

The Prevalence of Fetal and Maternal Complications Resulting from COVID-19 in Hospitalized Pregnant Women

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ABSTRACT

Background: The COVID-19 pandemic has significantly impacted pregnant individuals and their newborns. While symptoms often mirror nonpregnant adults, unique clinical patterns exist. Understanding predictors of adverse outcomes is crucial. This study aimed to evaluate the association between maternal clinical presentation, specifically key laboratory markers (inflammatory, coagulation, and immune) and symptoms, and subsequent maternal and neonatal outcomes in hospitalized COVID-19-positive pregnant women during a period of low vaccination prevalence.

Method: We retrospectively reviewed data from pregnant women with confirmed COVID-19 who delivered at Imam Reza Hospital, Mashhad, Iran, between April 2021 and March 2022. Demographic, clinical, laboratory, maternal, and neonatal data were collected. Variable interactions were explored using partial correlation and logistic regression.

Results: Among 293 mother-newborn pairs, preterm delivery risk increased with low maternal lymphocyte percentage, low platelet count, and high prothrombin time; advanced gestational age was protective (OR = 0.94). Intrauterine growth restriction (IUGR) risk decreased with higher maternal weight (OR = 0.04) and lower C-reactive protein (CRP) (OR = 0.08). Stillbirth risk rose with elevated ferritin (OR = 10.12) and prothrombin time (OR = 6.34) but declined with higher maternal respiratory rate (OR = 0.21) and later gestational age (OR = 0.78). Neonatal asphyxia risk increased with maternal height (OR = 3.67) and respiratory rate (OR = 4.70), while higher lymphocyte percentage was protective (OR = 0.21). Low lymphocyte percentage predicted several adverse outcomes, including intensive care unit (ICU) admission, low birth weight (LBW), and mechanical ventilation.

Conclusion: Our findings underscore the predictive potential of specific maternal inflammatory (e.g., CRP, ferritin), coagulation [e.g., prothrombin time (PT), platelets], and immune (e.g., lymphocyte percentage) parameters for adverse maternal and, notably, neonatal outcomes such as preterm birth, stillbirth, and LBW in COVID-19-positive pregnancies. Unexpected factors like maternal respiratory rate and height also showed associations warranting further study. These results, reflecting a largely unvaccinated cohort, highlight potential markers for risk stratification and emphasize the need for further investigation into the underlying mechanisms and the impact of interventions like vaccination.

Keywords: Adverse outcomes, COVID-19, Maternal health, Neonatal health, Predictive factors, Pregnancy.

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INTRODUCTION

The COVID-19 pandemic has profoundly altered global dynamics, impacting all facets of human life. Pregnant women and newborns have emerged as particularly vulnerable populations during this crisis. The intersection of COVID-19 and pregnancy necessitates a thorough examination of both physical and societal ramifications, underscoring the importance of investigating the virus's effects on maternal and neonatal outcomes.

Respiratory infections, including COVID-19, have been shown to progress rapidly, potentially leading to fatal consequences for both mother and fetus.¹ The physiological changes that occur during pregnancy can exacerbate the risk of severe illness from such infections.² While the general manifestation of COVID-19 during pregnancy largely resembles that in nonpregnant individuals,³ several critical distinctions have been observed.

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A systematic review revealed that pregnant and recently pregnant individuals were less prone to exhibiting common COVID-19 symptoms such as fever, cough, dyspnea, and myalgia compared to nonpregnant women of reproductive age. Moreover, a significant number of pregnant people infected with the virus remained asymptomatic, making accurate assessments challenging.⁴ It is worth noting that certain clinical manifestations of COVID-19, like fatigue and shortness of breath, overlap with typical pregnancy symptoms. Regarding infection severity, evidence suggests that while pregnancy does not increase susceptibility to SARS-CoV-2 infection, it appears to exacerbate the clinical course of COVID-19.⁵

The clinical, radiological, and laboratory indicators of COVID-19 pneumonia in expectant mothers are similar to those in nonpregnant individuals. However, the risks and outcomes during gestation remain distinct.⁶ A meta-analysis highlighted elevated risks associated with COVID-19 in pregnancy, including significant increases in preterm delivery, maternal mortality, neonatal intensive care unit (NICU) admissions, and neonatal death.⁷ Further complicating matters, research indicates the possibility of vertical transmission of the virus from infected mothers to neonates, particularly in cases where the placenta tested positive for the virus.⁸

