1):399-401.

28. Klein NP, Bartlett J, Rowhani-Rahbar A, Fireman B, Baxter R. Waning protection after fifth dose of acellular pertussis vaccine in children. N Engl J Med. 2012;367(11):1012-9.

29. Wendelboe AM, Van Rie A, Salmaso S, Englund JA. Duration of immunity against pertussis after natural infection or vaccination. Pediatr Infect Dis J. 2005;24(5 Suppl):S58-61.

30. Healy CM, Rench MA, Edwards KM, Baker CJ. Pertussis serostatus among neonates born to Hispanic women. Clin Infect Dis. 2006;42(10):1439-42.

31. de Greeff SC, Mooi FR, Westerhof A, Verbakel JM, Peeters MF, Heuvelman CJ, et al. Pertussis disease burden in the household: how to protect young infants. Clin Infect Dis. 2010;50(10):1339-45.

32. Tartof SY, Lewis M, Kenyon C, White K, Osborn A, Liko J, et al. Waning immunity to pertussis following 5 doses of DTaP. Pediatrics. 2013;131(4):e1047-52.

33. Anderson RM, May RM. Immunisation and herd immunity. Lancet. 1990;335(8690):641-5.

34. Glezen WP, Alpers M. Maternal immunization. Clin Infect Dis. 1999;28(2):219-24.

35. Healy CM, Munoz FM, Rench MA, Halasa NB, Edwards KM, Baker CJ. Prevalence of pertussis antibodies in maternal delivery, cord, and infant serum. J Infect Dis. 2004;190(2):335-40.

36. Leuridan E, Hens N, Peeters N, de Witte L, Van der Meeren O, Van Damme P. Effect of a prepregnancy pertussis booster dose on maternal antibody titers in young infants. Pediatr Infect Dis J. 2011;30(7):608-10.

37. Shakib JH, Ralston S, Raissy HH, Stoddard GJ, Edwards KM, Byington CL. Pertussis antibodies in postpartum women and their newborns. J Perinatol. 2010;30(2):93-7.

38. Van Savage J, Decker MD, Edwards KM, Sell SH, Karzon DT. Natural history of pertussis antibody in the infant and effect on vaccine response. J Infect Dis. 1990;161(3):487-92.

39. Steinhoff MC. Assessments of vaccines for prenatal immunization. Vaccine. 2013;31 Suppl 4:D27-30.

40. Zaman K, Roy E, Arifeen SE, Rahman M, Raqib R, Wilson E, et al. Effectiveness of maternal influenza immunization in mothers and infants. N Engl J Med. 2008;359(15):1555-64.

41. Poehling KA, Szilagyi PG, Staat MA, Snively BM, Payne DC, Bridges CB, et al. Impact of maternal immunization on influenza hospitalizations in infants. Am J Obstet Gynecol. 2011;204(6 Suppl 1):S141-8.

42. Dabrera G, Amirthalingam G, Andrews N, Campbell H, Ribeiro S, Kara E, et al. A case-control study to estimate the effectiveness of maternal pertussis vaccination in protecting newborn infants in England and Wales, 2012-2013. Clin Infect Dis. 2015 Feb 1;60(3):333-7.

43. Amirthalingam G, Andrews N, Campbell H, Ribeiro S, Kara E, Donegan K, et al. Effectiveness of maternal pertussis vaccination in England: an observational study. Lancet. 2014 Oct 25;384(9953):1521-8.

44. Forsyth KD, Wirsing von Konig CH, Tan T, Caro J, Plotkin S. Prevention of pertussis: recommendations derived from the second Global Pertussis Initiative roundtable meeting. Vaccine. 2007;25(14):2634-42.

45. Committee on Obstetric Practice. ACOG Committee Opinion No. 566: Update on immunization and pregnancy: tetanus, diphtheria, and pertussis vaccination. Obstet Gynecol. 2013 Jun;121(6):1411-4.

46. Broder KR, Cortese MM, Iskander JK, Kretsinger K, Slade BA, Brown KH, et al. Preventing tetanus, diphtheria, and pertussis among adolescents: use of tetanus toxoid, reduced

diphtheria toxoid and acellular pertussis vaccines recommendations of the Advisory Committee on Immunization Practices (ACIP). MMWR Recomm Rep. 2006 Mar 24;55(RR-3):1-34.

47. Halperin BA, Morris A, Mackinnon-Cameron D, Mutch J, Langley JM, McNeil SA, et al. Kinetics of the antibody response to tetanus-diphtheria-acellular pertussis vaccine in women of childbearing age and postpartum women. Clin Infect Dis. 2011;53(9):885-92.

48. Kirkland KB, Talbot EA, Decker MD, Edwards KM. Kinetics of pertussis immune responses to tetanus-diphtheria-acellular pertussis vaccine in health care personnel: implications for outbreak control. Clin Infect Dis. 2009;49(4):584-7.

49. Le T, Cherry JD, Chang SJ, Knoll MD, Lee ML, Barenkamp S, et al. Immune responses and antibody decay after immunization of adolescents and adults with an acellular pertussis vaccine: the APERT Study. J Infect Dis. 2004;190(3):535-44.

50. Lloyd KL. Protecting pregnant women, newborns, and families from pertussis. J Midwifery Womens Health. 2013;58(3):288-96.

51. Centers for Disease Control and Prevention. Updated recommendations for use of tetanus toxoid, reduced diphtheria toxoid and acellular pertussis vaccine (Tdap) in pregnant women–Advisory Committee on Immunization Practices (ACIP), 2012. MMWR Morb Mortal Wkly Rep 2013;62(07):131-5.

52. ACOG Committee on Obstetric Practice. ACOG Committee Opinion No. 566: Update on immunization and pregnancy: tetanus, diphtheria, and pertussis vaccination. Obstet Gynecol. 2013;121(6):1411-4.

