MATERNAL VACCINATION: A PROMISING STRATEGY FOR MATERNAL AND INFANT PROTECTION

Meri Hristamyan[1]

[1] Department of Epidemiology and Disaster Medicine, Faculty of Public Health, Medical University of Plovdiv, Bulgaria

ABSTRACT

Infectious diseases remain one of the leading causes of morbidity in pregnant women and newborns. Maternal vaccination has become an important public health strategy to prevent maternal, fetal, and neonatal infections. This approach takes advantage of a natural biological phenomenon where antibodies are transferred from mother to fetus transplacentally, primarily in the second and third trimesters, and additionally through breast milk after birth, providing protection during the first few months of life before neonates can be vaccinated themselves. Currently, several safe and effective maternal vaccines are recommended universally: influenza, Covid-19, tetanus, diphtheria, acellular pertussis (Tdap), and respiratory syncytial virus (RSV), with some additional in development. Other vaccines, like the ones against hepatitis A and B, pneumococcal diseases, meningococcal diseases, Japanese encephalitis (JE), rabies, typhus, cholera, and polio (IPV), have the potential to be used in risk populations or when there is a risk of fatal outcomes, while some remain contraindicated due to theoretical risks. Despite the scientific advantages and growing evidence supporting vaccination during pregnancy, significant gaps exist in our understanding of their efficacy and safety. Additionally, public acceptance of maternal vaccination has historically been low, presenting another challenge to implementation. There are still gaps in the understanding of maternal vaccination, leading to hesitancy, and effort should be made to fix them in order to achieve better health outcomes for mothers and their children.

ADDRESS FOR CORRESPONDENCE:
Meri Arman Hristamyan
Medical University of Plovdiv, Blvd Vasil Aprilov 15A,
4002 Plovdiv, Bulgaria
phone: 0883399364
email: meri.hristamyan@mu-plovdiv.bg

Key words: pregnancy vaccines, Covid-19, influenza, pertussis, RSV

INTRODUCTION

Infectious diseases remain one of the leading causes of morbidity in pregnant women and newborns, with vaccine-preventable infections contributing significantly to the global disease burden [1]. Maternal vaccination has become an important public health strategy to prevent maternal, fetal, and neonatal infections [2]. Vaccines given during pregnancy can provide direct and indirect protection against various infectious diseases and reduce illness and adverse health outcomes in both mothers and their infants [3].

This approach takes advantage of a natural biological phenomenon where antibodies are transferred from mother to fetus transplacentally during gestation, primarily in the second and third trimesters, and additionally through breast milk after birth, providing passive, antigen-specific protection against infections during the first few months of life - a period when infants are most vulnerable, especially before they can be vaccinated themselves [4,5]. Maternal immunization can also prevent long-term complications in infants, such as neurological damage [6].

Vaccination during pregnancy can induce active immune protection in the mother while simultaneously triggering systemic immunoglobulin G (IgG) and mucosal IgG, IgA, and IgM responses that provide protection for the neonates [1]. The maternal immune system undergoes significant changes during pregnancy, which influences responsiveness to vaccines and subsequently affects the efficacy of maternal immunization programs [1].

There are two main reasons for maternal immunization: it protects the pregnant woman from infections that could harm her and/or the fetus, and it provides passive immunity to the infant, reducing the risk of infections such as influenza, pertussis, and neonatal tetanus in early life [7]. Over the years, this approach has shown to be effective and continues to be a key public health strategy worldwide, especially in low- and middle-income countries where infant morbidity and mortality from vaccine-preventable diseases remain high [4,8].

Currently, several maternal vaccines are recommended universally, including those against influenza, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), tetanus, diphtheria, pertussis (Tdap), and respiratory syncytial virus (RSV), with some additional in development [9,10]. Other vaccines have the potential to be used in risk populations or when there is a risk of fatal outcomes [11, 12], while some remain contraindicated due to theoretical risks [13,14].

Despite the scientific advantages and growing evidence supporting maternal vaccines, significant gaps exist in our understanding of their efficacy and safety [1, 9,10]. As a result, the development, evaluation, and wide acceptance of safe and effective vaccines for pregnant women continue to be slowed down [10]. Additionally, public acceptance of maternal vaccination has been historically low, presenting another challenge to implementation [1]. As research in this field advances, a systems biology approach combined with careful clinical evaluation will be essential in improving all aspects of maternal vaccines in order to provide the public with informed vaccination choices [1].

This review article aims to explore maternal vaccination as a way to protect both mothers and their infants from vaccine-preventable infectious diseases.

