

Women and children first: the importance of pertussis and influenza vaccination in pregnant women and how to increase vaccine uptake

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ABSTRACT

Vaccination during pregnancy has been proven effective in protecting both pregnant women and their newborns from infectious diseases. An increasing number of countries have issued recommendations for the use of pertussis and influenza vaccines during pregnancy and are offering these vaccines free of charge. However, even in such countries, despite the demonstrated effectiveness and strong safety profile of maternal pertussis and influenza vaccination, vaccine uptake has remained suboptimal. This paper gives a succinct overview of the available evidence supporting maternal pertussis and influenza vaccination, summarizes the factors that can influence vaccine uptake during pregnancy and provides practical advice on how healthcare providers in an obstetrics setting can contribute to the successful implementation of maternal immunization programs.

To help increase uptake, practitioners should recommend maternal pertussis and influenza vaccination to their patients during the first antenatal visit. They should give information about the effectiveness and safety of maternal immunization, and about the risk of infection and severity of the respective diseases in the absence of vaccination. Ideally, vaccines should be offered on-site during one of the routine antenatal visits, thereby maximizing convenience for the patient. Strategies to increase uptake will need to be tailored to the antenatal care model of the specific country but, regardless of the model, should aim to incorporate vaccination into standard antenatal care. To do so, healthcare professionals involved in the delivery of vaccines should be clearly identified and adequately trained, standing orders could be instituted (allowing midwives and obstetric nurses to administer vaccines), reminders about vaccination could be added to the patient's medical records and the patient's vaccination status should be well documented. These measures could help establish maternal immunization as the norm in the general population and increase acceptance and uptake.

KEYWORDS

Maternal immunization, Tdap, obstetricians, gynecologists, midwives.

Introduction

In the last two decades, tremendous progress has been made in reducing global child mortality, in part due to the successful implementation of infant vaccination programs to prevent infectious diseases^[1-4]. As most pediatric vaccines are not administered until 6-12 weeks of age, and full protection is not normally achieved until completion of a multi-dose primary series several months later, newborns and young infants are particularly vulnerable to vaccine-preventable infectious diseases^[5,6]. Protection against these diseases during the first months of life relies on passive immunity by maternal antibodies transferred via the placenta, particularly during the third trimester^[7-10]. However, maternal antibody levels are often suboptimal (if a mother has not been recently vaccinated against or exposed to the pathogen) and decline rapidly in infants during the first months of life, leaving a susceptibility gap of several months (Figure 1)^[8,10,11]. Maternal immunization is increasingly being used as a strategy to close this susceptibility gap:

Article history

Received 4 Nov 2020 - Accepted 1 Feb 2021

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vaccination during pregnancy increases pathogen-specific antibody concentrations in the mother's serum and thereby aims to achieve protective levels of transplacentally transferred maternal antibodies in the newborn that persist until protection can be achieved from the infant vaccination series (Figure 1)^[6,8-10]. Vaccine-induced antibodies in breast milk and a reduced risk of transmission from the mother to her infant after birth may further contribute to infant protection^[12,13]. Moreover, vaccinating pregnant women protects the women themselves during a period when they are more vulnerable to severe disease from some infections, due to pregnancy-related physiological and immunological changes^[9,10,13].

Tetanus vaccination of pregnant women in developing countries has been used successfully for decades to protect infants from neonatal tetanus [14-16].

Additionally, maternal pertussis and influenza vaccination programs have been introduced in many countries and have proven to be effective in preventing disease in young infants and/or pregnant women [17, 18]. Nevertheless, pertussis and influenza vaccine uptake during pregnancy remain suboptimal, even in countries where recommendations from governing

bodies are in place and vaccines are reimbursed [19-24].

Our paper i) provides an overview of the available evidence supporting maternal pertussis and influenza vaccination, ii) summarizes the factors that can influence vaccine uptake during pregnancy and iii) provides practical advice on how healthcare providers in an obstetrics setting can translate the available evidence into clinical practice and contribute to the successful implementation of maternal immunization programs. A plain language summary is provided in Figure 2.

Figure 1 Protecting young infants through maternal immunization. Maternal antibody levels in infants from mothers that have not been recently exposed to or vaccinated against a specific pathogen (dotted blue line) are often suboptimal and decline rapidly after birth, leaving a susceptibility gap of several months (green line) until the infant is protected through its primary vaccination series. Vaccination during pregnancy aims to increase pathogen-specific antibody concentrations in the mother's serum and achieve protective levels of transplacentally transferred maternal antibodies in the newborn (full blue line) that persist until the infant is protected through its primary vaccination series.

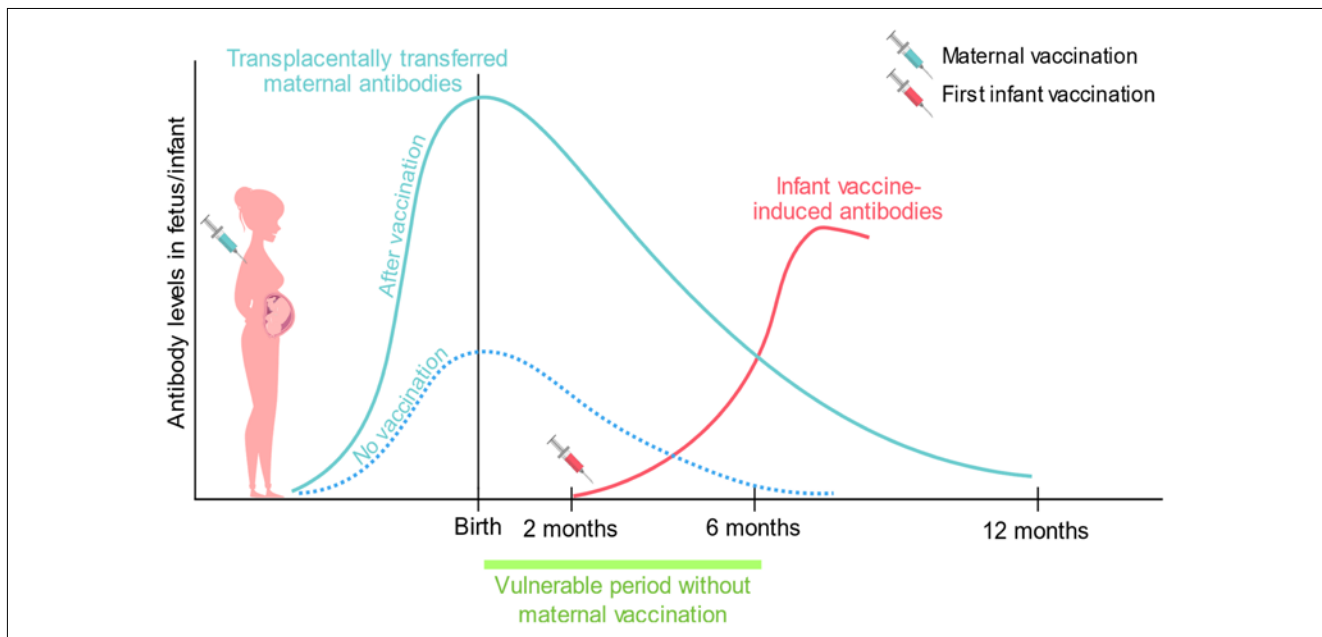


Figure 2 Plain language summary.

What is the context?

- Diseases such as whooping cough and flu can be very serious for young babies before they are protected by childhood vaccinations. Flu can also be harmful to pregnant women.
- Vaccinating mothers during pregnancy can help protect them and their babies from these diseases.
- Although many countries recommend vaccination against whooping cough and flu during pregnancy, vaccine uptake remains suboptimal in pregnant women..

What is new?

- This paper summarizes the factors that can influence vaccine uptake during pregnancy and advises how healthcare practitioners such as obstetricians, midwives and nurses can encourage vaccination in pregnant women.
- To improve vaccine uptake, healthcare providers in an obstetric setting should:
 - recommend vaccination to their pregnant patients at their first antenatal visit
 - educate about the effectiveness and safety of vaccines
 - explain the potential consequences of not vaccinating
- In addition, obstetric facilities should consider:
 - offering the vaccines on-site
 - administering the vaccines during a routine antenatal visit

What is the impact?

- These approaches should help raise awareness of the benefits of maternal immunization, encourage its standardization in antenatal care and improve vaccine uptake in pregnant women.