53. Advisory Committee on Immunization Practices. Summary report. October 24-25, 2012. http://www.cdc.gov/vaccines/acip/meetings/downloads/min-archive/min-oct12.pdf (Accessed Jul 02 2013).

54. ACIP Pertussis Vaccine Working Group. Considerations for recommendation on Tdap for every pregnancy. Advisory Committee for Immunization Practices. 2012 Oct 24.

http://www.cdc.gov/vaccines/acip/meetings/downloads/slides-oct-2012/03-pertussis-Liang.pdf (Accessed Jul 02 2013).

55. Ahluwalia IB, Ding H, D'Angelo D, Shealy KH, Singleton JA, Liang J, et al. Tetanus, diphtheria, pertussis vaccination coverage before, during, and after pregnancy - 16 States and New York City, 2011. MMWR Morb Mortal Wkly Rep. 2015 May 22;64(19):522-6.

56. Housey M, Zhang F, Miller C, Lyon-Callo S, McFadden J, Garcia E, et al. Vaccination with tetanus, diphtheria, and acellular pertussis vaccine of pregnant women enrolled in Medicaid--Michigan, 2011-2013. MMWR Morb Mortal Wkly Rep. 2014 Sep 26;63(38):839-42.

57. Kharbanda EO, Vazquez-Benitez G, Lipkind H, Naleway AL, Klein NP, Cheetham TC, et al. Receipt of pertussis vaccine during pregnancy across 7 Vaccine Safety Datalink sites. Prev Med. 2014;67:316-9.

58. Koepke R, Eickhoff JC, Ayele RA, Petit AB, Schauer SL, Hopfensperger DJ, et al. Estimating the effectiveness of tetanus-diphtheria-acellular pertussis vaccine (Tdap) for preventing pertussis: evidence of rapidly waning immunity and difference in effectiveness by Tdap brand. J Infect Dis. 2014 Sep 15;210(6):942-53.

59. Donaldson B, Jain P, Holder BS, Lindsay B, Regan L, Kampmann B. What determines uptake of pertussis vaccine in pregnancy? A cross sectional survey in an ethnically diverse population of pregnant women in London. Vaccine. 2015 Sep 25.

60. Winter K, Glaser C, Watt J, Harriman K. Pertussis epidemic--California, 2014. MMWR Morb Mortal Wkly Rep. 2014 Dec 5;63(48):1129-32.

61. Henninger M, Crane B, Naleway A. Trends in influenza vaccine coverage in pregnant women, 2008 to 2012. Perm J. 2013;17(2):31-6.

62. Whitney CG, Zhou F, Singleton J, Schuchat A. Benefits from immunization during the vaccines for children program era - United States, 1994-2013. MMWR Morb Mortal Wkly Rep. 2014 Apr 25;63(16):352-5.

63. Williams WW, Lu PJ, O'Halloran A, Bridges CB, Kim DK, Pilishvili T, et al. Vaccination coverage among adults, excluding influenza vaccination - United States, 2013. MMWR Morb Mortal Wkly Rep. 2015 Feb 6;64(4):95-102.

64. Centers for Disease Control and Prevention. Influenza and pneumococcal vaccination levels among persons aged >= 65 years--United States, 2001. MMWR Morb Mortal Wkly Rep. 2002;51(45):1019-24.

65. Lees KA, Wortley PM, Coughlin SS. Comparison of racial/ethnic disparities in adult immunization and cancer screening. Am J Prev Med. 2005;29(5):404-11.

66. Centers for Disease Control and Prevention. Tetanus and pertussis vaccination coverage among adults aged >=18 years -- United States, 1999 and 2008. MMWR Morb Mortal Wkly Rep. 2010 Oct 15; 59(40): 1302-6.

67. Williams WW, Lu PJ, O'Halloran A, Bridges CB, Pilishvili T, Hales CM, et al. Noninfluenza vaccination coverage among adults - United States, 2012. MMWR Morb Mortal Wkly Rep. 2014 63(5):95-102.

68. Roush SW, Murphy TV. Historical comparisons of morbidity and mortality for vaccine-preventable diseases in the United States. JAMA. 2007;298(18):2155-63.

69. Centers for Disease Control and Prevention. Pertussis--United States, 1997-2000. MMWR Morb Mortal Wkly Rep. 2002;51(4):73-6.

70. Centers for Disease Control and Prevention. Pertussis--United States, 2001-2003. MMWR Morb Mortal Wkly Rep. 2005;54(50):1283-6.

71. California Department of Public Health. Pertussis report. April 24, 2012. http://www.cdph.ca.gov/programs/immunize/pages/pertussissummaryreports.aspx (Accessed July 26, 2013).

72. Halperin SA, Wang EE, Law B, Mills E, Morris R, Dery P, et al. Epidemiological features of pertussis in hospitalized patients in Canada, 1991-1997: report of the Immunization Monitoring Program--Active (IMPACT). Clin Infect Dis. 1999;28(6):1238-43.

73. Tanaka M, Vitek CR, Pascual FB, Bisgard KM, Tate JE, Murphy TV. Trends in pertussis among infants in the United States, 1980-1999. J Am Med Assoc. 2003;290(22):2968-75.

74. Skoff TH, Cohn AC, Clark TA, Messonnier NE, Martin SW. Early Impact of the US Tdap vaccination program on pertussis trends. Arch Pediatr Adolesc Med. 2012;166(4):344-9.

75. California Department of Public Health. Pertussis report. July 10, 2013. http://www.cdph.ca.gov/programs/immunize/pages/pertussissummaryreports.aspx (Accessed July 26, 2013).

76. Pan American Health Organization. Norms and Standards in Epidemiology. Case Definitions: Diphteria and Pertussis. http://www1.paho.org/english/sha/be994diphtpert.htm (Accessed Oct 29 2013).