MATERIAL AND METHODS

A focused, non-systematic review was conducted to identify relevant studies and reviews on maternal vaccination and its role in protecting mothers and infants. The PubMed, Web of Sinece, Scopus and Google Scholar databases were searched for articles published from 2014 up to April 15, 2025. Various combinations of keywords, such as "maternal vaccination, maternal immunization, pregnancy, infant protection, outcomes, safety, efficiency, current recommendations, and transplacental antibody transfer," were used to narrow down and identify relevant sources. Articles were included if they addressed the safety, immunogenicity, effectiveness, and mechanisms of vaccines administered during pregnancy. Original research studies, as well as reviews, meta-analyses, and systematic reviews, were considered. Studies focusing on vaccines recommended for pregnant women (influenza, Tdap, COVID-19, and RSV) and on vaccines in potential but limited use, as well as vaccines under development, were also included. Only publications written in English were reviewed, and key information was extracted. The review focused on the vaccines recommended for maternal vaccination, the efficiency and safety of those vaccines for mother and infant, other vaccines with potential use throughout gestation, and future directions. Findings were analyzed and synthesized to provide an overview of the current implementation and potential of maternal vaccination strategies.

RESULTS

Maternal vaccination remains one of the leading strategies for limiting the impact of vaccine-preventable diseases among the most vulnerable populations, most specifically pregnant women and infants. The knowledge of the available vaccines for pregnant women, their safety and effectiveness, as well as the hesitancy regarding administering vaccines during pregnancy, is crucial.

Current maternal vaccines

Currently, several maternal vaccines are recommended universally, namely those against influenza, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), tetanus, diphtheria, pertussis (Tdap), and respiratory syncytial virus (RSV):

1. Influenza Vaccine

The recommended maternal flu vaccines are inactivated or recombinant [15,16]. Vaccination protects pregnant women from severe influenza and reduces infant risk via antibody transfer. It's administered intramuscularly, with an annual dose during any trimester, and typically recommended in any trimester during flu season [15,16].

2. Tetanus, Diphtheria, and Acellular Pertussis (Tdap) Vaccine

Tdap is an inactivated bacterial toxoids and antigens (combination) vaccine [17,18,19]. It promotes placental transfer of maternal antibodies, providing passive immunity against pertussis, tetanus, and diphtheria in infants [17]. The vaccine is administered intramuscularly, with a single dose typically during 27-36th weeks of gestation, ideally around 28th week for optimal antibody transfer [17,18].

3. COVID-19 Vaccines

The Covid-19 vaccines that are recommended during pregnancy are messenger ribonucleic acid (mRNA) based (Pfizer-BioNTech, Moderna) [20,21]. Protein subunit adjuvanted vaccines (Novavax) can also be used as an alternative if mRNA vaccines are contraindicated or unavailable [20]. The immunization triggers spike protein production, inducing antibodies that cross the placenta and protect against severe SARS-CoV-2 infection. The vaccine is administered intramuscularly and is recommended in any trimester, with boosters administered according to public health guidelines [21].

4. Respiratory Syncytial Virus (RSV) Vaccine

The RSV (Pfizer's Abrysvo) vaccine is a recombinant protein vaccine containing stabilized pre-fusion (pre-F) F protein antigens [22]. Once transferred to the fetus, the maternal antibodies neutralize RSV, reducing severe lower respiratory tract infections in infants [22]. The vaccine is administered intramuscularly, with a single dose in late pregnancy, and is recommended right before or during RSV season (September – January [22].

A comparison of current maternal vaccination recommendations according to the WHO, as well as across

Table 1. Comparison of current maternal vaccination recommendations

Region/Authority	Influenza Vaccine	Tdap (Pertussis)	COVID-19 Vaccine	RSV Vaccine	Source(s)
WHO (Global)	Recommended for pregnant women, especially in high-risk settings	Recommended where feasible, especially in countries with high pertussis prevalence	mRNA vaccines recommended in any trimester	Recommended maternal RSV vaccine, 28–36 weeks	[23,24]
Europe (UK/ECDC)	Recommended in any trimester during flu season	Recommendations vary by country; generally recommended for every pregnancy, 16–32 weeks (UK); 27–36 weeks (ECDC)	mRNA vaccines recommended in any trimester	Recommended maternal RSV vaccine, 28–36 weeks	[24,25,26]
United States	Recommended in any trimester during flu season	Recommended for every pregnancy, 27–36 weeks	mRNA vaccines recommended in any trimester	Recommended maternal RSV vaccine, 32–36 weeks	[3,27,28]
Americas (PAHO)	Recommended in any trimester during flu season	Recommended where feasible	mRNA vaccines recommended in any trimester	Recommended maternal RSV vaccine, 32–36 weeks	[24,29]

ECDC – European Centre for Disease Prevention and Control; mRNA – messenger Ribonucleic Acid; PAHO – Pan American Health Organization; RSV – Respiratory Syncytial Virus; Tdap – Tetanus, Diphtheria, and Acellular Pertussis vaccine; UK – United Kingdom; WHO – World Health Organization.

Europe, the United States, and the Americas, including recent updates for RSV vaccination, is presented in Table 1.

The WHO and Gavi (the Global Alliance for Vaccines and Immunization) focus on expanding access to maternal vaccines, especially RSV, in lower-income countries. This action aims to reduce infant morbidity and mortality rates in places where disease burden is highest [23, 30].