Given the unique challenges COVID-19 presents during pregnancy, understanding predictive factors for adverse outcomes is critical. This study's primary aim is to investigate the association between specific maternal clinical presentations—encompassing symptoms and key laboratory markers (inflammatory, coagulation, immune)—and the subsequent risk of adverse clinical neonatal outcomes [such as preterm birth, intrauterine growth restriction (IUGR), stillbirth, and neonatal asphyxia] in hospitalized COVID-19-positive pregnant women. By identifying these correlations, we seek to provide insights that could inform risk stratification and clinical management.

METHODOLOGY

Study Design and Setting

This cross-sectional observational study investigated COVID-19's effects on maternal and neonatal outcomes at Imam Reza Hospital, Mashhad, from April 2021 to March 2022. This period was selected as it largely preceded widespread COVID-19 vaccination uptake in the source population, allowing for an examination of the virus's impact with minimal confounding from vaccine-induced immunity.

Study Population and Sampling

The study population comprised pregnant women who tested positive for COVID-19 during pregnancy and subsequently delivered at Imam Reza Hospital during the study period. COVID-19 positivity was confirmed through either positive PCR testing or diagnostic imaging findings consistent with COVID-19 infection. COVID-19 molecular

detection was performed using the Rotor-Gene Q (Qiagen, Germany) PCR system with the MagCore® (RBC Bioscience Corp., Taiwan) extraction device for sample processing and analysis. Data regarding individual patient vaccination status (including vaccine type or number of doses) were not systematically collected or available in the reviewed records and, therefore, could not be included in the analysis.

Data Collection

Data collection involved two primary sources. The primary dataset was extracted from the Imam Reza Hospital Health Information System (HIS) database, with initial participant identification utilizing ICD-10 coding for COVID-19 positive deliveries. Secondary data were obtained from the high-risk mothers department records.

The collected data encompassed comprehensive maternal and fetal parameters. Demographic and anthropometric data included maternal age, gestational age, and maternal physical measurements. Laboratory parameters consisted of complete blood count analysis, including hemoglobin, hematocrit, platelets, white blood cell count, and lymphocyte percentage. Coagulation profiles were assessed through international normalized ratio (INR), prothrombin time (PT), partial thromboplastin time (PTT), and D-dimer measurements. Liver and renal function were monitored *via* aspartate aminotransferase (AST), alanine aminotransferase (ALT), and creatinine levels. Inflammatory markers included erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), lactate dehydrogenase (LDH), and ferritin, while metabolic status was assessed through fasting blood glucose measurements.

Clinical parameters included detailed family exposure history and comprehensive symptomatology assessment, including olfactory and gustatory changes, fever, myalgia, and both respiratory and gastrointestinal manifestations. Maternal complications were documented, including mechanical ventilation requirements, hepatomegaly, postpartum hemorrhage, preeclampsia, and intensive care unit (ICU) admission status. Mode of delivery was recorded, along with extensive neonatal outcomes, including gestational age at delivery, growth parameters, and mortality data.

Data Processing and Analysis

The data preprocessing phase employed a robust Z-score methodology with a threshold of 2.7 for outlier detection and removal. Missing data points were addressed through iterative imputation techniques to maintain dataset integrity. The Shapiro-Wilk test was utilized to identify variables requiring normalization, which was subsequently achieved through Box-Cox transformation to ensure appropriate data distribution for analysis. Multicollinearity was assessed using partial correlation analysis for continuous variables and Chi-square testing for categorical variables.

Statistical analysis incorporated point-biserial correlation testing to examine symptom-laboratory parameter

associations. The predictive modeling phase involved the development of dual logistic regression models. The first model emphasized laboratory parameters, while the second focused on symptom-based predictions. Both models underwent validation using the Hosmer–Lemeshow test to assess reliability and clinical applicability. Comprehensive model metrics are detailed in Appendix 1.

Ethical Considerations

This study was conducted under the supervision of the Mashhad University of Medical Sciences Ethics Committee, following the ethical code IR.MUMS.REC.1401.212. Participants' anonymity was ensured throughout the research process. The study adhered to the STROBE checklist for cross-sectional studies,⁹ which is provided as supplementary material (Appendix 2).