77. Bisgard KM, Pascual FB, Ehresmann KR, Miller CA, Cianfrini C, Jennings CE, et al. Infant pertussis: who was the source? Pediatr Infect Dis J. 2004;23(11):985-9.

78. Gindler JS, Atkinson WL, Markowitz LE. Update--the United States measles epidemic, 1989-1990. Epidemiol Rev. 1992;14:270-6.

79. Mertsola J, Ruuskanen O, Eerola E, Viljanen MK. Intrafamilial spread of pertussis. J Pediatr. 1983;103(3):359-63.

80. Lambert HJ. Epidemiology of a small pertussis outbreak in Kent County, Michigan. Public Health Rep. 1965;80:365-9.

81. Broome CV, Preblud SR, Bruner B, McGowan JE, Hayes PS, Harris PP, et al. Epidemiology of pertussis, Atlanta, 1977. J Pediatr. 1981;98(3):362-7.

82. Tan T, Trindade E, Skowronski D. Epidemiology of pertussis. Pediatr Infect Dis J. 2005;24(5 Suppl):S10-8.

83. Wendelboe AM, Njamkepo E, Bourillon A, Floret DD, Gaudelus J, Gerber M, et al. Transmission of Bordetella pertussis to young infants. Pediatr Infect Dis J. 2007;26(4):293-9.

84. von Konig CH, Halperin S, Riffelmann M, Guiso N. Pertussis of adults and infants. Lancet Infect Dis. 2002;2(12):744-50.

85. Skoff TH, Kenyon C, Cocoros N, Liko J, Miller L, Kudish K, et al. Sources of Infant Pertussis Infection in the United States. Pediatr Neonatol. 2015 Oct;136(4):635-41.

86. Bamberger ES, Srugo I. What is new in pertussis? Eur J Pediatr. 2008;167(2):133-9.

87. Wendelboe AM, Hudgens MG, Poole C, Van Rie A. Estimating the role of casual contact from the community in transmission of Bordetella pertussis to young infants. Emerg Themes Epidemiol. 2007;4:15.

88. Elliott E, McIntyre P, Ridley G, Morris A, Massie J, McEniery J, et al. National study of infants hospitalized with pertussis in the acellular vaccine era. Pediatr Infect Dis J. 2004;23(3):246-52.

89. Kowalzik F, Barbosa AP, Fernandes VR, Carvalho PR, Avila-Aguero ML, Goh DY, et al. Prospective multinational study of pertussis infection in hospitalized infants and their household contacts. Pediatr Infect Dis J. 2007;26(3):238-42.

90. de Greeff SC, de Melker HE, Westerhof A, Schellekens JF, Mooi FR, van Boven M. Estimation of household transmission rates of pertussis and the effect of cocooning vaccination strategies on infant pertussis. Epidemiology. 2012;23(6):852-60.

91. Centers for Disease Control and Prevention. National and state vaccination coverage among adolescents aged 13–17 years -- United States, 2012. MMWR Morb Mortal Wkly Rep. 2013;62(34):685-93.

92. Centers for Disease Control and Prevention. National vaccination coverage among adolescents aged 13-17 years -- United States, 2006. MMWR Morb Mortal Wkly Rep. 2007;56(34):885-8.

93. Reagan-Steiner S, Yankey D, Jeyarajah J, Elam-Evans LD, Singleton JA, Curtis CR, et al. National, regional, state, and selected local area vaccination coverage among

adolescents aged 13-17 years--United States, 2014. MMWR Morb Mortal Wkly Rep. 2015 64(29):784-92.

94. Ward JI, Cherry JD, Chang SJ, Partridge S, Lee H, Treanor J, et al. Efficacy of an acellular pertussis vaccine among adolescents and adults. N Engl J Med. 2005;353(15):1555-63.

95. Acosta AM, Debolt C, Tasslimi A, Lewis M, Stewart L, Misegades LK, et al. Vaccine effectiveness and duration of protection of tetanus toxoid, reduced diphtheria toxoid and acellular pertussis among adolescents, Washington state, 2012. ID Week Poster Session. San Francisco, CA. Oct 3, 2013. https://idsa.confex.com/idsa/2013/webprogram/Paper41599.html.

96. Wei SC, Tatti K, Cushing K, Rosen J, Brown K, Cassiday P, et al. Effectiveness of adolescent and adult tetanus, reduced-dose diphtheria, and acellular pertussis vaccine against pertussis. Clin Infect Dis. 2010;51(3):315-21.

97. Booy R, Van der Meeren O, Ng SP, Celzo F, Ramakrishnan G, Jacquet JM. A decennial booster dose of reduced antigen content diphtheria, tetanus, acellular pertussis vaccine (Boostrix) is immunogenic and well tolerated in adults. Vaccine. 2010;29(1):45-50.

98. Tomovici A, Barreto L, Zickler P, Meekison W, Noya F, Voloshen T, et al. Humoral immunity 10 years after booster immunization with an adolescent and adult formulation combined tetanus, diphtheria, and 5-component acellular pertussis vaccine. Vaccine. 2012;30(16):2647-53.

99. Weston W, Messier M, Friedland LR, Wu X, Howe B. Persistence of antibodies 3 years after booster vaccination of adults with combined acellular pertussis, diphtheria and tetanus toxoids vaccine. Vaccine. 2011;29(47):8483-6.

100. Abu Raya B, Srugo I, Kessel A, Peterman M, Vaknin A, Bamberger E. The decline of pertussis-specific antibodies after tetanus, diphtheria, and acellular pertussis immunization in late pregnancy. J Infect Dis. 2015 Jun 8.

101. Hethcote HW. Simulations of pertussis epidemiology in the United States: effects of adult booster vaccinations. Math Biosci. 1999;158(1):47-73.