Efficacy and Safety Profile

Recent studies on the topic, predominantly systematic reviews and large randomized controlled trials, provide substantial evidence supporting the efficacy and safety of vaccines such as influenza, Tdap (tetanus, diphtheria, and pertussis), respiratory syncytial virus (RSV), and COVID-19 vaccines when administered throughout gestation.

A systematic review and meta-analysis of randomized controlled trials have demonstrated that maternal influenza vaccination significantly reduces laboratory-confirmed influenza cases in both mothers (RR 0.58, 95% CI 0.42 to 0.79) and infants (RR 0.66, 95% CI 0.52 to 0.85) [9]. An international consensus statement from 2020 also states that maternal immunization reduces the risk of influenza in pregnant women by approximately 35–50%, as well as the risk of laboratory-confirmed influenza in infants by 48% (95% CI, 33–59) [19]. In addition, a large 2024 cohort study of 82,055 women with two successive pregnancies demonstrates that influenza vaccination in both pregnancies is not associated with increased risk of adverse perinatal outcomes such as preeclampsia, placental abruption, preterm birth, or small for gestational age births and also reports no difference between trivalent and quadrivalent vaccination outcomes, showing the safety even with repeated vaccination [31].

Regarding COVID-19 vaccines, a recent cohort study of 30,311 infants found maternal vaccination reduced infant infections with the Delta-variant by 84% in the first two months, and by 56% in the first six months. In addition, hospitalization rates were 79% lower in infants of vaccinated mothers [32].

Maternal immunization with Tdap results in clinically and statistically significant reductions in mortality and morbidity of young children before they receive or complete their immunization schedules [33]. Vaccine effectiveness was 91% in the reduction of laboratory-confirmed cases in infants under 3 months of age in England [19]. Focusing on pertussis vaccination, a UK study found decreased infant infection rates from 9.1% to 1.4% within five years of program implementation [34].

Clinical trials of the RSV F-protein nanoparticle vaccine in pregnant women demonstrate safety and immunogenicity, and the vaccine is reported to efficiently reduce RSV-related respiratory infections in infants, supporting its potential use during pregnancy [35]. The phase 3 MATISSE trial involving over 7,400 pregnant participants reports vaccine efficacy of 82.4% against severe RSV-associated medically attended lower respiratory tract illness in infants during the first 90 days of life and 70% efficacy within the first 180 days. The vac-

Table 2. Key gaps leading to maternal vaccine hesitancy

Gap Area	Description	Implications	Sources
Long-Term Infant Outcomes	Limited data on neonatal health beyond six months, especially for newer mRNA vaccines.	Uncertainties regarding the duration of protection and potential delayed adverse effects.	[35]
Diverse Populations	Lack of representation of multiethnic cohorts in trials.	Reduced generalizability of findings; potential for different vaccine responses in various groups.	[19,32,35, 38,39]
Optimal Timing	Antibody transfer efficiency varies by trimester.	Suboptimal protection if vaccines are administered at less effective times during pregnancy.	[9,35]
Variant Adaptability	Variable effectiveness against emerging variants.	Need for updated vaccine formulations to maintain effectiveness against new variants.	[32]
Communication Strategies	Persistent vaccine hesitancy due to insufficient public health messaging about risk-benefit profiles.	Reduced vaccine uptake, potentially leading to increased disease incidence in mothers and infants.	[19,35]
Lack of Education	Many mothers lack formal education, and this leads to persistent vaccine hesitancy due to insufficient knowledge.	Lower vaccination rate, leading to potential higher risk of disease and worsened child health outcomes	[40]

mRNA – messenger Ribonucleic Acid.

cine induces strong maternal immune responses and efficient transplacental antibody transfer, with no significant safety concerns for mothers or newborns [36].

Generally, adverse effects of vaccines during pregnancy are mostly mild to moderate (such as localized pain or mild fever) and similar to those observed in nonpregnant individuals, and there is no significant increase in adverse pregnancy or neonatal outcomes associated with maternal vaccination [13,35].

Studies have confirmed the safety of influenza vaccines during all trimesters, with no association with gestational diabetes, pre-eclampsia, cesarean delivery, or other pregnancy complications [13]. Mass vaccination during the 2009 H1N1 pandemic showed no abnormal maternal or fetal outcomes [13]. A large study published in 2025 that involves 78,052 pregnant women shows that COVID-19 vaccination during early pregnancy does not increase the risk of major structural birth defects, confirming the safety of COVID-19 vaccines in pregnancy, including the first trimester, and found no increased risk even when combined with other vaccines such as Tdap or influenza [37].

Safety data from randomized controlled trials and observational studies indicate no increased risk of adverse pregnancy or neonatal outcomes following maternal Tdap immunization. In addition, simultaneous administration with the influenza vaccine is also safe, with no increase in preterm birth or low birth weight [9,13]. Recent trials of RSV maternal vaccines also demonstrate favorable safety profiles for mothers and infants, with no significant concerns regarding the safety since no increased risk of adverse maternal or neonatal outcomes is reported [9,35,36].

