

# Original Research Article

## Transmission of anti-SARS-CoV-2 antibodies to newborns by vaccination of pregnant women.

### ABSTRACT

**Aims:** Vaccination in pregnant women is already performed for viruses and bacteria, with advantages to the mother and the newborn. Besides a general rejection of Covid-19 vaccines in this population, these are considered safe, effective and may prevent severe disease in pregnant women. Neutralizing antibodies titer measured in vaccinated pregnant is highly predictive of immune protection and can have a protective effect on the newborn. This study aimed to confirm the transfer of the antibodies across the placenta and to test if other factors impact the antibodies titer levels in the newborn circulation.

**Study design and methodology:** We collect 24 samples of umbilical cord blood of women who were vaccinated during pregnancy or in the three months before the pregnancy and analyzed the data of those pregnancies.

**Place and Duration of Study:** This cohort study was developed in our hospital, between March 2021 and May 2022.

**Results:** It was possible to confirm the passage of anti-Spike antibodies to the newborn. When comparing the IgG anti-S titers with the timing of vaccination, the analysis suggests that vaccination during the second or third trimester of pregnancy is more effective than before or in early pregnancy ( $p=0,005$ ). As for the vaccine used ( $p=0,23$ ) and the mode of delivery ( $p=0,48$ ), there were no statistical differences.

**Conclusion:** We confirm the passage of antibodies during the pregnancy, which appears to be more effective during the second and third trimester of gestation. Despite lack of evidence for how long and how effectively this passive immunity can protect the neonate from infection, vaccination of pregnant women should be considered.

## 1. INTRODUCTION

In December 2019, uncommon cases of pneumonia of unknown etiology were reported in Wuhan (China), and within a few months, the coronavirus disease 2019 (COVID-19), caused by acute respiratory syndrome coronavirus 2 (SARS-CoV-2), spread rapidly all over the world. This viral infection can cause a mild to severe illness, depending on how effectively the virus is encountered by the immune system[1].

Early on it, was clear that the development of a vaccine would be essential to control the disease, and in less than a year after it was declared a pandemic disease by WHO (World Health Organization)disease, the first vaccines against SARS-CoV-2 were already being distributed around the world.

Vaccination in pregnant women is not a new topic as it is already being done for other viruses, like influenza, or bacteria, like Bordetella pertussis. These strategies can have some advantages for the mother, like protection from a severe form of the disease, as well for the newborn, with passive protection from the antibodies produced by pregnant women and transferred for the fetus throughout the pregnancy.

As for the COVID-19, some of the first effective vaccines were produced with a technology that theoretically was safe in pregnant women. Both the vaccines based on adenovirus vectors, like OxfordAstraZeneca ChAdOx1-S and the vaccines based on messenger RNA, like Pfizer-BioNTech BNT162b2, are secure and pose no risk of pregnant women or fetus infection and so are thought to be safe in this population [2-5].

However, it should be kept in mind that pregnant women were excluded from initial clinical trials for COVID-19 vaccines, limiting the recommendations that can be made to this specific population. This led to an initial rejection of vaccination by the obstetric population, despite current data suggesting that pregnant women may be at increased risk for severe illness, admission to an intensive care unit, mechanical ventilation, and even death when compared with nonpregnant women [6,7]. They are also more likely to deliver pre-term newborns which have higher probability to be admitted to the neonatal intensive care unit [6]. This is highlighted by the Centers for Disease Control and Prevention (CDC), which included pregnancy as a risk factor for severe COVID-19 illness [8].

It is therefore of great interest to study the maternal immune response to SARS-CoV-2 vaccination during pregnancy, as well as the extent to which maternal antibodies cross the placenta, to predict the degree of passive protection acquired by the newborn, and factors that can modulate the effectiveness of that process.

Since is already established that neutralizing antibodies titer is highly predictive of immune protection [9], this study aims primarily to document and confirm the presence of antibodies anti-SARS-CoV-2 in the umbilical cord blood of newborns of mothers vaccinated during pregnancy.