102. Healy CM, Ng N, Taylor RS, Rench MA, Swaim LS. Tetanus and diphtheria toxoids and acellular pertussis vaccine uptake during pregnancy in a metropolitan tertiary care center. Vaccine. 2015 Sep 11;33(38):4983-7.

103. de La Rocque F, Grimprel E, Gaudelus J, et al. Vaccination in parents of young infants survey. Arch Pediatr. 2007;14(12):1472-6.

104. Healy CM, Rench MA, Baker CJ. Implementation of cocooning against pertussis in a high-risk population. Clin Infect Dis. 2011;52(2):157-62.

105. Rosenblum E, McBane S, Wang W, Sawyer M. Protecting newborns by immunizing family members in a hospital-based vaccine clinic: a successful Tdap cocooning program during the 2010 California pertussis epidemic. Public Health Rep. 2014 May;129(3):245-51.

106. Quinn HE, Snelling TL, Habig A, Chiu C, Spokes PJ, McIntyre PB. Parental Tdap boosters and infant pertussis: a case-control study. Pediatrics. 2014 Oct;134(4):713-20.

107. Centers for Disease Control and Prevention. Noninfluenza vaccination coverage among adults - United States, 2011. MMWR Morb Mortal Wkly Rep. 2013 Feb 1; 62(4): 66-72.

108. Castagnini LA, Healy CM, Rench MA, Wootton SH, Munoz FM, Baker CJ. Impact of maternal postpartum tetanus and diphtheria toxoids and acellular pertussis immunization on infant pertussis infection. Clin Infect Dis. 2012;54(1):78-84.

109. Terranella A, Asay GR, Messonnier ML, Clark TA, Liang JL. Pregnancy dose Tdap and postpartum cocooning to prevent infant pertussis: a decision analysis. Pediatrics. 2013;131(6):e1748-56.

110. Peters TR, Banks GC, Snively BM, Poehling KA. Potential impact of parental Tdap immunization on infant pertussis hospitalizations. Vaccine. 2012;30(37):5527-32.

111. Kendrick P, Thompson M, Eldering G. Immunity response of mothers and babies to injections of pertussis vaccine during pregnancy. Am J Dis Child. 1945;70(1):25-8.

112. Lichty JA, Slavin B, Bradford WL. An attempt to increase resistance to pertussis in newborn infants by immunizing their mothers during pregnancy. J Clin Invest. 1938;17(5):613-21.

113. Gall SA, Myers J, Pichichero M. Maternal immunization with tetanus-diphtheria-pertussis vaccine: effect on maternal and neonatal serum antibody levels. Am J Obstet Gynecol. 2011;204(4):334 e1-5.

114. Healy CM, Rench MA, Baker CJ. Importance of timing of maternal combined tetanus, diphtheria, and acellular pertussis (Tdap) immunization and protection of young infants. Clin Infect Dis. 2013;56(4):539-44.

115. Cohen P, Scadron SJ. The effects of active immunization of the mother upon the offspring. J Pediatr. 1946;29(5):609-19.

116. Centers for Disease Control and Prevention. Updated recommendations for use of tetanus toxoid, reduced diphtheria toxoid and acellular pertussis vaccine (Tdap) in pregnant women–Advisory Committee on Immunization Practices (ACIP), 2012. MMWR Morb Mortal Wkly Rep 2012;62(07):131-5.

117. Yeh S, Mink C, Kim M, Naylor S, Zangwill KM, Allred NJ. Effectiveness of hospital-based postpartum procedures on pertussis vaccination among postpartum women. Am J Obstet Gynecol. 2014 Mar;210(3):237.

118. Chamberlain AT, Seib K, Ault KA, Rosenberg ES, Frew PM, Cortés M, et al. Improving influenza and Tdap vaccination during pregnancy: A cluster-randomized trial of a multi-component antenatal vaccine promotion package in late influenza season. Vaccine. 2015 Jul;33(30):3571-9.

119. Baxter CE, Barata PC. The paradox of HPV vaccines: how to reach sexually inexperienced women for protection against a sexually transmitted infection. Womens Health Issues. 2011;21(3):239-45.

120. Kirby SD, Ureda JR, Rose RL, Hussey J. Peripheral cues and involvement level: influences on acceptance of a mammography message. J Health Commun. 1998;3(2):119-35.

121. Petty R, Cacioppo J. Communication and Persuasion: Central and Peripheral Routes to Attitude Change. New York, NY: Springer-Verlag; 1986.

122. Paulussen TG, Hoekstra F, Lanting CI, Buijs GB, Hirasing RA. Determinants of Dutch parents' decisions to vaccinate their child. Vaccine. 2006 Jan 30;24(5):644-51.

123. Walters A, Long M. The effect of food label cues on perceptions of quality and purchase intentions among high-involvement consumers with varying levels of nutrition knowledge. J Nutr Educ Behav. 2012 Jul-Aug;44(4):350-4.

124. Crowcroft NS, Andrews N, Rooney C, Brisson M, Miller E. Deaths from pertussis are underestimated in England. Arch Dis Child. 2002;86(5):336-8.

125. Haberling DL, Holman RC, Paddock CD, Murphy TV. Infant and maternal risk factors for pertussis-related infant mortality in the United States, 1999 to 2004. Pediatr Infect Dis J. 2009;28(3):194-8.

126. Murphy TV, Slade BA, Broder KR, Kretsinger K, Tiwari T, Joyce PM, et al. Prevention of pertussis, tetanus, and diphtheria among pregnant and postpartum women and their infants recommendations of the Advisory Committee on Immunization Practices (ACIP). MMWR Recomm Rep. 2008;57(RR-4):1-51.

127. Vitek CR, Pascual FB, Baughman AL, Murphy TV. Increase in deaths from pertussis among young infants in the United States in the 1990s. Pediatr Infect Dis J. 2003;22(7):628-34.