Maternal vaccination hesitancy

Despite the proven efficacy and safety, there is still stigma and misunderstanding surrounding maternal vaccinations. The key gaps leading to vaccine hesitancy during pregnancy are presented in Table 2.

More efforts should be made to fix these gaps in order to reach better vaccination results and to improve child health outcomes, as well as to lower the overall disease risks.

Future research should focus on long-term studies with follow-ups to evaluate children's health outcomes beyond infancy, including duration of immune protection and potential adverse effects. Current reviews emphasize this, as well as the need to analyze the cost-effectiveness in order to fully understand all aspects of maternal vaccines [35,41]. In addition, studies should include diverse populations with different ethnicities, geographic locations, and socioeconomic backgrounds, since expanding research is critical to generating globally relevant data [35].

Even though the relevant data indicates that vaccination during the later stages of pregnancy provides the best neonatal outcomes in the majority of cases, further studies are needed to refine timing for different vaccines, as well as in different populations [41,42].

When dealing with constantly and rapidly evolving pathogens like the COVID-19 virus, the adaptation of the vaccines to the new emerging variants is of great importance. Some authors suggest that hybrid immu-

nity (vaccination plus natural infection) may provide broader and more durable protection and emphasize the need for vaccine formula updates [42].

Lastly, when dealing with vaccine hesitancy, transparent and evidence-based communication by healthcare providers, tailored education programs, and public health messaging to improve maternal vaccine acceptance are essential. Studies point to the need for clear discussions about vaccine safety, as well as vaccine benefits, to overcome misinformation and build trust among pregnant women [35].

Use of other vaccines during pregnancy and vaccines in development

Vaccines like the ones against hepatitis A and B, pneumococcal diseases, meningococcal diseases, Japanese encephalitis (JE), rabies, typhoid, cholera, and polio (IPV) can also be applied during pregnancy when indicated, as in case of a high risk of exposure or a high chance of fatalities [11,12].

A summary of other vaccines with potential use during pregnancy according to CDC [43] vaccination guidelines and the peer-reviewed reviews by Arora & Lakshmi (2021) [12] and Simionescu et al. (2021) [11] is shown in Table 3.

Vaccines containing live attenuated viruses (MMR, Varicella, Typhoid live oral, Cholera live oral, etc.) remain contraindicated during pregnancy due to theoretical risks, although unintended exposures have not shown evidence of adverse fetal effects in limited studies [2,12,13,43]. As for the yellow fever (YF-VAX) live-attenuated vaccine, pregnancy is a precaution. Rarely, the vaccine may be given if traveling to a high-risk area is unavoidable, but further risk-benefit assessment is required [44].

The recently introduced HPV vaccines (recombinant) are not recommended during gestation by major health authorities, including the CDC, WHO, and others, and women who are known to be pregnant should delay initiation or completion of the HPV vaccination series until after pregnancy [45-47]. However, HPV vaccination is not associated with adverse pregnancy or fetal outcomes, and no intervention is required if a dose is given before knowing about the pregnancy [45-48].

Vaccines in development for maternal use are Group B Streptococcus (GBS) and cytomegalovirus (CMV) vaccines, which have shown promising results in clinical trials, with GBS being the more advanced and more likely to enter phase 3 trials [10,49,50]. Additionally, in

Table 3. Other vaccines with potential use throughout gestation

Disease / Vaccine	Vaccine Examples	Vaccine Type	Pregnancy Use Status
Hepatitis A	Havrix, Vaqta	Inactivated virus	Can be given if indicated (outbreak, exposure); no safety concerns reported.
Hepatitis B	Engerix-B, Recombivax HB	Recombinant subunit	Recommended if unvaccinated and at risk; safe and routinely used during pregnancy when indicated.
Pneumococcal	PCV13 (Prevnar 13), PPSV23	Conjugate and polysaccharide	May be given if high-risk conditions present (chronic illness); no routine pregnancy recommendation but no evidence of adverse events.
Meningococcal	MenACWY (Menactra, Menveo), MenB	Conjugate and protein subunit	Can be administered if benefits outweighs potential risks (outbreak, exposure); pregnancy is a precaution, not contraindication.
Japanese Encephalitis (JE)	Ixiaro	Inactivated virus	May be given if travel to endemic areas is unavoidable; generally deferred if possible; limited data but no evidence of adverse events.
Polio	IPV (inactivated polio vaccine)	Inactivated virus	May be given if indicated (outbreak, travel); pregnancy is a precaution but no evidence of adverse events.
Rabies	RabAvert, Imovax Rabies	Inactivated virus	Recommended if indicated (post-exposure or pre-exposure prophylaxis); benefits outweigh theoretical risks; no evidence of adverse events.
Typhoid (injectable)	Vi polysaccharide vaccine	Polysaccharide	Injectable vaccine may be used if clearly indicated after risk assessment.
Cholera (inactivated oral)	Dukoral	Inactivated oral vaccine	May be used if benefit outweighs risk (outbreak, travel); generally avoided if possible; limited pregnancy data.