Clinical evidence supporting maternal pertussis and influenza vaccination

Medical need for maternal pertussis and influenza vaccination

Pertussis

Pertussis (or whooping cough) is a highly contagious respiratory disease caused by the bacterium *Bordetella pertussis*. It has its greatest burden in infants, especially during the first months of life before protection through infant vaccination has been established [25-27]. Neonates and very young infants are at greatest risk of severe pertussis-related complications, including hypoxia, seizures, encephalopathy, leukocytosis, pneumonia, pulmonary hypertension and death [28, 29]. Despite effective vaccination programs, *B. pertussis* continues to circulate within populations, and cyclical peaks of disease occur every 2–5 years [26, 30]. In response to a rise in the number of pertussis cases and associated infant deaths in some countries between 2008 and 2012, supplemental strategies to reduce infant mortality from pertussis infections were explored [26]. These include cocooning (vaccination of a newborn's mother [*postpartum*], other household contacts and caregivers to reduce the newborn's risk of exposure to *B. pertussis*), neonatal immunization and maternal immunization [26, 30]. While successes were observed with cocooning in some settings, immunization of all household contacts and caregivers can be logistically challenging and is estimated to be less cost-effective than maternal immunization. In addition, a susceptibility gap likely remains while immunity is being established in the mother/household contacts [26, 31, 32]. A birth dose of acellular pertussis vaccine (neonatal vaccination) was shown to be immunogenic and well tolerated in clinical trials, but protection cannot be expected in the first vulnerable weeks of life [26, 33-35]. Currently, maternal immunization is considered as the most effective and favorable option to supplement infant vaccination to combat pertussis disease in young infants [26, 30, 32].

Influenza

Data from influenza pandemics and epidemics have shown that pregnant women are at increased risk of severe influenza-related complications, hospitalization and death [17, 36]. Influenza infection during pregnancy may also lead to fetal growth restriction, preterm delivery, stillbirth and neonatal death [17, 36]. Moreover, infants younger than 6 months (who are not eligible to receive influenza vaccination) have a high risk of developing severe influenza disease [17, 36]. As a result, maternal influenza vaccination is offered in many countries to reduce these risks to mother and infant [10, 17].

Effectiveness and safety of maternal pertussis and influenza vaccination

Pertussis

(Systematic) reviews including up to nearly 200,000 women immunized with acellular pertussis-containing vaccines during pregnancy showed no significant differences between pertussis-vaccinated and unvaccinated women in terms of pregnancy- and neonate-related safety outcomes, except for a small increased relative risk (but low absolute risk) of chorioamnionitis

(i.e., an infection of the amniotic cavity) [18, 37-41]. However, no increased risk for clinical sequelae related to chorioamnionitis (such as preterm birth or neonatal sepsis) were found [18, 39, 41]. Hence, the clinical significance of this finding is questionable. A possible association between maternal Tdap vaccination and chorioamnionitis is being further evaluated [42]. Vaccine effectiveness estimates were 69%–93% for laboratory-confirmed pertussis, 91%–94% for pertussis-related hospitalizations and 95% for pertussis-related deaths in infants younger than 2 or 3 months [18, 43-49]. These data underscore the great benefit and strong safety profile of maternal pertussis vaccination.

Influenza

Inactivated influenza vaccines have been administered to millions of pregnant women to date, and no increased risk of maternal complications or adverse fetal outcomes associated with influenza vaccination have been found [17]. Maternal influenza vaccination was proven to protect pregnant women from laboratory-confirmed influenza [17, 50], reduce the risk of adverse pregnancy outcomes (e.g., pre-eclampsia, stillbirth) [17, 51], and protect infants from laboratory-confirmed influenza and influenza-related hospitalization [17, 52, 53].

Current recommendations

Pertussis

Prompted by a rise in the reported number of pertussis cases leading to several infant deaths, the United States (US) and the United Kingdom (UK) were the first countries to recommend the administration of pertussis-containing vaccines during pregnancy (from 2011 and 2012, respectively) [54-57]. Both countries currently recommend vaccination of all pregnant women in each pregnancy with the tetanus-reduced-antigen-content-diphtheria-acellular pertussis vaccine (Tdap, in the US) or Tdap-inactivated poliovirus vaccine (Tdap-IPV, in the UK) [55, 58].

Currently (as of June 2020), more than 40 countries worldwide (including at least 15 countries in Europe) have official Tdap maternal immunization recommendations in place, issued by national recommending bodies or professional organizations (Table 1, Figure 3). The World Health Organization (WHO) recommends vaccination of pregnant women with one dose of Tdap (in the second or third trimester and preferably at least 15 days before the end of pregnancy to ensure sufficient time for antibody transfer) in countries or settings with high or increasing pertussis-related infant morbidity or mortality [30].

Influenza

Influenza vaccination in pregnant women was first recommended in the US in the 1960s, after a higher risk of complications was noted in this population during the 1957 flu pandemic [14, 15]. Recommendations changed over time in terms of target group and window of vaccination, but since 2004, the Advisory Committee on Immunization Practices recommends immunization with inactivated influenza vaccines for all pregnant women who are or will be pregnant during the influenza season at any gestation [59]. In 2012, the WHO issued a recommendation for

Table 1 Recommendations for pertussis vaccination during pregnancy in different countries and by international organizations.

Country/Organization	Recommendation	Reference
Argentina	Tdap from 20 weeks' gestation	95
Australia	Tdap ideally at 20–32 weeks' gestation	96
Bahamas	Tdap in each pregnancy	97
Belgium	Tdap ideally at 24–32 weeks' gestation	98
Bermuda	Tdap in second or third trimester	99
Brazil	Tdap ideally at 27–36 weeks' gestation ^a	100
Canada	Tdap ideally at 27–32 weeks' gestation ^b	101
Chile	Acellular pertussis vaccine at 27–36 weeks' gestation	102
Colombia	Tdap from 26 weeks' gestation	103
Costa Rica	Tdap in third trimester	104
Czech Republic	Tdap ideally at 28–36 weeks' gestation	105
Denmark	Tdap ideally at 32 weeks' gestation ^c	106
El Salvador	Tdap from 20 weeks' gestation	107
French Territories (Mayotte)	Tdap-IPV ideally at 18–39 weeks' gestation ^d	108
Germany	Tdap at the beginning of the third trimester	109
Greece	Tdap at 27–36 weeks' gestation	110
Honduras	Tdap during pregnancy in whooping cough outbreak situations	111
Hong Kong	Tdap (or Tdap-IPV) in second or third trimester (ideally before 35 weeks)	112
Iceland	Tdap or Tdap-IPV in second or third trimester	113, 114
India	Tdap in third trimester (ideally at 27–36 weeks)	115
Ireland	Tdap ideally at 16–36 weeks' gestation	116
Israel	Tdap at 27–36 weeks' gestation	117
Italy	Tdap at 27–36 (ideally 28) weeks' gestation	118
Mexico	Tdap at 20–32 weeks' gestation	119
Netherlands	Tdap from 22 weeks' gestation	120
New Zealand	Tdap from 16 weeks' gestation	121
Panama	Tdap in third trimester	122
Paraguay	Tdap from 20 weeks' gestation	123
Peru	Tdap at 27–36 weeks' gestation	124
Philippines	Tdap at 28–36 weeks' gestation	125
Poland	Tdap at 27–36 weeks' gestation	126
Portugal	Tdap at 20–36 weeks' gestation	114
Qatar	Tdap at 27–36 weeks' gestation	127
San Marino	Tdap at 21–36 weeks' gestation	128
Saudi Arabia	Tdap in third trimester	129
Singapore	Tdap ideally at 16–32 weeks' gestation	130
Slovenia	Tdap from 24 weeks' gestation	114
South Korea	Tdap at 27–36 weeks' gestation	131
Spain	Tdap from 27 weeks' gestation	132
Switzerland	Tdap ideally at 13–26 weeks' gestation ^f	133
Taiwan	Tdap at 28–36 weeks' gestation	134
Thailand	Tdap in third trimester	135
UK	Tdap-IPV ideally at 16–32 weeks' gestation (up to 38 weeks)	136, 137
Uruguay	Tdap in each pregnancy	138
USA	Tdap at 27–36 weeks' gestation	55
EBCOG	Tdap ideally at 27–36 weeks' gestation ^g	139
FIGO	Tdap ideally at 27–36 weeks' gestation	140
PAHO	Tdap in second or third trimester ^h	141
WHO	Tdap in second or third trimester ^h	30

Note, this list may not be complete and may change over time.

EBCOG, European Board and College of Obstetrics and Gynecology; FIGO, International Federation of Gynecology and Obstetrics; PAHO, Pan American Health Organization; Tdap, tetanus-reduced-antigen-content-diphtheria-acellular pertussis vaccine; Tdap-IPV, tetanus-reduced-antigen-content-diphtheria-acellular pertussis-inactivated poliovirus vaccine; UK, United Kingdom; USA, United States of America; WHO, World Health Organization.

^a In areas that are hard to reach, vaccines can be administered from 20 weeks' gestation. Women should ideally be vaccinated at least 20 days before planned delivery.

^b Vaccination between 13 and 26 weeks of gestation may be considered in women with an increased risk of preterm delivery. Women should ideally be vaccinated at least 4 weeks before planned delivery.

^c Temporary program starting on 1 November 2019 and concluding on 31 January 2020. Vaccines can be offered after 32 weeks' gestation, until 1 week before planned delivery. Women with a high risk of preterm delivery should be vaccinated in the second trimester (but not before 16 weeks' gestation).