128. Centers for Disease Control and Prevention. 2013 Final Pertussis Surveillance Report. 2014.

129. Centers for Disease Control and Prevention, 2014 Recommended Immunizations for Children from Birth Through 6 Years Old. http://www.cdc.gov/vaccines/schedules/easy-to-read/child.html [accessed 18 Nov 2014].

130. Housey M, Zhang F, Miller C, Lyon-Callo S, McFadden J, Garcia E, et al. Vaccination with tetanus, diphtheria, and acellular pertussis vaccine of pregnant women enrolled in Medicaid--Michigan, 2011-2013. MMWR Morb Mortal Wkly Rep. 2014;63(38):839-42.

131. Unpublished data, Centers for Disease Control and Prevention.

132. Centers for Disease Control and Prevention. Vaccines and preventable diseases: combined Tdap vaccine. http://www.cdc.gov/vaccines/vpd-vac/combo-vaccines/dtap-td-dt/tdap.htm (Accessed Jul 18, 2013).

133. Martin JA, Hamilton BE, Osterman MJ, Curtin SC, Matthews TJ. Births: final data for 2013. Natl Vital Stat Rep. 2015 Jan 15;64(1):1-65.

134. Goldfarb IT, Little S, Brown J, Riley LE. Use of the combined tetanus-diphtheria and pertussis vaccine during pregnancy. Am J Obstet Gynecol. 2014 Sep;211(3):299.e1-5.

135. Healy CM, Rench MA, Castagnini LA, Baker CJ. Pertussis immunization in a high-risk postpartum population. Vaccine. 2009 Sep 18;27(41):5599-602.

136. Johns TL, Roetzheim R, Chen R. Predictors of tetanus-diphtheria- acellular pertussis vaccination among adults receiving tetanus vaccine in the United States: data from the 2008 national health interview survey. J Prim Care Community Health. 2013;4(2):95-100.

137. Zimmerman RK, Santibanez TA, Janosky JE, Fine MJ, Raymund M, Wilson SA, et al. What affects influenza vaccination rates among older patients? An analysis from inner-city, suburban, rural, and Veterans Affairs practices. Am J Med. 2003;114(1):31-8.

138. Lindley MC, Wortley PM, Winston CA, Bardenheier BH. The role of attitudes in understanding disparities in adult influenza vaccination. Am J Prev Med. 2006;31(4):281-5.

139. Pew Research Center. Statistical portrait of Hispanics in the United States, 1980-2013. May 12, 2015. Available: http://www.pewhispanic.org/2015/05/12/statistical-portrait-of-hispanics-in-the-united-states-1980-2013/ (Accessed Oct 19 2015).

140. Harris KM, Maurer J, Lurie N. Do people who intend to get a flu shot actually get one? J Gen Intern Med. 2009;24(12):1311-3.

141. Centers for Disease Control and Prevention. Immunization schedules for infants and children. http://www.cdc.gov/vaccines/schedules/easy-to-read/child.html (Accessed Oct 12 2015).

142. Murphy TV, Slade BA, Broder KR, Kretsinger K, Tiwari T, Joyce PM, et al. Prevention of pertussis, tetanus, and diphtheria among pregnant and postpartum women and their infants recommendations of the Advisory Committee on Immunization Practices (ACIP). MMWR Recomm Rep. 2008 May 30;57(RR-4):1-51.

143. Ding H, Black CL, Ball S, Donahue S, Izrael D, Williams WW, et al. Influenza vaccination coverage among pregnant women--United States, 2013-14 influenza season. MMWR Morb Mortal Wkly Rep. 2014;63(37):816-21.

144. Clark SJ, Adolphe S, Davis MM, Cowan AE, Kretsinger K. Attitudes of US obstetricians toward a combined tetanus-diphtheria-acellular pertussis vaccine for adults. Infect Dis Obstet Gynecol. 2006;2006:87040.

145. Bonville CA, Cibula DA, Domachowske JB, Suryadevara M. Vaccine attitudes and practices among obstetric providers in New York State following the recommendation for pertussis vaccination during pregnancy. Hum Vaccin Immunother 2015;11(3):713-8.

146. Perkins RB, Anderson BL, Gorin SS, Schulkin JA. Challenges in cervical cancer prevention: a survey of U.S. obstetrician-gynecologists. Am J Prev Med. 2013;45(2):175-81.

147. Hurley LP, Bridges CB, Harpaz R, Allison MA, O'Leary ST, Crane LA, et al. U.S. physicians' perspective of adult vaccine delivery. Ann Intern Med. 2014;160(3):161.

148. Power ML, Leddy MA, Anderson BL, Gall SA, Gonik B, Schulkin J. Obstetrician-gynecologists' practices and perceived knowledge regarding immunization. Am J Prev Med. 2009;37(3):231-4.

149. Centers for Disease Control and Prevention. Pertussis (whooping cough). Pertussis cases by year (1922-2013). http://www.cdc.gov/pertussis/surv-reporting/cases-by-year.html (Accessed Nov 18, 2014).

150. Gustafsson L, Hessel L, Storsaeter J, Olin P. Long-term follow-up of Swedish children vaccinated with acellular pertussis vaccines at 3, 5, and 12 months of age indicates the need for a booster dose at 5 to 7 years of age. Pediatrics. 2006;118(3):978-84.

151. Tiwari TS, Baughman AL, Clark TA. First pertussis vaccine dose and prevention of infant mortality. Pediatrics. 2015 Jun;135(6):990-9.

152. Centers for Disease Control and Prevention. 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 -- Advisory Committee on Immunization Practices (ACIP), 2011. MMWR Morb Mortal Wkly Rep 2011;60(41):1424-6.

153. Nichol KL, MacDonald R, Hauge M. Factors associated with influenza and pneumococcal vaccination behavior among high-risk adults. J Gen Intern Med. 1996 Nov;11(11):673-7.