## 2. METHODOLOGY

This cohort study was developed in our hospital, between March 2021 and May 2022. To every woman, who was vaccinated at least with one dose during the current pregnancy or in the three months before pregnancy, without known previous infection with SARS-CoV-2, and who were admitted to the delivery room in labor, was given the opportunity to participate in the study.

Samples of posterior oropharyngeal and nasopharyngeal to exclude asymptomatic SARS-CoV-2 infection were obtained at admission, and positive results were excluded from this study.

**Comment [AT1]:** Please add the information about the ethical clearance of this study

After consent, was collected an umbilical cord blood sample at the time of the delivery, regardless of the mode of delivery and the gestational age.

Then, the blood samples were tested to determine the circulating IgG anti-S protein level by Chemiluminescence.

The primary goal of this study was to evaluate the transfer of the antibodies across the placenta. Additionally, there was an evaluation to determine if the gestational age at vaccination, mode of delivery or type of vaccine used, was important to the titer of circulating antibodies in the newborn circulation

### 3. RESULTS

In total were collected 24 samples between May 2021 and March 2022 (Table 1). The characteristics of the population studied are resumed in Table 2.

**Table 1.** Description of the cases included in the cohort

Mother Age (years)	Complications during pregnancy	Gestational age at birth (weeks)	Mode of Delivery	Gestational age at vaccination (weeks)		Vaccine administered	IgG anti-S spike	
				1 <sup>st</sup> dose	2 <sup>nd</sup> dose			
1	36	None	40+2	Vaginal	20+5	23+5	Pfizer BNT 162b2	703 BAU/mL
2	27	None	38+4	Vaginal	28+6	31+6	Pfizer BNT 162b2	>2080 BAU/mL
3	28	None	39+0	Cesarean	PC	3	Pfizer BNT 162b2	98.6 BAU/mL
4	32	None	39+1	Vaginal	1	4	Pfizer BNT 162b2	1500 BAU/mL
5	31	None	40+6	Cesarean	30+3	33+3	Pfizer BNT 162b2	>2080 BAU/mL
6	36	None	40+2	Vaginal	30+5	33+5	Pfizer BNT 162b2	>2080 BAU/mL
7	38	None	39+1	Vaginal	32+4	35+4	Pfizer BNT 162b2	676 BAU/mL
8	33	None	39+1	Vaginal	PC	PC	Pfizer BNT 162b2	259 BAU/mL
9	31	None	39+4	Vaginal	PC	PC	Pfizer BNT 162b2	163BAU/mL
10	37	None	40+0	Vaginal	23+1	26+1	Pfizer BNT 162b2	335 BAU/mL
11	31	None	38+3	Vaginal	20+5	23+5	Pfizer BNT 162b2	704 BAU/mL
12	37	None	37+3	Vaginal	24+5	27+6	Pfizer BNT 162b2	>2080 BAU/mL
13	43	Small intestine GIST	39+0	Vaginal	23+6	27+6	Pfizer BNT 162b2	430 BAU/mL
14	39	None	38+6	Cesarean	PC	PC	Pfizer BNT 162b2	59.40 BAU/mL
15	37	None	39+2	Cesarean	23+0	26+0	Pfizer BNT 162b2	765 BAU/mL
16	31	None	38+4	Cesarean	PC	PC	Pfizer BNT 162b2	260 BAU/mL
17	31	None	38+0	Cesarean	23+0	26+0	Pfizer BNT 162b2	784 BAU/mL
18	29	None	39+5	Vaginal	PC	NA	ChAdOx1 S recombinant	6.33 BAU/mL
19	28	None	39+0	Cesarean	22+0	25+0	Pfizer BNT 162b2	1080 BAU/mL
20	28	Pre-eclampsia at term	37+1	Cesarean	27+4	30+0	Pfizer BNT 162b2	1110 BAU/mL
21	33	None	40+0	Vaginal	PC	23+2	ChAdOx1 S recombinant	698 BAU/mL
22	32	Positive aneuploidy screening	39+2	Cesarean	22+3	25+3	Pfizer BNT 162b2	1060 BAU/mL
23	32	None	40+3	Vaginal	30+5	33+6	Pfizer BNT 162b2	1880 BAU/mL
24	30	None	39+5	Vaginal	26+6	29+6	Pfizer BNT 162b2	2050 BAU/mL

Abbreviations: PC, Preconception; NA, not applicable; GITS, Gastrointestinal Stromal Tumor.