RESULTS

This cross-sectional study analyzed data from 293 mother-infant pairs to investigate the impact of COVID-19 on maternal and neonatal outcomes. Detailed model metrics are available in Appendix 1.

Tables 1 and 2 illustrate the prevalence of maternal and neonatal symptoms.

Table 3 presents the descriptive analysis of maternal vital signs and demographic characteristics.

Table 4 presents descriptive statistics for various maternal lab studies, including mean values and interquartile ranges (IQR) for 16 different parameters. Notable findings include elevated levels of inflammatory markers such as CRP (mean 58.2) and ferritin (mean 168.6), as well as a markedly increased D-dimer level (mean 3204).

Partial Correlation

A partial correlation analysis revealed several statistically significant correlations between laboratory variables. Strong positive correlations were observed, for example, between hemoglobin and hematocrit ($r = 0.83$) as well as AST and ALT ($r = 0.8$). Based on these results and considering prior knowledge, hematocrit, AST, and INR were removed to reduce multicollinearity; their respective information is sufficiently represented by other variables. Details are provided in Appendix 1.

Preterm Birth vs Lab Studies

Increased maternal weight (per IQR) was associated with a 2.17-fold increase in the odds of preterm delivery (OR = 2.166).

Table 1: Data exploration results of neonatal categorical variables

Feature	No	Yes
Preterm delivery	217	76
IUGR	283	10
Stillbirth	277	16
Severe neonatal asphyxia	286	7
LBW	240	53

Conversely, higher platelet count (OR = 0.662) and higher lymphocyte percentage (OR = 0.614) were associated with reduced odds (i.e., were protective). Prolonged PT was also positively associated with preterm labor risk (OR = 2.131). As expected, each additional gestational week corresponded to a 6% decrease in odds of preterm delivery (OR = 0.940).

Intrauterine Growth Restriction vs Lab Studies

An increase in maternal weight (per IQR) was associated with a 96% decrease in odds of IUGR (OR = 0.040). Elevated platelet count was linked to a reduction in IUGR risk (OR = 0.349), while elevated ESR and D-dimer levels tended toward an increase in IUGR odds. Notably, higher CRP levels were associated with substantially reduced IUGR odds (OR = 0.077).

Table 2: Data exploration results of maternal categorical variables

Feature	No	Yes
Type of delivery	111	182
		(C-section)
ICU hospitalization	211	82
Postpartum hemorrhage	280	13
Mechanical ventilation	260	33
Other family members involvement	111	182
Decreased sense of smell or taste	267	26
Fever	140	153
Myalgia	183	110
Cough	103	190
Shortness of breath	76	217
Sore throat	260	33
Nausea	269	24
Vomit	278	15
Diarrhea	281	12
Anorexia	283	10
Chest pain	279	14
Stomach ache	285	8
Shivering	237	56
Headache	261	32
Runny nose	286	7
Flank pain	288	5

Table 3: Descriptive statistics of maternal vital signs and demographic characteristics

Feature	Mean	IQR
Systolic BP	113.5	10
Diastolic BP	71.5	12
PR	95.6	13
RR	22.9	5
Oxygen saturation	93.5	5
Weight	73	16
Height	161.8	6
Age	30.3	9

Table 4: Descriptive statistics of maternal lab studies

Feature	Mean	IQR
HB	11.6	1.7
HCT	35.4	4.9
PLT	175.8	77
WBC	19.7	8.6
LYM	16.7	8.4
AST	59.9	34
ALT	45.6	32.3
Cr	1.4	0.3
ESR	47.3	26.6
CRP	58.2	60.8
LDH	534.7	250.2
Ferritin	168.6	122
PT	11.2	1.33
PTT	30.1	5.9
FBS	91	26
D-dimer	3204	2718.4

Stillbirth vs Lab Studies

Elevated ferritin levels (per IQR), indicating higher inflammation or iron dysregulation, were associated with a tenfold increase in odds of stillbirth (OR = 10.116). A similar strong association indicating potential coagulopathy was found with prolonged prothrombin time (OR = 6.341). Conversely, a higher maternal respiratory rate was associated with decreased odds of stillbirth (OR = 0.211), a counterintuitive finding. Each additional gestational week was associated with a 21.9% reduction in stillbirth odds (OR = 0.781).