154. Zimmerman RK, Santibanez TA, Janosky JE, Fine MJ, Raymund M, Wilson SA, et al. What affects influenza vaccination rates among older patients? An analysis from inner-city, suburban, rural, and Veterans Affairs practices. Am J Med. 2003 Jan;114(1):31-8.

155. Guerry SL, De Rosa CJ, Markowitz LE, Walker S, Liddon N, Kerndt PR, et al. Human papillomavirus vaccine initiation among adolescent girls in high-risk communities. Vaccine. 2011 Mar 9;29(12):2235-41.

156. Ding H, Black CL, Ball S, Donahue S, Izrael D, Williams WW, et al. Influenza vaccination coverage among pregnant women--United States, 2013-14 influenza season. MMWR Morb Mortal Wkly Rep. 2014 Sep 19;63(37):816-21.

157. Vaughan PW, Rogers EM, Singhal A, Swalehe RM. Entertainment-education and HIV/AIDS prevention: a field experiment in Tanzania. J Health Commun. 2000;5 Suppl:81-100.

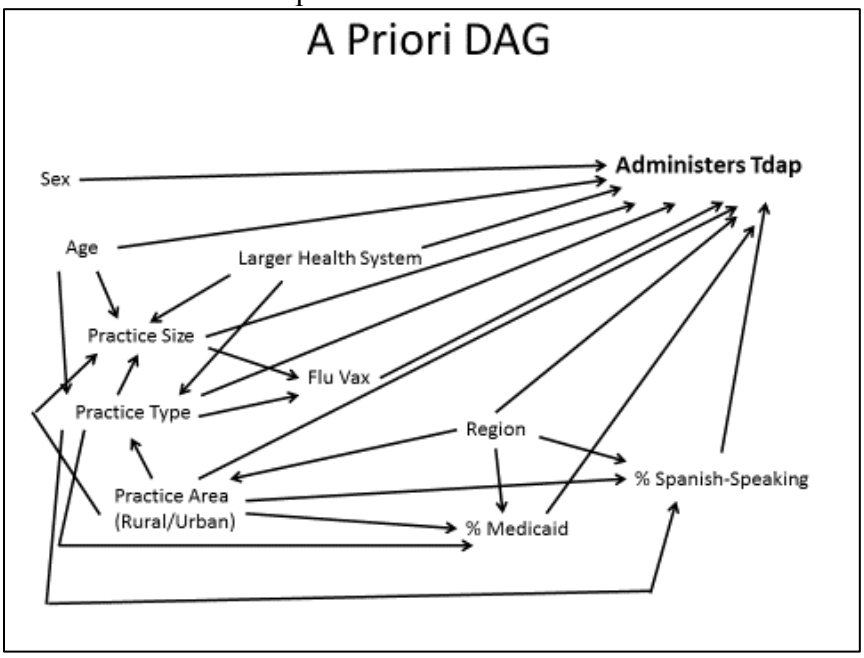
158. Jones R, Hoover DR, Lacroix LJ. A randomized controlled trial of soap opera videos streamed to smartphones to reduce risk of sexually transmitted human immunodeficiency virus (HIV) in young urban African American women. Nurs Outlook. 2013 Jul-Aug;61(4):205-15.

159. Mohammed S. Personal communication networks and the effects of an entertainment-education radio soap opera in Tanzania. J Health Commun. 2001 Apr-Jun;6(2):137-54.

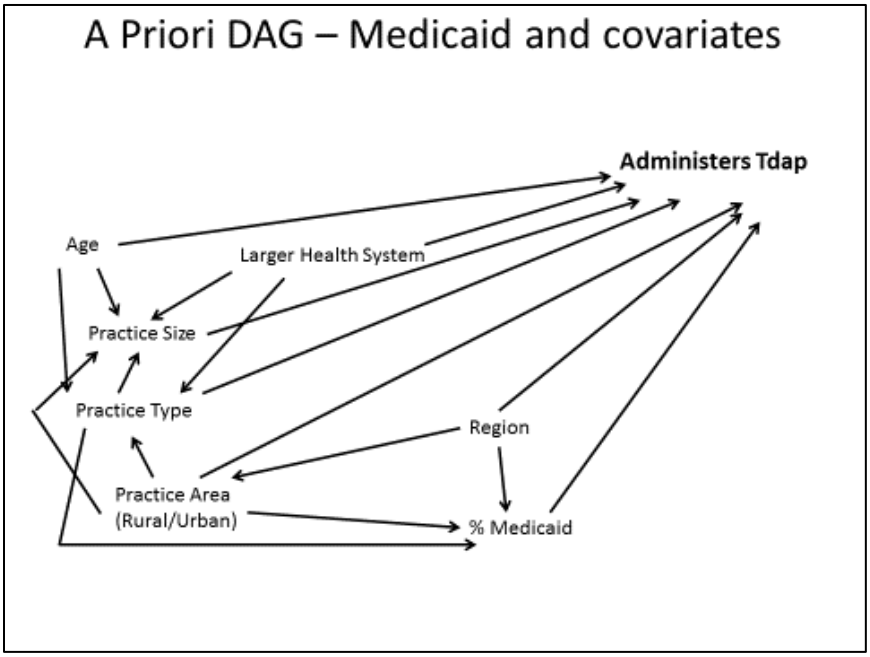
160. Glik D, Nowak G, Valente T, Sapsis K, Martin C. Youth performing arts entertainment-education for HIV/AIDS prevention and health promotion: practice and research. J Health Commun. 2002 Jan-Feb;7(1):39-57.

APPENDICES

Appendix 3.1. Directed acyclic graph for association between ob-gyn characteristics and Tdap administration.



Appendix 3.2. Directed acyclic graph for association between ob-gyn characteristics and Tdap administration, focusing on causal path between Medicaid and the outcome.