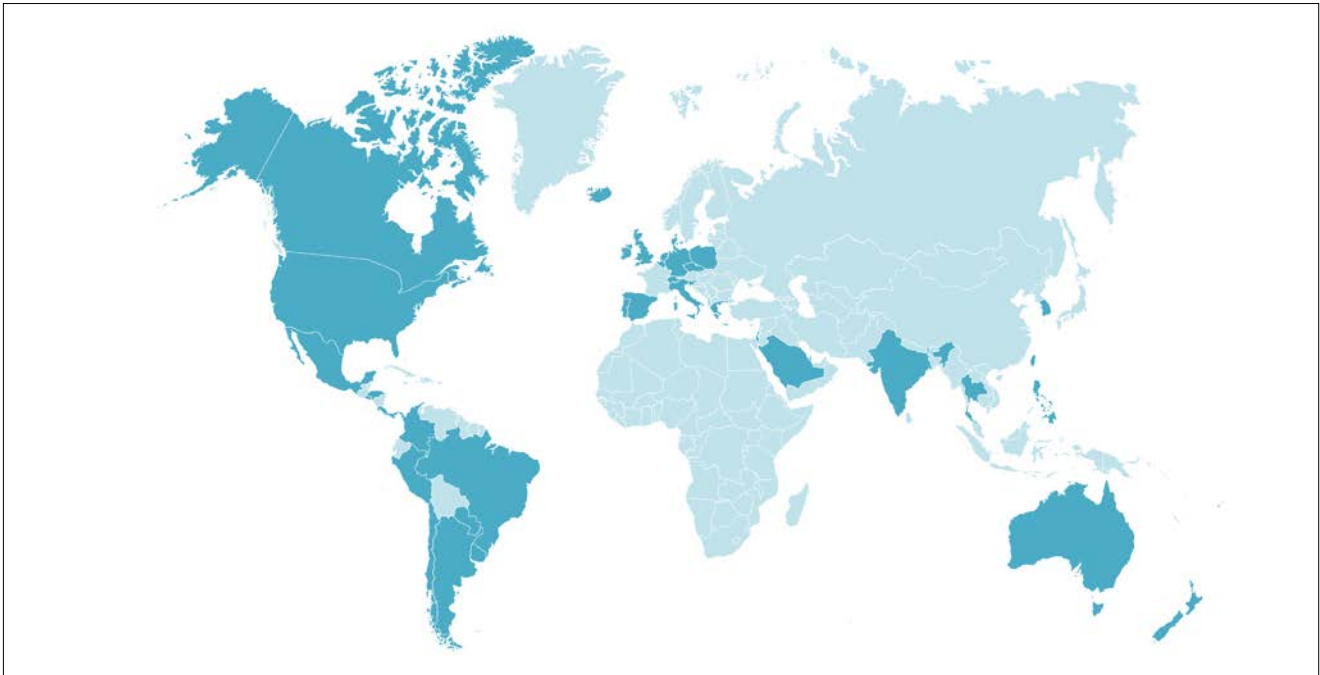
^d Program in place for the duration of the ongoing pertussis epidemic.

^e Women with a high risk of preterm delivery should be vaccinated in the second trimester.

^f Vaccination allowed throughout the second or third trimester.

^g Tdap can be given any time during pregnancy.

^h Vaccination preferably at least 15 days before delivery.

Figure 3 Countries with recommendations for maternal immunization with pertussis-containing vaccines. See references in Table 1.

countries to include pregnant women in their seasonal influenza vaccination programs and give them the highest priority ^[60]. Recommendations for maternal influenza vaccination are now in place in many countries across the Americas, Europe and Asia ^[10]. As of June 2020, at least 90 countries have influenza vaccination programs specifically aimed at pregnant women ^[61].

Factors affecting vaccine uptake during pregnancy

Pertussis and influenza vaccine uptake during pregnancy

Despite the strong safety profile and demonstrated effectiveness of maternal pertussis and influenza vaccination in protecting newborns and/or pregnant women, vaccine uptake has remained suboptimal, even in countries with recommendations for their use ^[19]. Pertussis vaccine uptake during pregnancy is often higher than that of influenza (possibly because mothers prioritize their newborns' health over their own and perceive pertussis vaccination as protecting the newborn and influenza vaccination as protecting the mother ^[62]) but remains below desired levels ^[20-24]. Based on results from an internet panel survey, vaccination coverage in the US in the 2017–18 influenza season was 54% for Tdap during pregnancy (among women with live births) and 49% for influenza before or during pregnancy (among women pregnant during the peak influenza period) ^[21]. The estimated vaccine uptake in pregnancy in the UK (2018–19) and Belgium (2016) was around 70% for pertussis and 45% for influenza ^[22-24]. Vaccination coverage varies widely between countries, even among those with recommendations in place. For instance, among 11 European countries with readily available coverage data, influenza vaccine uptake during pregnancy varied from <1% to 86.5% in 2014–15, with a median of 8.7% ^[20].

Factors affecting vaccine uptake

Several factors have been identified that either positively or negatively affect vaccine uptake in pregnant women. These have been discussed in detail in recent reviews ^[17, 63-67] and are summarized in Figure 4. A key factor in vaccine acceptance and uptake by pregnant women is a recommendation by a trusted healthcare provider ^[64, 65]. This was reported in multiple studies and surveys addressing barriers and facilitators for vaccine uptake in pregnant women ^[17, 64, 65]. A meta-analysis showed that pregnant women who had received a recommendation from a healthcare provider had 12-times and 10-times greater odds of accepting seasonal influenza and pertussis vaccination, respectively ^[68]. Other important barriers identified by pregnant women may vary between vaccines and include concerns about their own safety and (most importantly) that of their fetus and newborn, lack of knowledge about the risk of infection and severity of the diseases, doubts about vaccine effectiveness (mostly noted for influenza) and general vaccine hesitancy ^[17, 64, 65]. In addition, access to a healthcare facility offering the vaccine, cost/insurance coverage (in settings in which the vaccines are not offered free of charge) and demographic and psychosocial factors influence a woman's decision to get vaccinated (Figure 4) ^[17, 64, 65].

Barriers identified by healthcare workers partly overlap with those reported by pregnant women and include concerns about vaccine safety and effectiveness, and lack of knowledge about disease risk and severity. Healthcare workers also highlight additional barriers related to knowledge and education (e.g., inadequate training on how to administer vaccines and educate pregnant women, confusion or unawareness about guidelines and recommendations), related to implementation (e.g., vaccination not being part of their routine practice, logistical and financial concerns around obtaining, ordering, storing and administering vaccines, difficulties in accessing patients' vaccination records, increased workload and staff shortage,

questions about liability), and related to uptake (e.g., unwillingness of pregnant women to be vaccinated) [17, 64, 65].

How to improve vaccine uptake during pregnancy

Below, we highlight actions that healthcare providers in an obstetrics setting can take to improve vaccine uptake among pregnant women (Figure 5). We focused on interventions for

which evidence is available from randomized, controlled trials or prospective or retrospective observational studies [69-71]. Most available evidence originates from studies in the US and may not always fully apply to other parts of the world. Strategies to increase uptake need to be tailored to the maternal healthcare infrastructure of the specific country [72]. For instance, official recommendations may or may not be in place, vaccines may or may not be available free of charge, and the principal care of pregnant women may be provided by the obstetrician, the midwife or the general practitioner.

Figure 4 Factors affecting uptake of vaccines during pregnancy, identified by pregnant women and healthcare providers.