JE - Japanese Encephalitis; IPV - inactivated polio vaccine; PCV13 - Pneumococcal conjugate vaccine 13-valent; PPSV23 - Pneumococcal polysaccharide vaccine 23-valent; MenACWY - Meningococcal conjugate vaccine types A, C, W, Y; MenB = Meningococcal B vaccine.

March 2025, a Phase II clinical trial was launched in Mali to evaluate the safety, immunogenicity, and efficacy of Malaria vaccine R21/Matrix-M in women of childbearing potential (WOCBP), a key step toward eventual use in pregnancy [51]. Zika vaccine candidates completed Phase 1 trials in non-pregnant humans with good safety and immunogenicity and phase 2 trials in pregnant populations are pending, as ethical guidelines traditionally exclude pregnant women from early-stage trials [52,53]. Regarding the Ebola virus, vaccines such as recombinant vesicular stomatitis virus (rVSV) ones have been used in outbreaks, but data on safety in pregnancy are limited and research continues on safe maternal immunization strategies for Ebola-endemic regions [54].

Despite the growing evidence supporting maternal vaccination, several limitations remain. Most notably, follow-up durations for studies assessing mRNA vaccines are relatively short, restricting insight into long-term infant health outcomes beyond early infancy. Moreover, low- and middle-income country populations remain under-represented in clinical trials and observational cohorts, limiting the generalizability of current safety and efficacy data. Addressing these gaps by including diverse ethnic and geographic populations is essential for optimizing maternal immunization strategies globally. Additionally, evolving viral variants necessitate ongoing vaccine adaptation and monitoring to ensure sustained protection. Efforts to reduce vaccine hesitancy must also consider these gaps in knowledge and representation to build trust in maternal vaccines worldwide

CONCLUSION

Scientific evidence affirms that maternal vaccination is a safe and effective intervention, emphasizing that the use of these vaccines is a key public health intervention to protect mothers and infants. This plays an extremely important role in reducing the burden of infectious diseases in mothers and their infants, supporting current public health recommendations advocating for vaccination during pregnancy. Despite the safety and effectiveness of maternal vaccines, there are still gaps in the understanding and implementation of maternal vaccination, leading to hesitancy about maternal vaccination, and efforts should be made to fix these gaps in order to achieve better health outcomes for mothers and their children.

REFERENCES

1. Faucette AN, Unger BL, Gonik B, Chen K. Maternal vaccination: moving the science forward. Hum Reprod Update. 2015 Jan-Feb;21(1):119-35. https://doi.org/10.1093/humupd/dmu041.
2. Munoz FM, Jamieson DJ. Maternal Immunization. Obstet Gynecol. 2019 Apr;133(4):739-753. https://doi.org/10.1097/AOG.0000000000003161.
3. Centers for Disease Control and Prevention. About maternal vaccination. Available from: https://www.cdc.gov/vaccines-pregnancy/about/index.html. Accessed on: May 10, 2025.
4. Etti M, Calvert A, Galiza E, Lim S, Khalil A, Le Doare K, Heath PT. Maternal vaccination: a review of current evidence and recommendations. Am J Obstet Gynecol. 2022 Apr;226(4):459-474. https://doi.org/10.1016/j.ajog.2021.10.041.
5. Sereme Y, Toumi E, Saifi E, Faury H, Skurnik D. Maternal immune factors involved in the prevention or facilitation of neonatal bacterial infections. Cell Immunol. 2024 Jan-Feb;395-396:104796. https://doi.org/10.1016/j.cellimm.2023.104796.
6. Patel CD, Backes IM, Taylor SA, Jiang Y, Marchant A, Pesola JM, Coen DM, Knipe DM, Ackerman ME, Leib DA. Maternal immunization confers protection against neonatal herpes simplex mortality and behavioral morbidity. Sci Transl Med. 2019 Apr 10;11(487):eaau6039. https://doi.org/10.1126/scitranslmed.aau6039.
7. Swamy GK, Beigi RH. Maternal benefits of immunization during pregnancy. Vaccine. 2015 Nov 25;33(47):6436-40. https://doi.org/10.1016/j.vaccine.2015.08.035.
8. Khan T, Malik S, Rafeekh L, Halder S, Desai S, Das Bhattacharya S. Facilitators and barriers to maternal immunization and strategies to improve uptake in low-income and lower-middle income countries: A systematic review. Hum Vaccin Immunother. 2024 Dec 31;20(1):2411823. https://doi.org/10.1080/21645515.2024.2411823.
9. de Bruin O, Phijffer E, Ahmadizar F, van der Maas N, Wildenbeest J, Sturkenboom M, Bont L, Bloemenkamp K. Are maternal vaccines effective and safe for mothers and infants? A systematic review and meta-analysis of randomised controlled trials. BMJ Glob Health. 2023 Oct;8(10):e012376. https://doi.org/10.1136/bmjgh-2023-012376.
10. Cho HK, Frivold C, Chu HY. Maternal Immunization. J Infect Dis. 2025 Apr 15;231(4):830-836. https://doi.org/10.1093/infdis/jiae509.
11. Simionescu AA, Streinu-Cercel A, Popescu FD, Stanescu AMA, Vieru M, Danciu BM, Miron VD, Săndulescu O. Comprehensive Overview of Vaccination during Pregnancy in Europe. J Pers Med. 2021 Nov 13;11(11):1196. https://doi.org/10.3390/jpm11111196.
12. Arora M, Lakshmi R. Vaccines - safety in pregnancy. Best Pract Res Clin Obstet Gynaecol. 2021 Oct;76:23-40. https://doi.org/10.1016/j.bpobgyn.2021.02.002.
13. Regan AK. The safety of maternal immunization. Hum Vaccin Immunother. 2016 Dec;12(12):3132-3136. https://doi.org/10.1080/21645515.2016.1222341.
14. Centers for Disease Control and Prevention. (2025, August 28). Guidelines for vaccinating pregnant women. CDC. Available from: https://www.cdc.gov/vaccines-pregnancy/hcp/vaccination-guidelines/index.html. Accessed on: September 3, 2025.Drezner D, Youngster M, Klainer H, Youngster I. Maternal vaccinations coverage and reasons for non-compliance - a cross-sectional observational study. BMC Pregnancy Childbirth. 2020 Sep 16;20(1):541. https://doi.org/10.1186/s12884-020-03243-w.
15. Bisset KA, Paterson P. Strategies for increasing uptake of vaccination in pregnancy in high-income countries: A systematic