Appendix 3.3. Sample weights* used for ob-gyn survey

Age	Male	Female
20-39	1.08	0.50
40-49	2.19	0.82
50-59	1.20	1.06
60+	1.82	2.04

*Based on age and sex distribution of all ACOG members.

Appendix 3.4. Results from secondary weighted analysis
Demographic and practice characteristics of ob-gyns, in relation to administration and recommendation of Tdap vaccine to their pregnant patients **(Weighted Analyses*)**

	Total	Administers Tdap	Recommends Tdap[a]	Does not administer or recommend Tdap
Total	2,228 (100%)	1,685 (76%)	488 (22%)	55 (2%)
Sex				
Female	1,242 (56%)	970 (78%)	250 (20%)	22 (2%)
Male	986 (44%)	715 (73%)	238 (24%)	33 (3%)
Age group				
<40	471 (21%)	391 (83%)	74 (16%)	6 (1%)
40-49	660 (30%)	511 (77%)	132 (20%)	18 (3%)
50-59	629 (28%)	466 (74%)	151 (24%)	13 (2%)
60+	468 (21%)	318 (68%)	131 (28%)	19 (4%)
Practice type				
Private solo	224 (10%)	87 (39%)	124 (55%)	14 (6%)
Private group, 2-3 practitioners	217 (10%)	112 (52%)	92 (42%)	13 (6%)
Private group, 4+ practitioners	854 (38%)	668 (78%)	177 (21%)	8 (1%)
Hospital	516 (23%)	454 (88%)	51 (10%)	11 (2%)
Other type[b]	409 (18%)	359 (88%)	41 (10%)	10 (2%)
Number of practitioners in practice[c]				
1	171 (8%)	72 (42%)	93 (54%)	6 (3%)
2-5	615 (29%)	389 (63%)	199 (32%)	27 (4%)
6-9	509 (24%)	405 (79%)	99 (19%)	6 (1%)
10 or more	860 (40%)	769 (89%)	83 (10%)	8 (1%)
Part of a larger health system				
No	960 (44%)	599 (62%)	330 (34%)	30 (3%)
Yes	1,243 (56%)	1,068 (86%)	152 (12%)	23 (2%)
Administration of influenza vaccine				
Does not administer	346 (16%)	73 (21%)	255 (74%)	18 (5%)
Administers	1,869 (84%)	1,608 (86%)	232 (12%)	29 (2%)
Region				
Northeast	445 (21%)	330 (74%)	104 (23%)	11 (3%)
Midwest	522 (24%)	424 (81%)	83 (16%)	14 (3%)
South	684 (32%)	477 (70%)	183 (27%)	24 (3%)
West	504 (23%)	410 (81%)	90 (18%)	4 (1%)
Other territory	14 (1%)	9 (65%)	5 (35%)	0 (0%)
Practice area				
Rural	316 (14%)	251 (80%)	60 (19%)	5 (2%)
Suburban	986 (45%)	714 (72%)	252 (26%)	19 (2%)
Urban	907 (41%)	710 (78%)	169 (19%)	29 (3%)
Proportion of patients with Medicaid				
None	305 (14%)	213 (70%)	90 (29%)	2 (1%)
1-25%	799 (36%)	625 (78%)	166 (21%)	8 (1%)
26-50%	558 (25%)	424 (76%)	120 (22%)	14 (3%)
51-75%	338 (15%)	244 (72%)	76 (23%)	18 (5%)
>75%	202 (9%)	165 (81%)	27 (13%)	11 (5%)
Proportion of Spanish-speaking patients				
None	179 (8%)	121 (68%)	54 (30%)	3 (2%)
1-25%	1,668 (75%)	1,266 (76%)	366 (22%)	36 (2%)
26-50%	227 (10%)	181 (80%)	41 (18%)	5 (2%)

51-75%	82 (4%)	62 (76%)	16 (19%)	4 (5%)
>75%	60 (3%)	51 (84%)	7 (12%)	2 (4%)

[a] But refers them elsewhere for Tdap vaccination.
[b] Includes academic medical centers, community health clinics, and multispecialty practices.
[c] Number of doctors, nurse practitioners, physician assistants, and midwives in the practice.

Associations between characteristics of ob-gyns and administration/recommendation of Tdap vaccine to their pregnant patients **(Weighted Analyses*)**