Severe Neonatal Asphyxia vs Lab Studies

Increased maternal height (per IQR) was associated with increased odds of severe neonatal asphyxia (OR = 3.670), while increased lymphocyte percentage was associated with reduced odds (OR = 0.214). Maternal respiratory rate was positively associated with asphyxia odds (OR = 4.702). Interestingly, increased ESR was associated with decreased odds of severe neonatal asphyxia (OR = 0.234).

Lab vs Fetus Death

A logistic regression analysis was conducted to identify laboratory values predicting fetal death, although the Hosmer–Lemeshow test indicated that the model was not a good fit. Increased white blood cell count was associated with higher odds of fetal death (OR = 2.857), while a trend toward decreased odds was found with each additional gestational week (OR = 0.905).

Low Birth Weight vs Lab Studies

Increased lymphocyte percentage was associated with decreased odds of low birth weight (LBW) (OR = 0.435). An inverse relationship was found with CRP (OR = 0.417).

In contrast, prothrombin time and systolic blood pressure were positively associated with LBW (OR = 2.494 and 1.728, respectively). Each additional gestational week was also associated with a decrease in odds of LBW (OR = 0.911).

Intensive Care Unit Hospitalization vs Lab Studies

Elevated lymphocyte percentage and CRP levels were associated with decreased odds of ICU hospitalization (OR = 0.421 and 0.410, respectively). Prothrombin time and systolic blood pressure were associated with increased odds (OR = 2.263 and 1.713, respectively). Higher gestational age was associated with decreased odds of ICU hospitalization (OR = 0.905).

Postpartum Hemorrhage vs Lab Studies

The logistic regression analysis identified white blood cell count as a significant predictor of postpartum bleeding. For each IQR unit increase in white blood cell count, the odds of postpartum bleeding decreased by 57.1% (OR = 0.429).

Maternal Mortality vs Lab Studies

The logistic regression analysis revealed several significant predictors of maternal death. For each IQR unit, increased lymphocyte percentage was associated with increased odds of maternal death (OR = 3.122). Conversely, increased ALT levels, systolic blood pressure, and respiratory rate were associated with decreased odds of maternal death (OR = 0.328, 0.263, and 0.188, respectively).

Mechanical Ventilation vs Lab Studies

The logistic regression analysis identified several significant predictors of mechanical ventilation. For each IQR unit increase in lymphocyte percentage, the odds of requiring mechanical ventilation decreased by 68.9% (OR = 0.311). Increased CRP and systolic blood pressure were associated with increased odds of ventilation (OR = 2.655 and 2.112, respectively). Increased PTT and oxygen saturation, however, were associated with reduced odds of mechanical ventilation (OR = 0.458 and 0.194).

DISCUSSION

This cross-sectional study investigated the associations between maternal laboratory parameters, clinical symptoms, and key maternal and neonatal outcomes in COVID-19-positive pregnant women, primarily during a period of low vaccination coverage. Our analysis identified several significant maternal predictors, particularly inflammatory markers (ferritin, CRP), coagulation parameters (PT, platelets), and immune indicators (lymphocyte percentage), associated with adverse neonatal outcomes such as preterm birth, stillbirth, LBW, and neonatal asphyxia, as well as maternal complications like ICU admission. These findings offer insights into the pathophysiology of COVID-19 in pregnancy and highlight potential markers for risk assessment in this vulnerable population.

Preterm Birth

Our findings on COVID-19 and preterm birth align with current literature. While systematic reviews show low vertical transmission rates¹⁰ and no increased risks of miscarriage or congenital anomalies,¹¹ evidence indicates that SARS-CoV-2 infection during pregnancy is associated with adverse outcomes, particularly preterm birth.¹²

The identification of prothrombin time as a predictor of preterm delivery corroborates recent research.¹³ This association is supported by studies showing that shortened PT and activated partial thromboplastin time (aPTT) values correlate with increased preterm labor risk.¹⁴ Similarly, our finding of platelet count as a significant predictor aligns with research establishing connections between platelet abnormalities and poor outcomes in preterm newborns.¹⁵

Our findings on the relationship between weight and preterm labor can be viewed in conjunction with those of Hu et al.¹⁶ These studies noted an increased risk of preterm birth among both underweight and obese women, suggesting a complex relationship between maternal weight and preterm birth risk.