**Table 2.** Median characteristics of the population studied

Characteristics of the population studied	Median	
Age (years)	33	
Gestational age at birth (week)	39 + 1 (37+1; 40+6)	
Mode of delivery	Vacuum delivery	3 (12,5%)
	Euthocic delivery	12 (50%)
	Cesarian delivery	9 (37,5%)
IgG anti spike	Positive result	23 (95,8%)
	Negative result	1 (4,2%)

Pregnant women were on average 33 years and all pregnancies went to term, with delivery between 37 weeks <sup>+ 1 day</sup> and 40 weeks <sup>+ 6 days</sup>. The mode of delivery was a vaginal delivery in 15 cases (62,5%), including 3 vacuum deliveries, and a cesarean delivery in 9 cases (37,5%).

Most pregnancies included in this study were uneventful. The exceptions were one pregnant woman who developed pre-eclampsia at term, one who was diagnosed with small intestine GIST, and another one with a positive aneuploidy screening (who refused amniocentesis but had an infant without apparent structural anomalies).

In 2 cases the vaccine administered was the ChAdOx1 S recombinant vaccine and in the other 22 cases was administered the BNT162b2 vaccine.

In 95,5% of cases the result was above the cut-off to be considered positive (33.6 BAU/mL). So, there was only one negative case, in which the woman was vaccinated with the ChAdOx1 S recombinant vaccine, some days after the last menstrual period, having rejected the second dose, due to a pregnancy positive test.

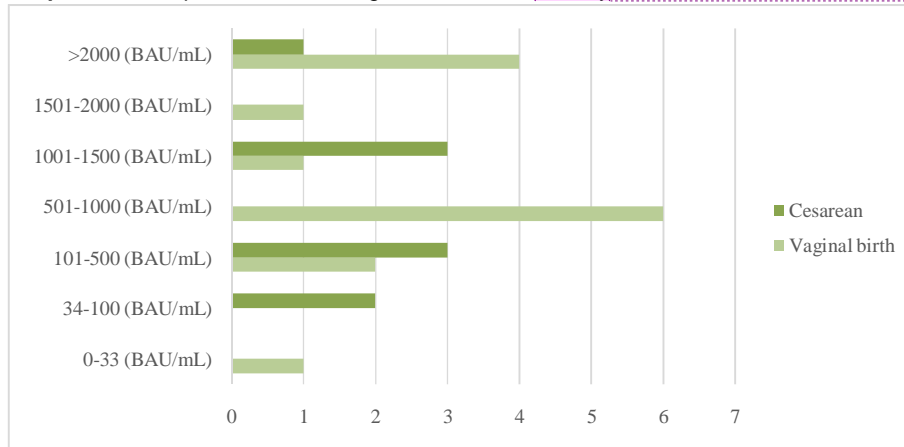
As shown in Table 3, in one-third of the cases the first dose of the vaccine was administered before conception, and the same for 15,4% of the second dose. The vaccines were administered during different gestational ages in different pregnant women: only 2 doses were administered in the first trimester (none as a first dose); 21 in the second trimester (11 as a first dose); and 12 in the third trimester (5 as a first dose). The latest dose was given at 35 weeks <sup>+ 4 days</sup>, nonetheless, had a delay of 25 days between the second dose and the delivery.