review. Vaccine. 2018 May 11;36(20):2751-2759. https://doi.org/10.1016/j.vaccine.2018.04.013.
16. Regan AK, Moore HC, Binks MJ, McHugh L, Blyth CC, Pereira G, Lust K, Sarna M, Andrews R, Foo D, Effler PV, Lambert S, Van Buynder P. Maternal Pertussis Vaccination, Infant Immunization, and Risk of Pertussis. Pediatrics. 2023 Nov 1;152(5):e2023062664. https://doi.org/10.1542/peds.2023-062664.
17. Kamath GD, Kukreja S, Mukherjee P, Kolhapure S, Sathyanarayanan S. Maternal immunization: trends in South and Southeast Asian countries. J Matern Fetal Neonatal Med. 2022 Dec;35(25):8372-8381. https://doi.org/10.1080/14767058.2021.1974389.
18. Abu-Raya B, Maertens K, Edwards KM, Omer SB, Englund JA, Flanagan KL, Snape MD, Amirthalingam G, Leuridan E, Damme PV, Papaevangelou V, Launay O, Dagan R, Campins M, Cavaliere AF, Frusca T, Guidi S, O'Ryan M, Heininger U, Tan T, Alsuwaidi AR, Safadi MA, Vilca LM, Wanlapakorn N, Madhi SA, Giles ML, Prymula R, Ladhani S, Martinón-Torres F, Tan L, Michelin L, Scambia G, Principi N, Esposito S. Global Perspectives on Immunization During Pregnancy and Priorities for Future Research and Development: An International Consensus Statement. Front Immunol. 2020 Jun 24;11:1282. https://doi.org/10.3389/fimmu.2020.01282.
19. US Food and Drug Administration. COVID-19 vaccines 2024-2025. Available from: https://www.fda.gov/emergency-preparedness-and-response/coronavirus-disease-2019-covid-19/covid-19-vaccines-2024-2025. Accessed on: May 10, 2025.
20. Kalafat E, Heath P, Prasad S, O Brien P, Khalil A. COVID-19 vaccination in pregnancy. Am J Obstet Gynecol. 2022 Aug;227(2):136-147. https://doi.org/10.1016/j.ajog.2022.05.020.
21. Phijffer EW, de Bruin O, Ahmadizar F, Bont LJ, Van der Maas NA, Sturkenboom MC, Wildenbeest JG, Bloemenkamp KW. Respiratory syncytial virus vaccination during pregnancy for improving infant outcomes. Cochrane Database Syst Rev. 2024 May 2;5(5):CD015134. https://doi.org/10.1002/14651858.CD015134.pub2.
22. World Health Organization. Immunization schedules: Table 2 – Summary of WHO Position Papers (updated January 2025). Available from: https://cdn.who.int/media/docs/default-source/immunization/immunization_schedules/table_2_january_2025_web_english.pdf. Accessed on: May 13, 2025.
23. World Health Organization. WHO prequalifies first maternal respiratory syncytial virus vaccine. Available from: https://www.who.int/news/item/19-03-2025-who-prequalifies-first-maternal-respiratory-syncytial-virus-vaccine. Accessed on: May 10, 2025.
24. UK Health Security Agency. Vaccine update issue 354 January 2025: maternity special. Available from: https://www.gov.uk/government/publications/vaccine-update-issue-354-january-2025-maternity-special/vaccine-update-issue-354-january-2025-maternity-special. Accessed on: May 10, 2025.
25. European Centre for Disease Prevention and Control. Vaccination during pregnancy: information for new and expecting parents. Available from: https://vaccination-info.europa.eu/en/new-and-expecting-parents/vaccination-during-pregnancy. Accessed on: May 10, 2025.
26. American College of Obstetricians and Gynecologists (ACOG). Maternal Immunization Webinar. Available from: https://www.acog.org/education-and-events/webinars/maternal-immunization. Accessed on: May 10, 2025.
27. Centers for Disease Control and Prevention (CDC). Recommended vaccines for pregnant people. Available from: https://www.cdc.gov/vaccines-pregnancy/recommended-vaccines/index.html. Accessed on: May 10, 2025.