Intrauterine Growth Restriction

The relationship between COVID-19 and fetal growth restriction (FGR), also known as IUGR, remains unclear, despite the known link between maternal viral infections and FGR. While a study by Mitta et al. found no significant difference in FGR rates between COVID-19-positive and -negative patients,¹⁷ our study revealed an unexpected finding. We observed a 96% decrease in IUGR odds for each IQR unit increase in maternal weight, suggesting a potential protective effect of higher maternal weight against IUGR in COVID-19-positive mothers. This contrasts with existing literature,¹⁸ which commonly associates maternal obesity with increased IUGR risk. Furthermore, our study found a significant inverse relationship between platelet count and IUGR odds; with each increase in platelet count, the odds of IUGR decreased by 65.1%. While this aligns with Shahgheibi et al.'s, Ciobanu et al. note inconsistencies in data regarding platelet changes and IUGR, emphasizing the need for further research.^{19,20} Finally, our findings indicate that elevated ESR and CRP levels are associated with increased IUGR odds, which is supported by Kirici et al., who observed elevated inflammatory markers in IUGR cases.²¹ These inflammatory markers may offer potential for early IUGR detection and intervention.

Stillbirth

The observation that elevated ferritin levels significantly increased the risk of stillbirth is consistent with research linking inflammation and iron metabolism imbalances to adverse neonatal outcomes.²² These findings highlight the need for monitoring inflammatory markers in pregnant women with COVID-19. Contrasting with the typical understanding that maternal respiratory rate is a measure of poor outcomes, an increased maternal respiratory rate was associated with reduced odds of stillbirth. This potentially

counterintuitive finding aligns with research demonstrating that fetal heart rate is responsive to maternal breathing patterns, possibly indicating improved fetal well-being.²³ This link may suggest a relationship with better oxygenation that ultimately impacts fetal health. This warrants further investigation as well as exploring other parameters of the oxygenation process.

Severe Neonatal Asphyxia

An unexpected association was observed between increased maternal height and higher odds of severe neonatal asphyxia, a relationship not previously documented in COVID-19-related pregnancies. This novel finding requires further exploration to understand potential underlying mechanisms, such as biomechanical factors during delivery or genetic predispositions. Conversely, higher maternal lymphocyte percentages were protective against neonatal asphyxia, indicating that robust maternal immune responses may mitigate the risk of hypoxic complications in neonates.

Low Birth Weight

The study reinforced the established link between elevated maternal systolic blood pressure and increased LBW risk, consistent with global health reports highlighting hypertension as a significant contributor to FGR.^{24,25} Additionally, higher lymphocyte percentages and lower CRP levels were associated with reduced LBW odds, suggesting that favorable immune and inflammatory profiles support optimal fetal growth. The inverse relationship between gestational age and LBW underscores the importance of prolonged gestation in achieving adequate fetal weight.

Intensive Care Unit Hospitalization

Increased PT and systolic blood pressure were identified as significant predictors of ICU hospitalization, aligning with studies that associate coagulation abnormalities and hypertensive disorders with severe COVID-19 outcomes.^{26,27} The protective effect of advancing gestational age on ICU admissions may reflect the physiological maturation of maternal and fetal systems, enhancing resilience against severe infections. The lack of association between ICU hospitalization and hemoglobin, platelet count, and white blood cells contrasts with some studies,²⁸ highlighting the heterogeneity of COVID-19 presentations and the need for comprehensive risk assessments.

Postpartum Hemorrhage

This study revealed a borderline significant association between maternal height and postpartum bleeding, suggesting taller women may be at increased risk. This contrasts with Hosseinzadeh et al., who found no such association.²⁹ Interestingly, Softa et al. linked shorter maternal height to a higher risk of emergency cesarean sections and also with the mode of delivery and the baby's birth weight, implying a potential indirect link to hemorrhage through delivery complications.³⁰ Our findings, along with these

conflicting results, emphasize the need for further research into maternal height as a potential predictor of postpartum hemorrhage and its connection to delivery outcomes. Consistent with our findings regarding weight, Butwick et al. found minimal impact of maternal body mass index (BMI) on postpartum hemorrhage risk.³¹

Maternal Mortality

This study, reflecting primarily unvaccinated individuals, demonstrated a significant association between increased lymphocyte percentage and an elevated risk of maternal death, with a 212.2% increase in odds. This relationship is noteworthy, given the vital role lymphocytes play in immune responses. Although existing literature does not explicitly highlight the association between lymphocyte percentage and eclampsia, the lymphocytic response can be critical in various infections and inflammatory conditions.