	Administers Tdap to pregnant patients[a]		Recommends Tdap but refers patients elsewhere[b]	
	Crude OR (95% CI)	Adjusted OR[c] (95% CI)	Crude OR (95% CI)	Adjusted OR[c] (95% CI)
Sex				
Female	Ref	Ref	Ref	Ref
Male	0.7 (0.6-0.9)	1.0 (0.8-1.3)	1.3 (1.1-1.6)	0.9 (0.8-1.2)
Age group				
<40	Ref	Ref	Ref	Ref
40-49	0.7 (0.5-0.9)	1.1 (0.8-1.6)	1.4 (1.0-1.9)	0.8 (0.6-1.2)
50-59	0.6 (0.4-0.8)	1.0 (0.7-1.4)	1.7 (1.3-2.4)	1.0 (0.7-1.4)
60+	0.4 (0.3-0.6)	0.9 (0.6-1.2)	2.2 (1.6-3.0)	1.1 (0.8-1.6)
Practice type				
Private solo	Ref	Ref	Ref	Ref
Private, 2-3 practitioners	1.7 (1.1-2.4)	1.6 (0.9-2.8)	0.6 (0.4-0.9)	0.7 (0.4-1.2)
Private, 4+ practitioners	5.7 (4.1-7.8)	2.9 (1.7-5.1)	0.2 (0.1-0.3)	0.4 (0.2-0.7)
Hospital	11.5 (7.9-16.8)	3.7 (2.0-6.9)	0.1 (0.1-0.1)	0.3 (0.1-0.5)
Other type[d]	11.2 (7.5-16.7)	4.0 (2.1-7.6)	0.1 (0.1-0.1)	0.3 (0.1-0.5)
Number of practitioners in practice[e]				
1	Ref	Ref	Ref	Ref
2-5	2.3 (1.7-3.3)	0.9 (0.5-1.5)	0.4 (0.3-0.6)	0.8 (0.5-1.2)
6-9	5.3 (3.6-7.7)	1.4 (0.7-2.6)	0.2 (0.1-0.3)	0.5 (0.3-0.9)
10 or more	11.5 (7.9-16.6)	2.5 (1.3-4.7)	0.1 (0.1-0.1)	0.3 (0.2-0.5)
Part of a larger health system				
No	Ref	Ref	Ref	Ref
Yes	3.7 (3.0-4.5)	2.2 (1.7-2.9)	0.3 (0.2-0.3)	0.5 (0.3-0.6)
Administration of influenza vaccine				
Does not administer	Ref	Ref	Ref	Ref
Administers	23.1 (17.3-30.9)	21.1 (15.0-29.7)	0.04 (0.03-0.06)	0.05 (0.03-0.07)
Region				
Northeast	Ref	Ref	Ref	Ref
Midwest	1.5 (1.1-2.1)	1.5 (1.1-2.2)	0.6 (0.5-0.9)	0.6 (0.4-0.9)
South	0.8 (0.6-1.1)	1.0 (0.7-1.3)	1.2 (0.9-1.6)	1.1 (0.8-1.5)
West	1.5 (1.1-2.1)	1.6 (1.1-2.3)	0.7 (0.5-0.9)	0.7 (0.5-1.0)
Other territory	0.7 (0.2-2.0)	2.6 (0.5-13.1)	1.7 (0.5-5.2)	0.4 (0.1-2.2)
Practice area				
Urban	Ref	Ref	Ref	Ref
Suburban	0.7 (0.6-0.9)	1.0 (0.8-1.3)	1.5 (1.2-1.9)	1.0 (0.8-1.4)
Rural	1.1 (0.8-1.5)	1.6 (1.1-2.3)	1.0 (0.7-1.4)	0.7 (0.5-1.0)
Proportion of patients with Medicaid				
None	Ref	Ref	Ref	Ref

1-25%	1.6 (1.2-2.1)	0.8 (0.6-1.2)	0.6 (0.5-0.9)	1.2 (0.8-1.7)
26-50%	1.4 (1.0-1.9)	0.6 (0.4-0.8)	0.7 (0.5-0.9)	1.7 (1.1-2.4)
51-75%	1.1 (0.8-1.6)	0.4 (0.3-0.6)	0.7 (0.5-1.1)	2.2 (1.4-3.4)
>75%	1.9 (1.2-2.9)	0.4 (0.2-0.8)	0.4 (0.2-0.6)	2.0 (1.1-3.7)
Proportion of Spanish-speaking patients				
None	Ref	Ref	Ref	Ref
1-25%	1.5 (1.1-2.1)	1.1 (0.8-1.7)	0.7 (0.5-0.9)	0.8 (0.6-1.3)
26-50%	1.9 (1.2-2.9)	1.1 (0.6-1.9)	0.5 (0.3-0.8)	0.8 (0.5-1.5)
51-75%	1.5 (0.8-2.7)	0.6 (0.3-1.3)	0.6 (0.3-1.1)	1.4 (0.6-2.9)
>75%	2.5 (1.2-5.3)	1.5 (0.6-4.1)	0.3 (0.1-0.7)	0.5 (0.2-1.6)

[a] Compared to 'Does not administer Tdap to pregnant patients'.
[b] Compared to 'Administers Tdap to pregnant patients.'
[c] Adjusted for provider age, practice type, practice size, larger health system, region, and urban/suburban/rural.
[d] Includes academic medical centers, community health clinics, and multispecialty practices.
[e] Number of doctors, nurse practitioners, physician assistants, and midwives in the practice.

Associations between knowledge of and personal experience with Tdap vaccine and pertussis and Ob-Gyn administration of Tdap vaccine to their pregnant patients **(Weighted Analyses*)**

	Administers Tdap n (%)	Crude OR[a] (95% CI)	Adjusted OR[b] (95% CI)
Knowledge			
Have there been cases of pertussis in past year in the state where you practice			
No	55 (59)	Ref	Ref
Yes	1,280 (78)	2.5 (1.6-3.8)	2.0 (1.2-3.4)
Household contacts are the most common source of pertussis infection for infants			
False	11 (78)	Ref	Ref
True	1,603 (77)	0.9 (0.3-3.3)	1.3 (0.3-5.3)
The CDC and ACOG recommend that women receive Tdap vaccine during every pregnancy			
False	25 (49)	Ref	Ref
True	1,618 (78)	3.6 (2.1-6.3)	3.1 (1.5-6.3)
Personal Experience			
Had pertussis	96 (77)	1.1 (0.7-1.6)	1.1 (0.6-1.7)
Know someone who had pertussis	389 (78)	1.1 (0.9-1.4)	1.0 (0.8-1.3)
Personally treated patients with pertussis	165 (80)	1.3 (0.9-1.9)	1.1 (0.8-1.7)
Personally treated patients exposed to pertussis	133 (78)	1.1 (0.8-1.6)	1.1 (0.7-1.7)
Delivered a baby who was diagnosed with pertussis	64 (67)	0.6 (0.4-1.0)	0.7 (0.4-1.1)
No personal experience with pertussis	995 (74)	0.8 (0.7-1.0)	0.9 (0.7-1.1)

*Weighted by age and sex to the ACOG member population using inverse probability weights.
[a] Compared to 'Does not administer Tdap to pregnant patients'.
[b] Adjusted for provider age, practice type, practice size, larger health system, region, and urban/suburban/rural.