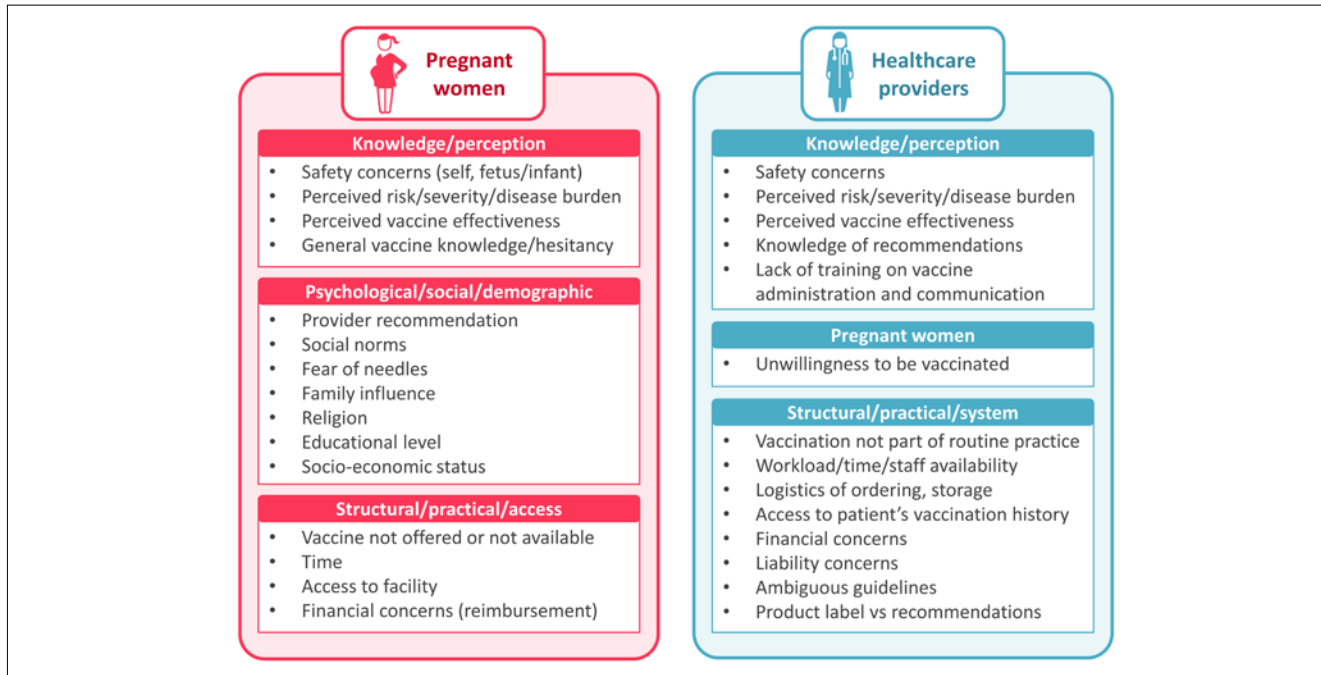
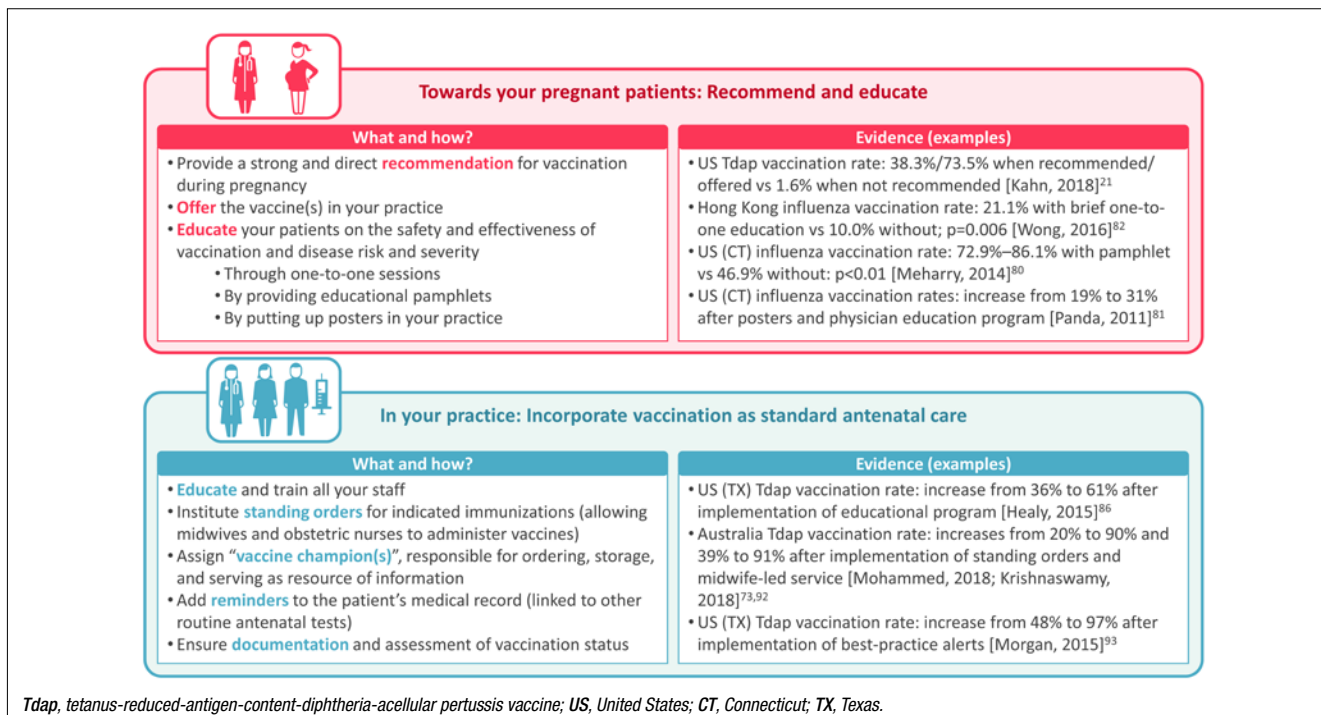


Figure 5 Interventions to increase vaccine uptake during pregnancy.



Tdap, tetanus-reduced-antigen-content-diphtheria-acellular pertussis vaccine; US, United States; CT, Connecticut; TX, Texas.

Recommend and educate

One of the strongest motivators for women to get vaccinated during pregnancy is a recommendation from a trusted healthcare provider [64, 65, 73–79]. We therefore advise that, during the first antenatal visit, practitioners recommend vaccination to their patients and give information and resources about antenatal pertussis and influenza vaccination, in particular about the official recommendations, the benefits for the newborn baby, the reassuring safety profile in mother and child and the risks of infection and severity of the respective diseases in the absence of vaccination.

One-to-one education sessions, pamphlets and posters have all been shown to improve vaccination rates (Figure 5) [80–82]. A randomized controlled trial in Hong Kong during the 2013–14 and 2014–15 influenza seasons showed higher influenza vaccination rates in women who had received a 10-minute one-to-one education compared to women who had received standard care [82]. A randomized trial in Connecticut (US) during the 2011–12 influenza season found higher influenza vaccination rates in pregnant women who had received an education pamphlet with or without a benefit statement compared to women who had received neither [80].

Additionally, a randomized trial conducted between 2013 and 2016 in Colorado (US) showed a significant impact of a vaccine information website with or without interactive social media components on the uptake of influenza but not Tdap vaccine [83] indicating that strategies to improve vaccine uptake likely need to be tailored to the specific vaccine.

Incorporate vaccination as standard antenatal care

Because the obstetrician and/or midwife are in many countries the only (or principal) healthcare provider a woman sees during her pregnancy, we advise that—in such countries—pertussis and influenza vaccines should be administered by the obstetrician or, if authorized by local law, by the midwife or obstetric nurse during one of the routine antenatal visits. This avoids an additional visit to a general practitioner, saves time and effort and maximizes convenience for the pregnant woman. Offering the vaccine(s) on-site has been shown to increase uptake (Figure 5) [21, 84]. Even in countries where the principal healthcare provider is the general practitioner, a recommendation by the obstetrician and midwife to vaccinate as part of standard care would be important.

To incorporate vaccination as a standard part of antenatal care and thereby making women (and the general population) see it as a normal component of pregnancy care, it is important to create a culture of immunization among all staff [72, 85]. Staff should be trained and educated in terms of vaccine and disease knowledge, recommendations about maternal vaccination and the technical aspects of stocking and administering vaccines, such that they feel confident about implementing an immunization program, a task that has not historically been theirs. A retrospective study in Texas (US) saw improved antenatal Tdap vaccination rates after a physician training program was set up (Figure 5) [86]. The American College of Obstetricians and Gynecologists suggests assigning an immunization “champion” (or team) serving as a resource center for other staff members and taking the responsibility of ordering, receiving and storing vaccines [85].

In countries where midwives provide a substantial portion of antenatal care, midwives are a highly accessed and trusted source of vaccine information [87, 88]. Surveys in Australia and the UK indicate that while the majority of midwives support antenatal immunizations, a large fraction do not feel adequately trained but would be willing to discuss and administer vaccines with appropriate training (provided this is authorized pursuant to local laws) [89–91]. Considering the important roles midwives play in prenatal follow-up of patients in many countries, it is advisable to institute standing orders for the indicated vaccinations, authorizing midwives to administer vaccines according to a protocol approved by a physician but without needing an individual physician order or prescription [85]. A prospective study in South Australia in 2014–16 showed an increased pertussis vaccine uptake after implementation of a midwife-delivered vaccination program for pregnant women (Figure 5) [73]. Similarly, a study in three hospitals in Melbourne (Australia) in 2015–17 saw a positive impact on maternal Tdap uptake after implementation of standing orders (Figure 5) [92].

Implementing an alert on medical records to remind the provider to discuss and offer antenatal vaccination to their pregnant patients can also be effective in improving uptake. A retrospective study in a hospital in Texas (US) noted a higher Tdap vaccine uptake in pregnant women after changing recommendations from postpartum to antepartum vaccination and implementing best-practice alerts in their electronic charting system that were repeated at each visit until documentation of vaccination or delivery (Figure 5) [93]. Likewise, a hospital in Wisconsin (US) saw significant increases in influenza vaccine uptake in pregnant women after implementation of a best-practice alert [94]. Linking vaccination to one of the routine visits, for instance at the same time as the 20-week fetal anomaly scan visit or testing for gestational diabetes can create a natural prompt [72, 85].