**Table 3.** Timing of vaccine doses

First Dose (n=24)	
Before pregnancy	8 (33,3%)
1° Trimester	0 (0%)
2° Trimester	11 (45,8%)
3° Trimester	5 (20,8%)
Second Dose (n=23)	
Before pregnancy	4 (15,4%)
1° Trimester	2 (8,7%)
2° Trimester	10 (43,5%)
3° Trimester	7 (30,4%)

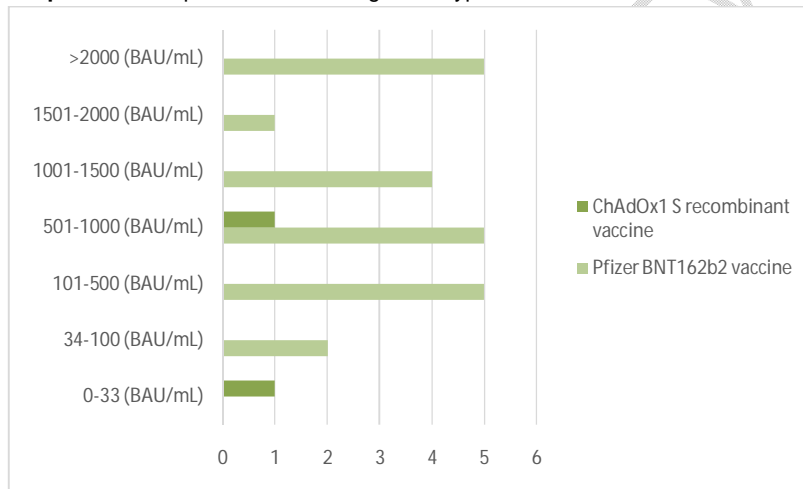
There was no statistical significance of the IgG anti-S titers ( $p=0,48$ ) when compared the result of samples obtained after a vaginal delivery (Median of 1043 BAU/mL  $\pm$  801) and after cesarean delivery (Median of 811 BAU/mL  $\pm$  634) (Graphic 1). When comparing the vaccine used, there was no statistical difference ( $p=0,23$ ) when pregnant women were vaccinated with the ChAdOx1 S recombinant vaccine (Median of 352 BAU/mL  $\pm$  489) or with Pfizer BNT162b2 vaccine (Median of 1011 BAU/mL  $\pm$  739) (Graphic 2).

**Graphic 1.** Anti-Spike titers according to the mode of delivery



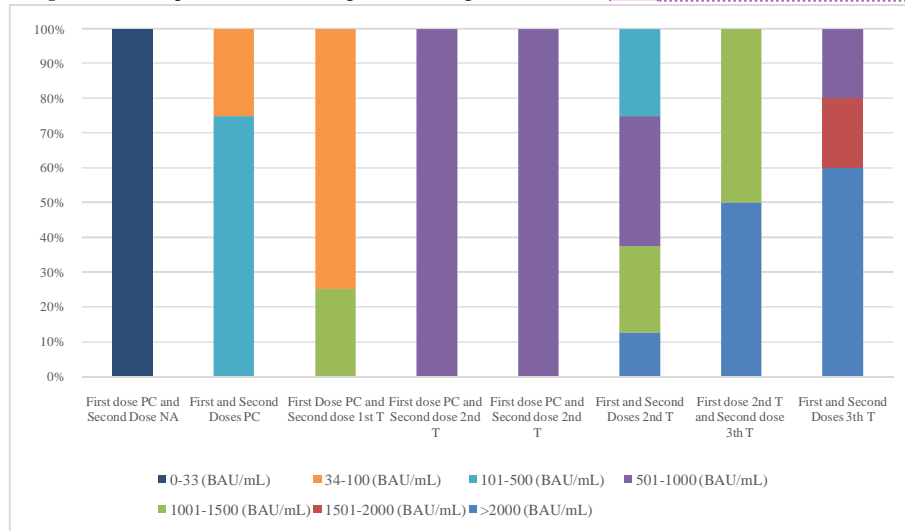
**Comment [AT2]:** The author distinguished between vaginal birth delivery and cesarean delivery, but does not provide reasons for the difference. It is better to explain why the author distinguished the level of Ig-G antibodies based on the birth delivery method. The author can explain this reason in the methods

