



Pre-eclampsia-like syndrome induced by severe COVID-19: a prospective observational study

M Mendoza,^a I Garcia-Ruiz,^a N Maiz,^a C Rodo,^a P Garcia-Manau,^a B Serrano,^a RM Lopez-Martinez,^b J Balcells,^c N Fernandez-Hidalgo,^{d,e} E Carreras,^a A Suy^a

^a Maternal-Fetal Medicine Unit, Department of Obstetrics, Hospital Universitari Vall d'Hebron, Universitat Autònoma de Barcelona, Barcelona, Spain ^b Biochemistry Department, Hospital Universitari Vall d'Hebron, Universitat Autònoma de Barcelona, Barcelona, Spain

^c Paediatric Critical Care Department, Hospital Universitari Vall d'Hebron, Universitat Autònoma de Barcelona, Barcelona, Spain

^d Department of Infectious Diseases, Hospital Universitari Vall d'Hebron, Universitat Autònoma de Barcelona, Barcelona, Spain

^e Red Española de Investigación en Patología Infecciosa (REIPI), Instituto de Salud Carlos III, Madrid, Spain

Correspondence: Dr A Suy, Department of Obstetrics, Hospital Universitari Vall d'Hebron, Universitat Autònoma de Barcelona, Passeig de la Vall d'Hebron, 119-129, Barcelona 08035, Spain. Email: asuy@vhebron.net

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Objectives To investigate the incidence of clinical, ultrasonographic and biochemical findings related to pre-eclampsia (PE) in pregnancies with COVID-19, and to assess their accuracy to differentiate between PE and the PE-like features associated with COVID-19.

Design A prospective, observational study.

Setting Tertiary referral hospital.

Participants Singleton pregnancies with COVID-19 at >20⁺⁰ weeks.

Methods Forty-two consecutive pregnancies were recruited and classified into two groups: severe and non-severe COVID-19, according to the occurrence of severe pneumonia. Uterine artery pulsatility index (UtAPI) and angiogenic factors (soluble fms-like tyrosine kinase-1/placental growth factor [sFlt-1/PlGF]) were assessed in women with suspected PE.

Main outcome measures Incidence of signs and symptoms related to PE, such as hypertension, proteinuria, thrombocytopenia, elevated liver enzymes, abnormal UtAPI and increased sFlt-1/PlGF.

Results Thirty-four cases were classified as non-severe and 8 as severe COVID-19. Five (11.9%) women presented signs and

symptoms of PE, all five being among the severe COVID-19 cases (62.5%). However, abnormal sFlt-1/PlGF and UtAPI could only be demonstrated in one case. One case remained pregnant after recovery from severe pneumonia and had a spontaneous resolution of the PE-like syndrome.

Conclusions Pregnant women with severe COVID-19 can develop a PE-like syndrome that might be distinguished from actual PE by sFlt-1/PlGF, LDH and UtAPI assessment. Healthcare providers should be aware of its existence and monitor pregnancies with suspected pre-eclampsia with caution.

Keywords Angiogenic factors, COVID-19, PlGF, pre-eclampsia, pre-eclampsia-like syndrome, pregnancy, SARS, SARS-CoV-2, sFlt-1.

Tweetable abstract This study shows that a pre-eclampsia-like syndrome could be present in some pregnancies with severe COVID-19.

Linked article This article is commented on by DL Rolnik, p. 1381 in this issue. To view this mini commentary visit <https://doi.org/10.1111/1471-0528.16369>

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Introduction

On 11 March 2020, the World Health Organization (WHO) declared the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) outbreak a pandemic disease, given its increasing number of cases worldwide.¹ Studies have shown that the disease caused by SARS-CoV-2, named as COVID-19 (coronavirus disease 2019) typically presents

with fever, dry cough and fatigue; nevertheless, up to 14% of the cases can evolve to severe pneumonia and 5% to severe acute respiratory syndrome (SARS), both requiring admission to intensive care for intensive respiratory support.² Whereas COVID-19 is primarily a respiratory infection, it has important systemic effects including hypertension, kidney disease, thrombocytopenia and liver injury.^{3–6} As SARS-CoV-2 is believed to invade the host

through the cell entry receptor angiotensin-converting enzyme 2 (ACE2), these signs and symptoms in SARS-CoV-2 infection are thought to be due to the vasoconstriction resulting from the dysfunction of the renin-angiotensin system.^{7,8} By contrast, clinical features of pre-eclampsia (PE) are mainly a consequence of the endothelial damage originated by placental oxidative stress and antiangiogenic status, which leads to the appearance of hypertension and proteinuria, elevated liver enzymes, renal failure or thrombocytopenia, among others.^{9,10} An increased incidence of PE has been reported among mothers infected with SARS-CoV-2 compared with the general population.¹¹ Misdiagnosis, however, might have occurred in some of these cases, as COVID-19 and PE have overlapping clinical features. Therefore, differential diagnosis might be challenging in COVID-19 pregnant women presenting with hypertension and proteinuria, thrombocytopenia or elevated liver enzymes.¹⁰ Thus, the aim of this study was to investigate the prevalence of clinical, ultrasonographic and biochemical findings related to PE in women with SARS-CoV-2 infection and to assess their accuracy in differentiating between actual PE and PE-like features associated with COVID-19.