In addition, documenting a woman’s vaccination status in all records (secondary and primary care) and assessing the status is key to successful implementation of immunization programs. Being able to easily track whether a woman has or has not received the recommended antenatal immunizations allows reintroducing the discussion and offering the vaccine(s) at the next visit [85]. It also makes overall assessments of immunization rates and possible impact of interventions possible.

Conclusions

Maternal immunization is an effective method of protecting pregnant women and their infants from vaccine-preventable diseases. Despite significant evidence supporting the effectiveness and safety of pertussis and influenza vaccines in pregnant women, uptake is suboptimal. Recommendation from a trusted healthcare provider and on-site availability of the vaccines are key factors in encouraging women to be immunized and increasing uptake. Educating pregnant women (through one-to-one discussions, pamphlets and posters) on the risk of infection, severity of pertussis and influenza disease in young infants and the effectiveness and safety of maternal immunization are means to further increase uptake. Healthcare professionals in-

volved in delivery of vaccines should be clearly identified and adequately trained as part of their role. Optimal strategies will depend on the antenatal care model applicable in a country, but regardless of the model, vaccination should be integrated into routine antenatal care and, where possible, tied to one of the routine antenatal visits. These measures could help establish maternal immunization as the norm in the general population and increase acceptance and uptake.

References

- Bustreo F, Okwo-Bele JM, Kamara L. World Health Organization perspectives on the contribution of the Global Alliance for Vaccines and Immunization on reducing child mortality. *Arch Dis Child*. 2015;100 Suppl 1:S34-37.
- GBD 2015 Child Mortality Collaborators. Global, regional, national, and selected subnational levels of stillbirths, neonatal, infant, and under-5 mortality, 1980-2015: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet*. 2016;388:1725-74.
- UNICEF. Under-five mortality. Available at: <https://data.unicef.org/topic/child-survival/under-five-mortality/>. Accessed February 18, 2020.
- Liu L, Oza S, Hogan D, et al. Global, regional, and national causes of under-5 mortality in 2000-15: an updated systematic analysis with implications for the Sustainable Development Goals. *Lancet*. 2016;388:3027-35.
- UNICEF. Newborn care. Available at: <https://data.unicef.org/topic/maternal-health/newborn-care/>. Accessed February 18, 2020.
- Perrett KP, Nolan TM. Immunization during pregnancy: impact on the infant. *Paediatr Drugs*. 2017;19:313-24.
- Palmeira P, Quinello C, Silveira-Lessa AL, Zago CA, Carneiro-Sampaio M. IgG placental transfer in healthy and pathological pregnancies. *Clin Dev Immunol*. 2012;2012:985646.
- Lindsey B, Jones C, Kampmann B. Bridging the gap: maternal immunisation as a means to reduce neonatal deaths from infectious diseases. *Pathog Glob Health*. 2012;106:137-8.
- Maertens K, Orije MRP, Van Damme P, Leuridan E. Vaccination during pregnancy: current and possible future recommendations. *Eur J Pediatr*. 2020;179:235-42.
- Vojtek I, Dieussaert I, Doherty TM, et al. Maternal immunization: where are we now and how to move forward? *Ann Med*. 2018;50:193-208.
- Voysey M, Pollard AJ, Sadarangani M, Fanshawe TR. Prevalence and decay of maternal pneumococcal and meningococcal antibodies: a meta-analysis of type-specific decay rates. *Vaccine*. 2017;35:5850-7.
- Maertens K, De Schutter S, Braeckman T, et al. Breastfeeding after maternal immunisation during pregnancy: providing immunological protection to the newborn: a review. *Vaccine*. 2014;32:1786-92.
- Marchant A, Sadarangani M, Garand M, et al. Maternal immunisation: collaborating with mother nature. *Lancet Infect Dis*. 2017;17:e197-e208.
- Munoz FM. Current challenges and achievements in maternal immunization research. *Front Immunol*. 2018;9:436.
- Rasmussen SA, Watson AK, Kennedy ED, Broder KR, Jamieson DJ. Vaccines and pregnancy: Past, present, and future. *Semin Fetal Neonatal Med*. 2014;19:161-9.
- World Health Organization. Maternal and Neonatal Tetanus Elimination (MNTE) - 1. The partnership and 5. Progress towards global MNT elimination. Available at: https://www.who.int/immunization/diseases/MNTE_initiative/en/. Accessed January 22, 2021.
- Buchy P, Badur S, Kassianos G, Preiss S, Tam JS. Vaccinating pregnant women against influenza needs to be a priority for all countries: an expert commentary. *Int J Infect Dis*. 2020;92:1-12.
- Vygen-Bonnet S, Hellenbrand W, Garbe E, et al. Safety and effectiveness of acellular pertussis vaccination during pregnancy: a systematic review. *BMC Infect Dis*. 2020;20:136.
- Brillo E, Tosto V, Giardina I, Buonomo E. Maternal tetanus, diphtheria, and acellular pertussis (Tdap) and influenza immunization: an overview. *J Matern Fetal Neonatal Med*. 2019;1-30.
- Jorgensen P, Mereckiene J, Cotter S, Johansen K, Tsoлова S, Brown C. How close are countries of the WHO European Region to achieving the goal of vaccinating 75% of key risk groups against influenza? Results from national surveys on seasonal influenza vaccination programmes, 2008/2009 to 2014/2015. *Vaccine*. 2018;36:442-52.
- Kahn KE, Black CL, Ding H, et al. Influenza and Tdap vaccination coverage among pregnant women - United States, April 2018. *MMWR Morb Mortal Wkly Rep*. 2018;67:1055-9.
- Maertens K, Braeckman T, Blaizot S, et al. Coverage of recommended vaccines during pregnancy in Flanders, Belgium. Fairly good but can we do better? *Vaccine*. 2018;36:2687-93.
- Public Health England. Seasonal influenza vaccine uptake in GP patients: winter season 2018 to 2019 (Final data for 1 September 2018 to 28 February 2019). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/804889/Seasonal_influenza_vaccine_uptake_in_GP_patients_1819.pdf. Accessed March 16, 2020.
- Public Health England. Pertussis vaccination programme for pregnant women update: vaccine coverage in England, January to March 2019 and 2018/19 annual coverage (Health Protection Report Volume 13 Number 2626 July 2019). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/821145/hpr2619_prnt-prtss_VC.pdf. Accessed March 16, 2020.
- Masseria C, Martin CK, Krishnarajah G, Becker LK, Buikema A, Tan TQ. Incidence and burden of pertussis among infants less than 1 year of age. *Pediatr Infect Dis J*. 2017;36:e54-e61.
- World Health Organization SAGE pertussis working group. Background paper; SAGE April 2014. Available at: https://www.who.int/immunization/sage/meetings/2014/april/1_Pertussis_background_FINAL4_web.pdf. Accessed February 19, 2020.
- Kandell W, van den Ende C, Bunge EM, Jenkins VA, Ceregido MA, Guignard A. A systematic review of the burden of pertussis disease in infants and the effectiveness of maternal immunization against pertussis. *Expert Rev Vaccines*. 2020;19:621-38.
- Mattoo S, Cherry JD. Molecular pathogenesis, epidemiology, and clinical manifestations of respiratory infections due to *Bordetella pertussis* and other *Bordetella* subspecies. *Clin Microbiol Rev*. 2005;18:326-82.
- Cherry JD. Pertussis in young infants throughout the world. *Clin Infect Dis*. 2016; 63(suppl 4):S119-S122.
- World Health Organization. Pertussis vaccines: WHO position paper - September 2015. *Wkly Epidemiol Rec*. 2015;90:433-58.
- Healy CM, Rench MA, Baker CJ. Implementation of cocooning against pertussis in a high-risk population. *Clin Infect Dis*. 2011;52:157-62.
- Forsyth K, Plotkin S, Tan T, Wirsing von König CH. Strategies to decrease pertussis transmission to infants. *Pediatrics*. 2015;135:e1475-82.
- Belloni C, De Silvestri A, Tinelli C, et al. Immunogenicity of a three-component acellular pertussis vaccine administered at birth. *Pediatrics*. 2003;111:1042-5.
- Wood N, McIntyre P, Marshall H, Robertson D. Acellular pertussis vaccine at birth and one month induces antibody responses by two months of age. *Pediatr Infect Dis J*. 2010;29:209-15.
- Wood N, Nolan T, Marshall H, et al. Immunogenicity and safety of monovalent acellular pertussis vaccine at birth: a randomized clinical trial. *JAMA Pediatr*. 2018;172:1045-52.
- Rasmussen SA, Jamieson DJ, Uyeki TM. Effects of influenza on pregnant women and infants. *Am J Obstet Gynecol*. 2012;207(3 Suppl):S3-8.
- Abu Raya B, Edwards KM, Scheifele DW, Halperin SA. Pertussis and influenza immunisation during pregnancy: a landscape review. *Lancet Infect Dis*. 2017;17:e209-e222.
- Campbell H, Gupta S, Dolan GP, et al. Review of vaccination in pregnancy to prevent pertussis in early infancy. *J Med Microbiol*. 2018;67:1426-56.
- Furuta M, Sin J, Ng ESW, Wang K. Efficacy and safety of pertussis vaccination for pregnant women - a systematic review of randomised controlled trials and observational studies. *BMC Pregnancy Childbirth*. 2017;17:390.
- Gkentzi D, Katsakiori P, Marangos M, et al. Maternal vaccination