**Graphic 2.** Anti-Spike titers according to the type of vaccine used



As for the timing of vaccine doses (Graphic 3), there was a statistical difference ( $p=0,005$ ) between women vaccinated in the second or third trimester (Median of 1211 BAU/mL  $\pm$  664) and women vaccinated before or very early in the gestation (Median of 163 BAU/mL  $\pm$  523). Even when comparing the titers of antibodies anti-S in the umbilical cord samples of women vaccinated in the 2nd trimester (Median of 864 BAU/mL  $\pm$  486) versus women vaccinated in the 3rd trimester (Median of 1708 BAU/mL  $\pm$  575), the results also favored a vaccination in the third trimester ( $p=0,005$ ). The smaller p-value was obtained when comparing women vaccinated before the pregnancy and women vaccinated in the 3rd trimester of the pregnancy ( $p=0,0005$ ).

**Graphic 3.** Anti-Spike titers according to the timing of the vaccine doses



**Comment [AT3]:** It is better to give very different color to each group therefore the reader is not confuse to distinguish each group of a IgG antibody titer level

Abbreviations: PC, Preconception; NA, not applicable; T, Trimester.

Table 4 resumes the statistical results described here.

**Table 4.** Effect of mode of delivery, the timing of vaccination, and vaccine used on IgG anti-Spike titers

Mode of delivery	
Vaginal delivery	Median of 1043 BAU/mL ± 801
Cesarean delivery	Median of 811 BAU/mL ± 634
p= 0,4671	
Timing of vaccination	
Second or third trimester	Median of 1211 BAU/mL ± 664
Before or very early on the gestation	Median of 163 BAU/mL ± 523
p= 0,0051	
Third Trimester	Median of 1708 BAU/mL ± 575
Before pregnancy	Median of 149 BAU/mL ± 115
p= 0,0005	
Third Trimester	Median of 1708 BAU/mL ± 575
Second trimester	Median of 864 BAU/mL ± 486
p= 0,0052	
During pregnancy	Median of 1168 BAU/mL ± 680
Before the pregnancy	Median of 149 BAU/mL ± 115
p= 0,0034	
Vaccine used	
Pfizer BNT 162b2 vaccine	Median of 1011 BAU/mL ± 739
ChAdOx1 S recombinant vaccine	Median of 352 BAU/mL ± 489
p= 0,2342	

#### 4. DISCUSSION

It is established that covid-19 disease can cause severe disease in pregnant women and can be associated with worse obstetric outcomes, with a meta-analysis reporting a rate of adverse events of 27%, with an unusually high cesarean rate [10]. As already mentioned, neonates born from mothers with covid-19 can also have severe comorbidities like respiratory distress syndrome, pneumonia, and other, secondary to iatrogenic preterm birth and maternal status[11]. Therefore, it is central to mention that vertical transmission can occur, and although the risk is quite low (estimated to be 8% or even lower)[10,12,13], it should not be ignored. Another consideration is the possibility of postnatal infection by respiratory transmission [14], emphasizing the importance of their previously acquired protection.

Production of IgG antibodies against SARS- CoV-2 virus occurs following natural infection, a process that also occurs with active immunization. Current data suggests that vaccine-induced immune responses are significantly greater than the response that occurs with natural infection [15,16].

Early in the final weeks of the first trimester of gestation, maternal IgG is transferred across the placenta to the developing fetus to protect them from infection as a neonate. This process is called passive immunization and it peaks in the last trimester, where the majority of IgG is transferred in the final 4 weeks of gestation. Although most IgG antibody crosses the placenta in the third trimester, the process is time-dependent, so immunization should be ideally done at least 6 or more weeks prior to delivery [17].

The COVID-19 vaccines that were early commercialized were based on messenger RNA technology that targeted the S protein (protein Spike). Therefore, the circulating level of IgG anti-S is a measure of the immune response to the vaccination [18]. Although this response does not only relies on the titer of IgG anti-S antibodies (since there is also a cellular immune response), these are an objective measure of the reactivity of the immune system and a measure to predict an eventual passive protection of the newborn. As evidence supports, anti-SARS-CoV-2 antibodies titers are associated with a lower risk of symptomatic disease [16,19,20].