28. Pan American Health Organization (PAHO). PAHO to facilitate access to maternal vaccines to protect babies in the Americas. Available from: https://www.paho.org/en/news/1-11-2024-paho-facilitate-access-maternal-vaccines-protect-babies-americas-respiratory. Accessed on: May 13, 2025.
29. Gavi, the Vaccine Alliance. Gavi welcomes first-ever prequalification of maternal RSV vaccine. Available from: https://www.gavi.org/news/media-room/gavi-welcomes-first-ever-prequalification-maternal-rsv-vaccine. Accessed on: May 13, 2025.
30. Getahun D, Liu IA, Sy LS, Glanz JM, Zerbo O, Vazquez-Benitez G, Nelson JC, Williams JT, Hambidge SJ, McLean HQ, Irving SA, Weintraub ES, Qian L. Safety of the Seasonal Influenza Vaccine in 2 Successive Pregnancies. JAMA Netw Open. 2024 Sep 3;7(9):e2434857. https://doi.org/10.1001/jamanetworkopen.2024.34857.
31. Zerbo O, Ray GT, Fireman B, Layefsky E, Goddard K, Lewis E, Ross P, Omer S, Greenberg M, Klein NP. Maternal SARS-CoV-2 vaccination and infant protection against SARS-CoV-2 during the first six months of life. Nat Commun. 2023 Feb 28;14(1):894. https://doi.org/10.1038/s41467-023-36547-4.
32. Engmann C, Fleming JA, Khan S, Innis BL, Smith JM, Hombach J, Sobanjo-Ter Meulen A. Closer and closer? Maternal immunization: current promise, future horizons. J Perinatol. 2020 Jun;40(6):844-857. https://doi.org/10.1038/s41372-020-0668-3.
33. Briga M, Goult E, Brett TS, Rohani P, Domenech de Cellès M. Maternal pertussis immunization and the blunting of routine vaccine effectiveness: a meta-analysis and modeling study. Nat Commun. 2024 Jan 31;15(1):921. https://doi.org/10.1038/s41467-024-44943-7
34. Chittajallu LVS, Kaku R, Kondadasula P, Lim JY, Zhumabekova A. Safety and Efficacy of Vaccines During Pregnancy: A Systematic Review. Cureus. 2025 Jan 9;17(1):e77176. https://doi.org/10.7759/cureus.77176.
35. Simões EAF, Pahud BA, Madhi SA, Kampmann B, Shittu E, Radley D, Llapur C, Baker J, Pérez Marc G, Barnabas SL, Fausett M, Adam T, Perreras N, Van Houten MA, Kantele A, Huang LM, Bont LJ, Otsuki T, Vargas SL, Gullam J, Tapiero B, Stein RT, Polack FP, Zar HJ, Staerke NB, Padilla MD, Richmond PC, Sarwar UN, Baber J, Koury K, Lino MM, Kalinina EV, Li W, Cooper D, Anderson AS, Swanson KA, Gurtman A, Munjal I; MATISSE (Maternal Immunization Study for Safety and Efficacy) Clinical Trial Group. Efficacy, Safety, and Immunogenicity of the MATISSE (Maternal Immunization Study for Safety and Efficacy) Maternal Respiratory Syncytial Virus Prefusion F Protein Vaccine Trial. Obstet Gynecol. 2025 Feb 1;145(2):157-167. https://doi.org/10.1097/AOG.0000000000005816.
36. Rowe SL, Sullivan SG, Muñoz FM, Coates MM, Agnew B, Arah OA, Regan AK. COVID-19 Vaccination During Pregnancy and Major Structural Birth Defects. Pediatrics. 2025 Apr 1;155(4):e2024069778. https://doi.org/10.1542/peds.2024-069778.
37. Oh SS, Galanter J, Thakur N, Pino-Yanes M, Barcelo NE, White MJ, de Bruin DM, Greenblatt RM, Bibbins-Domingo K, Wu AH, Borrell LN, Gunter C, Powe NR, Burchard EG. Diversity in Clinical and Biomedical Research: A Promise Yet to Be Fulfilled. PLoS Med. 2015 Dec 15;12(12):e1001918. https://doi.org/10.1371/journal.pmed.1001918.
38. Bicego A, Wood JG, Newall AT, Hogan AB. Effectiveness of maternal vaccines and long-acting monoclonal antibodies against respiratory syncytial virus hospitalisations in early life: a scoping review of dynamic modelling studies. medRxiv. 2025 Apr 16. [preprint] https://doi.org/10.1101/2025.04.16.25325979
39. Gebreyesus A, Tesfay K. Effect of maternal education on com-