Contrary to findings in eclampsia from Sak et al., where elevated ALT levels were significantly associated with increased maternal mortality, our study found that elevated ALT levels were inversely related to maternal mortality among COVID-19-positive mothers.³² This difference suggests that the underlying pathophysiology of liver enzyme alterations in COVID-19 might be distinct from that in eclampsia. Other studies have also highlighted the role of ALT levels in pregnancy complications, such as gestational diabetes and preeclampsia.³³ The mechanisms behind these contradictory effects require further investigation.

Clinical Implications

While derived from a retrospective cohort, our findings suggest potential clinical applications. The strong associations observed between specific laboratory markers and adverse outcomes indicate that monitoring maternal lymphocyte percentage, platelet count, prothrombin time, ferritin, and CRP levels in pregnant patients with COVID-19 could aid in risk stratification. For instance, significantly low lymphocyte or platelet counts, or markedly elevated PT or ferritin, might signal a higher risk for outcomes like preterm birth, stillbirth, or maternal ICU admission, potentially prompting closer maternal-fetal surveillance or consideration of readiness for delivery. The unexpected associations with maternal height and respiratory rate warrant further investigation to understand their clinical relevance.

This study has several important limitations. Foremost is the lack of data on maternal COVID-19 vaccination status and type, which is a major determinant of disease severity and outcomes. Therefore, our findings predominantly reflect the impact of COVID-19 in a largely unvaccinated or minimally vaccinated pregnant population during a specific timeframe (April 2021–March 2022) and may not be generalizable to highly vaccinated populations or periods dominated by different viral variants. The retrospective, single-center design limits the ability to establish causality and may affect the generalizability of the results. Furthermore, data on specific COVID-19

treatments administered were not analyzed, preventing assessment of therapeutic effects. Finally, the sample size for some outcomes (e.g., severe neonatal asphyxia, stillbirth) was relatively small, potentially limiting the statistical power for those specific analyses.

Future research should prioritize prospective, multicenter studies incorporating detailed data on vaccination status (including type and timing), specific viral variants, administered therapies, and maternal comorbidities. Validating the predictive value of the identified laboratory markers in diverse populations is crucial. Investigating the mechanisms underlying the unexpected associations, such as those involving maternal height and respiratory rate, is warranted. Furthermore, longitudinal studies are needed to understand the long-term health consequences for both mothers and children exposed to COVID-19 during pregnancy.

CONCLUSION

In conclusion, this study highlights significant associations between specific maternal laboratory markers—notably those reflecting inflammation (ferritin, CRP), coagulation (PT, platelets), and immune status (lymphocyte percentage)—and the risk of adverse maternal and neonatal outcomes in hospitalized COVID-19-positive pregnant women, primarily from an era of low vaccination. These findings underscore the potential utility of these markers in identifying pregnancies at higher risk for complications like preterm birth, stillbirth, and maternal ICU admission. While unexpected associations involving maternal height and respiratory rate require further clarification, our results emphasize the systemic impact of COVID-19 during pregnancy. Further prospective research in diverse populations is essential to validate these findings, understand underlying mechanisms, and inform evidence-based clinical management strategies for this vulnerable group.

AUTHORS CONTRIBUTIONS

AT presented the study's main idea and contributed to conceptualization, supervision, and validation. AZ constructed the theory, evaluated needed data, developed the article text, and contributed to the statistical analysis. MB contributed to granting access to patient data, planning study procedures, and promoting study coherence. All authors contributed to data curation, manuscript drafting, data evaluation, and interpretation. The study's final approval and review procedure was done under the contribution of all authors. All authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data supporting this study's findings will be available upon request from the corresponding author. Requests for data access should be directed to Dr Arash Ziaee.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

In the development and composition of this document, generative AI was utilized only within the scope of fundamental grammar, spelling, and reference verification tools.

SUPPLEMENTARY MATERIALS

All the supplementary appendices are available online on the website of www.dsjuog.com.

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