In agreement with other recent studies, it was observed that the anti-SARS-CoV-2 antibodies, produced by the pregnant woman's immune system in response to the vaccine, crossed the placenta and became present in the fetus's blood resulting in passive immunity, at least in the neonatal period [19,21,22].

The increasing levels of maternal IgG over time and the increasing placental IgG transfer ratio over time suggest that the timing between vaccination and delivery may be an important factor to consider in vaccination strategies in this population.

Although some studies suggest that a longer latency between vaccination and delivery correlates with higher anti-S IgG titers [21,23], there is already evidence that vaccination of pregnant women in the third trimester can be equally effective [24]. In fact, these vaccines induce a rapid stimulation of the immune system with antibody production as early as 5 days after the first dose, and transplacental transfer of passive immunity to the neonate as early as 16 days after the first vaccination dose [25,26]. As this study demonstrates, vaccination in the third trimester seems to correlate to higher titers of anti-Spike antibodies in the umbilical cord blood at the delivery.

**Comment [AT4]:** 1.in the results, you distinguished between SC delivery and vaginal birth delivery, but you didn't discuss about the result in the discussion. If you didn't discuss about this and you didn't have the reason why the IgG antibody level is different between SC delivery and vaginal birth delivery, it is better to delete it.

Note: you only wrote in the discussion '...As expected, the mode of delivery did not seem to interfere with the anti-S titers in the umbilical cord as that passage occurs during gestation and not at the time of the delivery'... you should discuss why it happen.

2. It is better you explain about what the ChAdOx1 recombinant vaccine and how it works and produce antibody then you relate it to the result you got. You write this in the discussion.

3. If the researcher still has old samples from this study and if it is possible to do, it is better to run the antibody neutralization assay so we could know whether vaccines can protect the neonates from SARS-CoV-2 infection. This result could give more reason why the pregnant woman should get a COVID-19 vaccine

This study also tried to prove if there was any correlation between the anti-S antibodies titers and the type of vaccine used or the mode of delivery. As expected, the mode of delivery did not seem to interfere with the anti-S titers in the umbilical cord as that passage occurs during gestation and not at the time of the delivery. Considering the type of vaccine used, although the only negative sample was from a pregnant woman vaccinated with the ChAdOx1 S recombinant vaccine, she received only one dose, instead of the usual two. Besides that, our sample was too small to draw a conclusion based on the vaccines used.

Despite the lack of evidence for how long this passive immunity can protect the neonate from infection and how effective is that protection, the confirmation of the passage of these antibodies through the placenta and the fact, already established, that pregnant women are a group of higher risk for severe disease when compared with the general population, may justify vaccination even during pregnancy.

## 5. CONCLUSION

In conclusion, this procedure should be encouraged and any misconception about risks for the mother and the fetus should be corrected considering the evidence available. Although is needed more investigation to make recommendations on when the vaccination is more efficient, this work suggest that vaccination during the second or third trimester of gestation is effective.

## CONSENT (WHEREEVER APPLICABLE)

All participants included in the study sign an informed consent stating their consent to participate in this study.

## ETHICAL APPROVAL (WHEREEVER APPLICABLE)

This study was approved by the ethics committee of our institution (with the approval code: Ref.<sup>a</sup> 1166/CES/2021). The procedures used in this study are in line with the principles of the Declaration of Helsinki.