- against pertussis: a systematic review of the recent literature. *Arch Dis Child Fetal Neonatal Ed.* 2017;102:F456-F463.
41. McMillan M, Clarke M, Parrella A, Fell DB, Amirthalingam G, Marshall HS. Safety of tetanus, diphtheria, and pertussis vaccination during pregnancy: a systematic review. *Obstet Gynecol.* 2017;129:560-73.
 42. Abu-Raya B, Maertens K, Edwards KM, et al. Global perspectives on immunization during pregnancy and priorities for future research and development: an international consensus statement. *Front Immunol.* 2020;11:1282.
 43. Amirthalingam G, Andrews N, Campbell H, et al. Effectiveness of maternal pertussis vaccination in England: an observational study. *Lancet.* 2014;384:1521-8.
 44. Amirthalingam G, Campbell H, Ribeiro S, et al. Sustained effectiveness of the maternal pertussis immunization program in England 3 years following introduction. *Clin Infect Dis.* 2016;63(suppl 4):S236-S243.
 45. Baxter R, Bartlett J, Fireman B, Lewis E, Klein NP. Effectiveness of vaccination during pregnancy to prevent infant pertussis. *Pediatrics.* 2017;139:e20164091.
 46. Bellido-Blasco J, Guiral-Rodrigo S, Míguez-Santiyán A, Salazar-Cifre A, González-Morán F. A case-control study to assess the effectiveness of pertussis vaccination during pregnancy on newborns, Valencian community, Spain, 1 March 2015 to 29 February 2016. *Euro Surveill.* 2017;22:30545.
 47. Dabrera G, Amirthalingam G, Andrews N, 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;60:333-7.
 48. Saul N, Wang K, Bag S, et al. Effectiveness of maternal pertussis vaccination in preventing infection and disease in infants: the NSW Public Health Network case-control study. *Vaccine.* 2018;36:1887-92.
 49. Skoff TH, Blain AE, Watt J, et al. Impact of the US maternal tetanus, diphtheria, and acellular pertussis vaccination program on preventing pertussis in infants <2 months of age: a case-control evaluation. *Clin Infect Dis.* 2017;65:1977-83.
 50. Quach THT, Mallis NA, Cordero JF. Influenza vaccine efficacy and effectiveness in pregnant women: systematic review and meta-analysis. *Matern Child Health J.* 2020;24:229-40.
 51. Getahun D, Fassett MJ, Peltier MR, et al. Association between seasonal influenza vaccination with pre- and postnatal outcomes. *Vaccine.* 2019;37:1785-91.
 52. Jarvis JR, Dorey RB, Warricker FDM, Alwan NA, Jones CE. The effectiveness of influenza vaccination in pregnancy in relation to child health outcomes: systematic review and meta-analysis. *Vaccine.* 2020;38:1601-13.
 53. Nunes MC, Madhi SA. Influenza vaccination during pregnancy for prevention of influenza confirmed illness in the infants: a systematic review and meta-analysis. *Hum Vaccin Immunother.* 2018;14:758-66.
 54. Centers for Disease Control and Prevention (CDC). 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;60:1424-26.
 55. Centers for Disease Control and Prevention (CDC). 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;62:131-5.
 56. Department of Health and Social Care. Newborns to be protected against whooping cough. Available at: <https://www.gov.uk/government/news/newborns-to-be-protected-against-whooping-cough>. Accessed February 25, 2020.
 57. Department of Health and Social Care. Whooping cough vaccination programme for pregnant women. Available at: <https://www.gov.uk/government/publications/whooping-cough-vaccination-programme-for-pregnant-women>. Accessed February 25, 2020.
 58. Joint Committee in Vaccination and Immunisation. Minutes of the meeting held on 05 June 2019 - Chapter V. Review of the maternal pertussis programme (paragraphs 28 to 37). Available at: <https://www.gov.uk/government/groups/joint-committee-on-vaccination-and-immunisation#minutes>. Accessed February 25, 2020.
 59. Harper SA, Fukuda K, Uyeky TM, Cox NJ, Bridges CB; Advisory Committee on Immunization Practices (ACIP), Centers for Disease Control and Prevention (CDC). Prevention and control of influenza. Recommendations of the Advisory Committee on Immunization Practices (ACIP). *MMWR Recomm Rep.* 2005;54(RR-8):1-40.
 60. World Health Organization. Vaccines against influenza WHO position paper – November 2012. *Wkly Epidemiol Rec.* 2012;47:461-76.
 61. World Health Organization. WHO vaccine-preventable diseases: monitoring system. 2020 global summary. Immunization schedule by disease covered by antigens within age range selection centre. Available at: https://apps.who.int/immunization_monitoring/globalsummary/diseases. Accessed August 24, 2020.
 62. Wiley KE, Cooper SC, Wood N, Leask J. Understanding pregnant women's attitudes and behavior toward influenza and pertussis vaccination. *Qual Health Res.* 2015;25:360-70.
 63. Kochhar S, Edwards KM, Ropero Alvarez AM, Moro PL, Ortiz JR. Introduction of new vaccines for immunization in pregnancy – Programmatic, regulatory, safety and ethical considerations. *Vaccine.* 2019;37:3267-77.
 64. Lutz CS, Carr W, Cohn A, Rodriguez L. Understanding barriers and predictors of maternal immunization: identifying gaps through an exploratory literature review. *Vaccine.* 2018;36:7445-55.
 65. MacDougall DM, Halperin SA. Improving rates of maternal immunization: challenges and opportunities. *Hum Vaccin Immunother.* 2016;12:857-65.
 66. Moniz MH, Beigi RH. Maternal immunization. Clinical experiences, challenges, and opportunities in vaccine acceptance. *Hum Vaccin Immunother.* 2014;10:2562-70.
 67. Wilson RJ, Paterson P, Jarrett C, Larson HJ. Understanding factors influencing vaccination acceptance during pregnancy globally: a literature review. *Vaccine.* 2015;33:6420-9.
 68. Kilich E, Dada S, Francis MR, et al. Factors that influence vaccination decision-making among pregnant women: a systematic review and meta-analysis. *PLoS One.* 2020;15:e0234827.
 69. Bisset KA, Paterson P. Strategies for increasing uptake of vaccination in pregnancy in high-income countries: a systematic review. *Vaccine.* 2018;36:2751-9.
 70. Ellingson MK, Dudley MZ, Limaye RJ, Salmon DA, O'Leary ST, Omer SB. Enhancing uptake of influenza maternal vaccine. *Expert Rev Vaccines.* 2019;18:191-204.
 71. Mohammed H, McMillan M, Roberts CT, Marshall HS. A systematic review of interventions to improve uptake of pertussis vaccination in pregnancy. *PLoS One.* 2019;14:e0214538.
 72. Wilcox CR, Woodward C, Rowe R, Jones CE. Embedding the delivery of antenatal vaccination within routine antenatal care: a key opportunity to improve uptake. *Hum Vaccin Immunother.* 2020;16:1221-4.
 73. Mohammed H, Clarke M, Koehler A, Watson M, Marshall H. Factors associated with uptake of influenza and pertussis vaccines among pregnant women in South Australia. *PLoS One.* 2018;13:e0197867.
 74. Quattrocchi A, Mereckiene J, Fitzgerald M, Cotter S. Determinants of influenza and pertussis vaccine uptake in pregnant women in Ireland: a cross-sectional survey in 2017/18 influenza season. *Vaccine.* 2019;37:6390-6.
 75. Vilca LM, Cesari E, Tura AM, et al. Barriers and facilitators regarding influenza and pertussis maternal vaccination uptake: a multi-center survey of pregnant women in Italy. *Eur J Obstet Gynecol Reprod Biol.* 2020;247:10-5.
 76. Psarris A, Sindos M, Theodora M, et al. Routine immunizations during pregnancy, doctors' compliance and patient hesitancy: a two stage study on vaccination uptake. *Eur J Obstet Gynecol Reprod Biol.* 2019;243:36-40.
 77. Wales DP, Khan S, Suresh D, Ata A, Morris B. Factors associated with Tdap vaccination receipt during pregnancy: a cross-sectional study. *Public Health.* 2020;179:38-44.
 78. Bartolo S, Deliege E, Mancel O, et al. Determinants of influenza vaccination uptake in pregnancy: a large single-Centre cohort study. *BMC*