pleting childhood vaccination in Ethiopia: systematic review and meta-analysis. Sci Rep. 2024 Jul 29;14(1):17453. https://doi.org/10.1038/s41598-024-68182-4.
40. Santilli V, Sgrulletti M, Costagliola G, Beni A, Mastrototaro MF, Montin D, Rizzo C, Martire B, Miraglia Del Giudice M, Moschese V; Italian Society of Pediatric Allergy and Immunology (SIAIP) Vaccine Committee. Maternal Immunization: Current Evidence, Progress, and Challenges. Vaccines (Basel). 2025 Apr 24;13(5):450. https://doi.org/10.3390/vaccines13050450.
41. Nowakowska A, Lee SM, Kim M, Chun J, Kim S, Kim BC, In HJ, Lee E, Lee C, Lee H, Jang Y, Cho H, Kim J, Lee J, Lee HJ, Lee YK, Park JS, Kim YB. Timing of maternal vaccination against COVID-19 for effective protection of neonates: cohort study. Front Immunol. 2024 Jul 8;15:1359209. https://doi.org/10.3389/fimmu.2024.1359209.
42. Centers for Disease Control and Prevention. Vaccination guidelines for healthcare professionals. Available from: https://www.cdc.gov/vaccines-pregnancy/hcp/vaccination-guidelines/index.html. Accessed on: May 10, 2025.
43. Centers for Disease Control and Prevention. Yellow fever vaccine and pregnancy. Available from: https://www.cdc.gov/yellow-fever/vaccine/pregnancy.html. Accessed on: May 10, 2025.
44. Centers for Disease Control and Prevention. HPV vaccination recommendations. Available from: https://www.cdc.gov/vaccines/vpd/hpv/hcp/recommendations.html. Accessed on: May 10, 2025.
45. American College of Obstetricians and Gynecologists. Human papillomavirus vaccination. Available from: https://www.acog.org/clinical/clinical-guidance/committee-opinion/articles/2020/08/human-papillomavirus-vaccination. Accessed on: May 10, 2025.
46. World Health Organization. Summary of WHO position on HPV. Available from: https://cdn.who.int/media/docs/default-source/immunization/position_paper_documents/hpv/summary-of-who-position-on-hpv-final.pdf?sfvrsn=1bdd5da0_1. Accessed on: May 10, 2025.
47. Centers for Disease Control and Prevention. HPV vaccine safety. Available from: https://www.cdc.gov/vaccine-safety/vaccines/hpv.html. Accessed on: May 10, 2025.
48. Smith WB, Seger W, Chawana R, Jefferies Z, de Monerri NCS, Feng Y, Gaylord M, Jongihlati B, Beeslaar J, Skinner JM, Bickham K, Anderson AS. A Phase 2b Trial Evaluating the Safety, Tolerability, and Immunogenicity of a 6-Valent Group B Streptococcus Vaccine Administered Concomitantly With Tetanus, Diphtheria, and Acellular Pertussis Vaccine in Healthy Nonpregnant Female Individuals. J Infect Dis. 2025 Feb 26:jiaf096. https://doi.org/10.1093/infdis/jiaf096.
49. Rasmussen SA, Kim J, Jamieson DJ. Vaccines in Pregnancy: An Update on Recommendations From CDC's Advisory Committee on Immunization Practices. Birth Defects Res. 2025 Feb;117(2):e2459. https://doi.org/10.1002/bdr2.2459.
50. European Vaccine Initiative. EVI initiates a new clinical trial to protect pregnant women against malaria. Available from: https://www.euvaccine.eu/post/evi-initiates-a-new-clinical-trial-to-protect-pregnant-women-against-malaria. Accessed on: May 10, 2025.
51. Texas Biomedical Research Institute. Zika vaccine safe, effective when administered during pregnancy. Available from: https://www.txbiomed.org/news-press/news/zika-vaccine-safe-effective-when-administered-during-pregnancy/. Accessed on: May 10, 2025.
52. Kim IJ, Gonzalez O, Tighe MP, Lanthier PA, Clark MJ, Travis KL, Low-Beer TC, Lanzer KG, Bernacki DT, Szaba FM, De La Barrera RA, Dussupt V, Mendez-Rivera L, Krebs SJ, Ross CN, Mdaki SD, Brasky KM, Layne-Colon D, Tardif SD, Thomas SJ, Modjarrad K, Blackman MA, Patterson JL. Protective efficacy of a Zika purified inactivated virus vaccine candidate during pregnancy in marmosets. NPJ Vaccines. 2024 Feb 17;9(1):35. https://doi.org/10.1038/s41541-024-00824-0.
53. Vress D. Future vaccines in pregnancy. Best Pract Res Clin Obstet Gynaecol. 2021 Oct;76:96-106. https://doi.org/10.1016/j.bpobgyn.2021.03.009.