## REFERENCES

1. Wang C, Horby PW, Hayden FG, & Gao GF (2020) A novel coronavirus outbreak of global health concern. *Lancet* 395(10223):470–473. [https://doi.org/10.1016/S0140-6736\(20\)30185-9](https://doi.org/10.1016/S0140-6736(20)30185-9)
2. Lopez Bernal J, Andrews N, Gower C, Robertson C, Stowe J, Tessier E et al (2021) Effectiveness of the Pfizer-BioNTech and Oxford-AstraZeneca vaccines on covid-19 related symptoms, hospital admissions, and mortality in older adults in England: test negative case-control study. *BMJ* 373:n1088. <https://doi.org/10.1136/bmj.n1088>
3. Leik NKO, Ahmedy F, Guad RM, & Baharuddin DMP (2021) Covid-19 vaccine and its consequences in pregnancy: Brief review. *Annals of medicine and surgery* 72:103103. <https://doi.org/10.1016/j.amsu.2021.103103>
4. Bookstein Peretz S, Regev N, Novick L, Nachshol M, Goffer E, Ben-David A et al (2021) Short-term outcome of pregnant women vaccinated with BNT162b2 mRNA COVID-19 vaccine. *Ultrasound in obstetrics & gynecology : the official journal of the International Society of Ultrasound in Obstetrics and Gynecology* 58(3): 450–456. <https://doi.org/10.1002/uog.23729>
5. Ciapponi A, Bardach A, Mazzoni A, Alconada T, Anderson SA, Argento FJ et al (2021)

Safety of components and platforms of COVID-19 vaccines considered for use in pregnancy: A rapid review. *Vaccine* 39(40):5891–5908. <https://doi.org/10.1016/j.vaccine.2021.08.034>

6. Ilotey J, Stallings E, Bonet M, Yap M, Chatterjee S, Kew T et al (2020) Clinical manifestations, risk factors, and maternal and perinatal outcomes of coronavirus disease 2019 in pregnancy: living systematic review and meta-analysis. *BMJ* 370:m3320. <https://doi.org/10.1136/bmj.m3320>
7. Celewicz A, Celewicz M, Michalczyk M, Wozniakowska-Gondek P, Krejczy K, Misiek M, Rzepka R (2021) Pregnancy as a Risk Factor of Severe COVID-19. *J. clin. Med.* 10, 5458. <https://doi.org/10.3390/jcm10225458>
8. CDC Underlying Medical Conditions Associated with Higher Risk for Severe COVID-19: Information for Healthcare Professionals. Updated Feb 9, 2023. Available Online: <https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinicalcare/underlyingconditions.html>. Accessed on 29, April, 2023
9. Khoury DS, Cromer D, Reynaldi A, Schlub TE, Wheatley AK, Juno JA et al (2021) Neutralizing antibody levels are highly predictive of immune protection from symptomatic SARS-CoV-2 infection. *Nature medicine* 27(7):1205–1211. <https://doi.org/10.1038/s41591-021-01377-8>
10. Dubey P, Reddy SY, Manuel S, & Dwivedi AK (2020) Maternal and neonatal characteristics and outcomes among COVID-19 infected women: An updated systematic review and meta-analysis. *European journal of obstetrics, gynecology, and reproductive biology* 252:490–501. <https://doi.org/10.1016/j.ejogrb.2020.07.034>
11. Kyle MH, Glassman ME, Khan A, Fernández CR, Hanft E, Emeruwa UN et al (2020) A review of newborn outcomes during the COVID-19 pandemic. *Seminars in perinatology* 44(7):151286. <https://doi.org/10.1016/j.semperi.2020.151286>
12. Gajbhiye RK, Modi DN, Mahale SD (2020) Pregnancy outcomes, Newborn complications and Maternal-Fetal Transmission of SARS-CoV-2 in women with COVID-19: A systematic review of 441 cases. *medRxiv* 7(2):21-28. <https://doi.org/10.1101/2020.04.11.20062356>
13. Fenizia C, Biasin M, Cetin I, Vergani P, Mileto D, Spinillo A et al (2020) Analysis of SARS-CoV-2 vertical transmission during pregnancy. *Nature communications* 11(1):5128. <https://doi.org/10.1038/s41467-020-18933-4>
14. Novoa RH, Quintana W, Llancarí P, Urbina-Quispe K, Guevara-Ríos E, & Ventura W (2021) Maternal clinical characteristics and perinatal outcomes among pregnant women with coronavirus disease 2019. A systematic review. *Travel medicine and infectious disease* 39:101919. <https://doi.org/10.1016/j.tmaid.2020.101919>
15. Flannery DD, Gouma S, Dhudasia MB, Mukhopadhyay S, Pfeifer MR, Woodford EC et al (2021) Assessment of Maternal and Neonatal Cord Blood SARS-CoV-2 Antibodies and Placental Transfer Ratios. *JAMA pediatrics* 175(6):594–600. <https://doi.org/10.1001/jamapediatrics.2021.0038>
16. Gray KJ, Bordt EA, Atyeo C, Deriso E, Akinwunmi B, Young N et al (2021) COVID-19 vaccine response in pregnant and lactating women: a cohort study. *medRxiv : the preprint server for health sciences*, 2021.03.07.21253094. <https://doi.org/10.1101/2021.03.07.21253094>
17. Munoz FM, & Jamieson DJ (2019) Maternal Immunization. *Obstetrics and gynecology* 133(4):739–753. <https://doi.org/10.1097/AOG.0000000000003161>
18. Walls AC, Park YJ, Tortorici MA, Wall A, McGuire AT, & Veasley D (2020) Structure, Function, and Antigenicity of the SARS-CoV-2 Spike Glycoprotein. *Cell* 181(2):281–292.e6. <https://doi.org/10.1016/j.cell.2020.02.058>
19. Cicalini I, Rossi C, Natale L, Cufaro MC, Catitti G, Vespa S et al (2021) Passive Immunity to SARS-CoV-2 at Birth Induced by Vaccination in the First Trimester of Pregnancy. *International journal of environmental research and public health* 18(23):12789. <https://doi.org/10.3390/ijerph182312789>
20. Feng S, Phillips DJ, White T, Sayal H, Aley PK, Bibi S et al (2021) Correlates of protection against symptomatic and asymptomatic SARS-CoV-2 infection. *Nature medicine* 27(11):2032–2040. <https://doi.org/10.1038/s41591-021-01540-1>
21. Trostle ME, Aguero-Rosenfeld ME, Roman AS, & Lighter JL (2021) High antibody levels in cord blood from pregnant women vaccinated against COVID-19. *American journal of obstetrics & gynecology MFM* 3(6):100481. <https://doi.org/10.1016/j.ajogmf.2021.100481>
22. Zdanowski W, & Waśniewski T (2021) Evaluation of SARS-CoV-2 Spike Protein