- Pregnancy Childbirth. 2019;19:510.
79. Collins J, Alona I, Tooher R, Marshall H. Increased awareness and health care provider endorsement is required to encourage pregnant women to be vaccinated. *Hum Vaccin Immunother.* 2014;10:2922-9.
 80. Meharry PM, Cusson RM, Stiller R, Vázquez M. Maternal influenza vaccination: evaluation of a patient-centered pamphlet designed to increase uptake in pregnancy. *Matern Child Health J.* 2014;18:1205-14.
 81. Panda B, Stiller R, Panda A. Influenza vaccination during pregnancy and factors for lacking compliance with current CDC guidelines. *J Matern Fetal Neonatal Med.* 2011;24:402-6.
 82. Wong VWY, Fong DYT, Lok KYW, et al. Brief education to promote maternal influenza vaccine uptake: a randomized controlled trial. *Vaccine.* 2016;34:5243-50.
 83. O'Leary ST, Narwaney KJ, Wagner NM, Kraus CR, Omer SB, Glanz JM. Efficacy of a web-based intervention to increase uptake of maternal vaccines: an RCT. *Am J Prev Med.* 2019;57:e125-e133.
 84. Alessandrini V, Anselem O, Girault A, et al. Does the availability of influenza vaccine at prenatal care visits and of immediate vaccination improve vaccination coverage of pregnant women? *PLoS One.* 2019;14:e0220705.
 85. The American College of Obstetricians and Gynecologists. Optimizing immunization programs in obstetric-gynecologic practices. Available at: <https://www.acog.org/-/media/project/acog/acogorg/files/pdfs/publications/optimizing-immunizations-toolkit.pdf>. Accessed August 24, 2020.
 86. 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;33:4983-7.
 87. Campbell H, Van Hoek AJ, Bedford H, et al. Attitudes to immunisation in pregnancy among women in the UK targeted by such programmes. *Br J Midwifery.* 2015;23:566-73.
 88. Danchin MH, Costa-Pinto J, Attwell K, et al. Vaccine decision-making begins in pregnancy: Correlation between vaccine concerns, intentions and maternal vaccination with subsequent childhood vaccine uptake. *Vaccine.* 2018;36:6473-9.
 89. Frawley JE, McKenzie K, Cummins A, Sinclair L, Wardle J, Hall H. Midwives' role in the provision of maternal and childhood immunisation information. *Women Birth.* 2020;33:145-52.
 90. Vishram B, Letley L, Jan Van Hoek A, et al. Vaccination in pregnancy: attitudes of nurses, midwives and health visitors in England. *Hum Vaccin Immunother.* 2018;14:179-88.
 91. Frawley JE, McKenzie K, Sinclair L, Cummins A, Wardle J, Hall H. Midwives' knowledge, attitudes and confidence in discussing maternal and childhood immunisation with parents: a national study. *Vaccine.* 2020;38:366-71.
 92. Krishnaswamy S, Wallace EM, Buttery J, Giles ML. Strategies to implement maternal vaccination: A comparison between standing orders for midwife delivery, a hospital based maternal immunisation service and primary care. *Vaccine.* 2018;36:1796-800.
 93. Morgan JL, Baggari SR, Chung W, Ritch J, McIntire DD, Sheffield JS. Association of a best-practice alert and prenatal administration with tetanus toxoid, reduced diphtheria toxoid, and acellular pertussis vaccination rates. *Obstet Gynecol.* 2015;126:333-7.
 94. Klatt TE, Hopp E. Effect of a best-practice alert on the rate of influenza vaccination of pregnant women. *Obstet Gynecol.* 2012;119(2 Pt 1):301-5.
 95. Argentina Ministerio de Salud. Vacunas y calendario nacional de vacunación: vacunas durante el embarazo. Available at: <https://www.argentina.gob.ar/salud/vacunas/embarazadas>. Accessed July 8, 2020.
 96. Australian Government Department of Health. Australian Immunisation Handbook. Vaccination for women who are planning pregnancy, pregnant or breastfeeding. Available at: <https://immunisationhandbook.health.gov.au/vaccination-for-special-risk-groups/vaccination-for-women-who-are-planning-pregnancy-pregnant-or>. Accessed July 8, 2020.
 97. The Government of The Bahamas Ministry of Health. Immunization schedule 2018. Expanded Program on Immunization (EPI). Available at: <https://www.bahamas.gov.bs/wps/portal/public/Health%20Children/>. Accessed July 8, 2020.
 98. Hoge Gezondheidsraad België. Vaccinatie tegen kinkhoest (april 2014) (HGR 9110)/Vaccination anticoquelucheuse (avril 2014) (CSS 9110). Available at: <https://www.health.belgium.be/nl/advies-9110-vaccinatie-tegen-kinkhoest>. Accessed July 8, 2020.
 99. Government of Bermuda. Immunization schedules for children and adults. Available at: <https://www.gov.bm/immunization-schedules-children-and-adults>. Accessed July 8, 2020.
 100. Ministério da Saúde, Secretaria de Vigilância em Saúde, Departamento de Vigilância Epidemiológica, Coordenação Geral do Programa Nacional de Imunizações. Informe técnico. Informe técnico para implantação da vacina adsorvida difteria, tétano e coqueluche (pertussis acelular) tipo adulto – dTpa. Available at: <https://www.saude.gov.br/images/pdf/2015/junho/26/Informe-T--cnico-dTpa-2014.pdf>. Accessed July 8, 2020.
 101. Government of Canada. Immunization in pregnancy and breastfeeding: Canadian Immunization Guide. Available at: <https://www.canada.ca/en/public-health/services/publications/healthy-living/canadian-immunization-guide-part-3-vaccination-specific-populations/page-4-immunization-pregnancy-breastfeeding.html>. Accessed July 8, 2020.
 102. Potin M, Fica A, Véliz L, Moreno G, Wilhelm J, Cerda J. [Strategies to protect the newborn and infants under 6 months of age against pertussis: Statement of the Advisory Committee for Immunizations of the Chilean Infectious Diseases Society]. *Rev Chilena Infectol.* 2016;33:543-6.
 103. Colombia Ministerio de Salud y Protección Social. Esquema de vacunación de Colombia (actualizado diciembre 2019). Available at: <https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/VS/PP/ET/ficha-esquema-vacunacion-vf2.pdf>. Accessed July 8, 2020.
 104. Ministerio de Salud Costa Rica. Esquemas de vacunación oficial en adultos en Costa Rica, 2019 Available at: <https://www.ministeriodesalud.go.cr/index.php/material-educativo/documentos-ministerio-de-salud/centro-de-informacion/material-comunicacion/vacunas-3/4177-esquemas-de-vacunacion-oficial-en-adultos-en-costa-rica-2019/file>. Accessed July 8, 2020.
 105. Czech Republic Ministry of Health - National Immunization Committee. Recommendation for pertussis vaccination in pregnancy for the Czech Republic. Amendment to the National pertussis immunisation strategy (8 December 2015). Available at: http://www.szu.cz/uploads/Epidemiologie/Pertuse/CR_Pertussis_Recommendation_for_pregnant_women.pdf. Accessed July 8, 2020.
 106. Statens Serum Institut. No 42/43 - 2019. Temporary free whooping cough vaccination for pregnant women. Available at: <https://en.ssi.dk/news/epi-news/2019/no-42-43---2019>. Accessed July 8, 2020.
 107. Gobierno de El Salvador - Ministerio de Salud. Esquema nacional de vacunación, El Salvador 2020. Available at: <https://www.salud.gob.sv/esquema-nacional-de-vacunacion-el-salvador-2020/>. Accessed July 8, 2020.
 108. Haute Autorité de Santé. Recommendations vaccinales: Vaccination contre la coqueluche chez la femme enceinte dans un contexte épidémique à Mayotte, Mars 2018. Available at: https://www.has-sante.fr/upload/docs/application/pdf/2018-05/recommandations_vaccination_coqueluche_femme_enceinte_mayotte_mars2018_2018-05-15_11-36-37_267.pdf. Accessed July 8, 2020.
 109. Robert Koch Institut. Epidemiologisches Bulletin. STIKO: Empfehlung der Pertussisimpfung in der Schwangerschaft. Available at: https://www.rki.de/DE/Content/Infekt/EpidBull/Archiv/2020/Ausgaben/13_20.pdf?__blob=publicationFile. Accessed July 8, 2020.
 110. Greek Republic Ministry of Health. National adult vaccination program 2018 - 2019. Available at: <https://www.moh.gov.gr/articles/health/dieythynsh-dhmosias-ygieinhs/metadotika-kai-mh-metadotika-noshmata/ethnika-programmata-emboliasmwn/5776-ethniko-programma-emboliasmwn-enhlikwn-2018-2019>. Accessed July 8, 2020.
 111. Gobierno de la República de Honduras - Secretaría de Salud. Esquema vacunación 2020. Available at: <https://www.salud.gob.hn/site/index.php/component/edocman/esquema-vacunacion-2020>. Accessed July 8, 2020.
 112. Hong Kong Centre for Health Protection. Surveillance and Epidemiology Branch. Recommendations on pertussis vaccination for pregnant women (4 March 2019). Available at: <https://www.chp.gov.hk/files/>