Antibody Titers in Cord Blood after COVID-19 Vaccination during Pregnancy in Polish Healthcare Workers: Preliminary Results. *Vaccines* 9(6):675.  
<https://doi.org/10.3390/vaccines9060675>

23. Mithal LB, Otero S, Shanes ED, Goldstein JA, & Miller ES (2021) Cord blood antibodies following maternal coronavirus disease 2019 vaccination during pregnancy. *American journal of obstetrics and gynecology* 225(2):192–194.  
<https://doi.org/10.1016/j.ajog.2021.03.035>
24. Beharier O, Plitman Mayo R, Raz T, Nahum Sacks K, Schreiber L, Suissa-Cohen Y et al (2021) Efficient maternal to neonatal transfer of antibodies against SARS-CoV-2 and BNT162b2 mRNA COVID-19 vaccine. *The Journal of clinical investigation* 131(13): e150319. <https://doi.org/10.1172/JCI150319>
25. Prabhu M, Murphy EA, Sukhu AC, Yee J, Singh S, Eng D (2021) Antibody Response to Coronavirus Disease 2019 (COVID-19) Messenger RNA Vaccination in Pregnant Women and Transplacental Passage Into Cord Blood. *Obstetrics and gynecology* 138(2):278–280. <https://doi.org/10.1097/AOG.0000000000004438>
26. Rottenstreich A, Zarbiv G, Oiknine-Djian E, Zigron R, Wolf DG, & Porat S (2021) Efficient Maternofetal Transplacental Transfer of Anti- Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) Spike Antibodies After Antenatal SARS-CoV-2 BNT162b2 Messenger RNA Vaccination. *Clinical infectious diseases: an official publication of the Infectious Diseases Society of America* 73(10):1909–1912.  
<https://doi.org/10.1093/cid/ciab266>

UNDER PEER REVIEW

UNDER PEER REVIEW