- pdf/letters_to_doctors_20190304.pdf. Accessed July 8, 2020.
113. Iceland Directorate of Health. Vaccination with whooping cough during pregnancy. Available at: <https://www.landlaeknir.is/um-embattid/frettir/frett/item37308/bolusetning-vid-kikhosta-a-medgongu>. Accessed July 8, 2020.
 114. European Centre for Disease Prevention and Control. Vaccine scheduler. Available at: <https://vaccine-schedule.ecdc.europa.eu/>. Accessed August 24, 2020.
 115. Vashishtha VM, Bansal CP, Gupta SG. Pertussis vaccines: position paper of Indian Academy of Pediatrics (IAP). *Indian Pediatr*. 2013;50:1001-9.
 116. Health Service Executive. National Immunisation Office. Pertussis in pregnancy. Available at: <https://www.hse.ie/eng/health/immunisation/hcpinfo/othervaccines/pertussis/>. Accessed July 8, 2020.
 117. State of Israel Ministry of Health. Whooping cough vaccination in pregnant women. Available at: https://www.health.gov.il/English/Topics/Pregnancy/during/Pages/Vaccination-Whooping_cough.aspx. Accessed July 8, 2020.
 118. Societa' Italiana di Ginecologia e Ostetricia. Vaccinazioni in gravidanza. Proteggila per proteggerli. Documento congiunto redatto dal gruppo di lavoro SIGO, SIMP, AOGOI, AGUI, SITI, SIN, FNOPO, Rete Interaziendale Milano Materna Infantile (RIMMI), Vivere Onlus, Cittadinanzattiva. Available at: https://www.sigo.it/wp-content/uploads/2019/03/Vaccinazioni_in_Gravidanza_14-03-19.pdf. Accessed July 8, 2020.
 119. Gobierno de México - Secretaría de Salud. Esquema de vacunación. Available at: <https://www.gob.mx/salud/articulos/esquema-de-vacunacion>. Accessed July 8, 2020.
 120. National Institute for Public Health and the Environment - Ministry of Health Welfare and Sport. 22-week vaccination. Available at: <https://www.rivm.nl/en/22-week-vaccination>. Accessed July 8, 2020.
 121. New Zealand Ministry of Health. Immunisation for pregnant women. Available at: <https://www.health.govt.nz/your-health/healthy-living/immunisation/immunisation-pregnant-women>. Accessed July 8, 2020.
 122. República de Panama Gobierno Nacional - Ministerio de Salud. Esquema nacional de vacunación 2017 (mujeres en edad fértil (embarazadas y puérperas)). Available at: http://minsa.b-cdn.net/sites/default/files/programas/esquema_nacional_de_vacunacion_2017_1.pdf. Accessed July 8, 2020.
 123. Republica del Paraguay - Ministerio de Salud Pública y Bienestar Social. Vacunas por edades - Esquema de vacunación Paraguay 2020. Available at: <http://pai.mspbs.gov.py/article/vacunas-por-edades-esquema-de-vacunacion-paraguay-2020>. Accessed July 8, 2020.
 124. Peru Ministerio de Salud. Resolución Ministerial N° 719-2018/MINSA (p. 25: 5.1.16 Vacuna combinada dTpa (solo para gestantes)). Available at: https://cdn.www.gob.pe/uploads/document/file/300034/d177030_opt.PDF. Accessed July 8, 2020.
 125. Philippine Obstetrical and Gynecological Society. Clinical practice guidelines for immunization for women. Available at: <https://pogsinc.org/clinical-practice-guidelines/>. Accessed January 22, 2021.
 126. Ministry of Health. Communication of October 25, 2018 on the protective vaccination program for 2019. Available at: <https://gis.gov.pl/wp-content/uploads/2018/01/akt.pdf>. Accessed July 8, 2020.
 127. Qatar Ministry of Public Health. Tdap vaccine recommendations for pregnant women. 2017
 128. Repubblica di San Marino - Istituto per la Sicurezza Sociale. Vaccinazioni raccomandate. Available at: <http://www.iss.sm/on-line/home/vaccini-e-vaccinazioni/vaccinazioni-raccomandate.html>. Accessed July 8, 2020.
 129. Saudi Arabia Ministry of Health. Immunization. Available at: <https://www.moh.gov.sa/en/HealthAwareness/EducationalContent/vaccination/Pages/003.aspx>. Accessed July 8, 2020.
 130. Singapore Ministry of Health. MOH establishes national adult immunisation schedule; extends use of medisave for vaccines under the schedule. Available at: <https://www.moh.gov.sg/news-highlights/details/moh-establishes-national-adult-immunisation-schedule-extends-use-of-medisave-for-vaccines-under-the-schedule>. Accessed July 8, 2020.
 131. Korean Society for Infectious Diseases. Adult Immunization schedule. Available at: http://www.ksid.or.kr/file/2019_vaccine.pdf. Accessed August 24, 2020.
 132. Asociación Española de Pediatría - Comité Asesor de Vacunas. Calendarios de vacunación en España. Available at: <https://vacunasaep.org/documentos/manual/cap-7>. Accessed July 8, 2020.
 133. Office fédéral de la santé publique OFSP. Plan de vaccination suisse 2020. Available at: <https://www.bag.admin.ch/bag/fr/home/gesund-leben/gesundheitsfoerderung-und-praevention/impfungen-prophylaxe/schweizerischer-impfplan.html>. Accessed July 8, 2020.
 134. Taiwan Centers for Disease Control. Pertussis: "7 Things you may not know about pregnancy" and "Pertussis Introduction and Prevention". Available at: https://www.cdc.gov.tw/En/Category/ListContent/bg0g_VU_Ysrgkes_KRUDgQ?uaid=tRFoq7YhMoz6moj0QsJcQA. Accessed August 24, 2020.
 135. Infectious Disease Association of Thailand. Recommended adult and elderly immunization schedule. Available at: <https://www.idthai.org/Contents/Views/?d=qwzJ!17!4!!390!fb86LuPe>. Accessed August 24, 2020.
 136. Public Health England. Guidance - Vaccination against pertussis (whooping cough) for pregnant women. Available at: <https://www.gov.uk/government/publications/vaccination-against-pertussis-whooping-cough-for-pregnant-women>. Accessed July 8, 2020.
 137. Public Health England. Timing of pertussis vaccine in pregnancy. Available at: <https://www.england.nhs.uk/south/wp-content/uploads/sites/6/2016/07/pertussis-brief-june16.pdf>. Accessed July 8, 2020.
 138. Ministerio de Salud Pública Uruguay. Vacunas. Available at: <https://www.gub.uy/ministerio-salud-publica/comunicacion/publicaciones/vacunas>. Accessed July 8, 2020.
 139. Benedetto C, Carosso A, Corezzi M, Zotti CM; EBCOG. EBCOG position statement: vaccination in pregnancy. *Eur J Obstet Gynecol Reprod Biol*. 2019;240:375-6.
 140. Nassar AH, Visser GHA, Nicholson WK, Ramasauskaite D, Kim YH, Barnea ER; FIGO Safe Motherhood, Newborn Health Committee. FIGO statement: vaccination in pregnancy. *Int J Gynaecol Obstet*. 2021;152:139-43.
 141. Pan American Health Organization and World Health organization Technical Advisory Group on Vaccine-Preventable Diseases. Twenty-fifth meeting of the Technical Advisory Group (TAG) on vaccine-preventable diseases. 9-11 July 2019. Cartagena, Colombia. Maternal pertussis immunization. Available at: https://www.paho.org/hq/index.php?option=com_docman&view=download&alias=50491-25-tag-final-report-2019&category_slug=tag-final-reports-1626&Itemid=270&lang=en. Accessed August 24, 2020.

Acknowledgements: This work was funded by GlaxoSmithKline Biologicals SA, including support with writing, editing and manuscript coordination, which were provided by Modis, on behalf of GSK: Natalie Denef provided medical writing support and Camille Turlure coordinated manuscript development and provided editorial support.

Conflict of interest statement: A Mihalyi and P Mukherjee are employees of the GSK group of companies (GSK) and declare financial (including shares) and non-financial relationships and activities. CE Jones reports personal fees from MSD and Pfizer outside the submitted work; CE Jones is also an investigator for clinical trials carried out on behalf of her institution, sponsored by various vaccine manufacturers (including GSK and Novavax) but receives no personal funding for these activities. RH Beigi, AR Genazzani and K Ralph declare no financial or non-financial relationships and activities, and no conflicts of interest.

Author contributions: P Mukherjee: conception of the paper, structure and scope; preparation of the initial outline; suggestion of references; critical review and input on drafts; approval of final version. A Mihalyi: conception of the paper; contribution to structure and scope; suggestion of references; critical review and input on drafts; approval of final version. K Ralph: contribution to structure and scope; provided conceptual framework of factors influencing vaccine-related decision-making among pregnant women; suggestion of references; critical review and input on drafts; approval of final version. RH Beigi: contribution to structure and scope; critical review and input on drafts; approval of final version. A Genazzani: contribution to structure and scope; critical review and input on drafts; approval of final version. CE Jones: contribution to structure and scope; critical review and input on drafts; approval of final version.