Methods

We carried out a prospective cohort study of all consecutive pregnant women at >20 weeks of gestation who presented to the emergency department of our tertiary care center for suspicion of COVID-19 (dry cough and fever) and had laboratory-confirmed SARS-CoV-2 infection, between 13 March and 10 April 2020. Patients were not actively involved in the research.

Patients were classified in two groups: severe and non-severe COVID-19, according to the occurrence of severe pneumonia. The laboratory and clinical data were prospectively recorded in a database. The recorded data included the following: platelet count (per microlitre), D-dimer (microg/l), lactate dehydrogenase (U/l), aspartate aminotransferase (U/l), alanine aminotransferase (U/l), urine protein to creatinine ratio (mg/g), systolic blood pressure (mmHg), diastolic blood pressure (mmHg), mean arterial pressure (mmHg), creatinine (mg/dl) and gestational age (GA) in weeks. GA to describe particular cases was expressed in weeks^{+days}. Mean arterial pressure was calculated as: $1/3 \times (\text{systolic blood pressure}) + 2/3 \times (\text{diastolic blood pressure})$. Maternal baseline characteristics were compared between groups. In severe cases, data were analysed at three different time points during COVID-19: before, during and after intensive care unit (ICU) admission for severe pneumonia.

According to the WHO guidance, laboratory confirmation for SARS-CoV-2 was defined as a positive result of real-time reverse transcriptase-polymerase chain reaction (RT-PCR) assay of nasal and pharyngeal swabs.¹²

PE was defined as new onset of high blood pressure (systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg) or worsening of previous high blood pressure in addition to new-onset proteinuria (protein to creatinine ratio >300) or worsening of previous proteinuria, or to at least one of the following signs and symptoms of severe PE: cerebral or visual symptoms, elevation of liver enzymes to twice normal concentration, platelet count $<100\,000/\mu\text{l}$, serum creatinine concentrations >1.1 mg/dl or pulmonary oedema.¹⁰ The HELLP syndrome is frequently considered a variant of PE. Diagnostic criteria for HELLP syndrome are haemolysis with increased LDH (>600 U/l) and AST (≥ 70 U/l), and platelets $<100\,000/\mu\text{l}$.¹³

In women with new-onset hypertension, the uterine artery pulsatility index (UtAPI) was assessed by transabdominal Doppler ultrasound and maternal serum levels of placental growth factor (PlGF) and soluble fms-like tyrosine kinase-1 (sFlt-1) in pg/ml were determined by means of the fully automated Elecsys assays for sFlt-1 and PlGF on an electrochemiluminescence immunoassay platform (cobas e analyzers; Roche® Diagnostics, Rotkreuz, Switzerland).^{14,15} The sFlt-1/PlGF was then calculated. UtAPI above the 95th centile for gestational age, and sFlt-1/PlGF values ≥ 85 (at <34 weeks) or ≥ 110 (at ≥ 34 weeks) were considered highly suggestive of underlying placental disease.^{16–19}

Statistical analysis

The open-source statistical software R Commander (R package version 2.3-1), which is freely available on CRAN (<https://cran.r-project.org>), was used for statistical analysis. Categorical data were reported as frequency and percentage, and comparisons between severity groups were estimated by Chi-square or Fisher tests, as appropriate. Continuous variables were described as median and interquartile (IQR) range and Mann–Whitney *U* test was used to assess differences between severity groups. The statistical significance level was set at $P < 0.05$.

Results

During the study period (31 days), 42 cases of SARS-CoV-2-infected women were identified at a median GA of 32.0 (IQR 26.0–37.5) weeks of gestation. Among them, eight (19.0%) cases developed severe pneumonia and required admission to the ICU. Median maternal age of cases with severe COVID-19 was significantly greater than in the non-severe cases (39.4 [34.2–44.5] versus 30.9 [25.0–41.8], $P = 0.006$). No other pregnancy baseline characteristics differed between severity groups. Among the eight severe cases, five (62.5%) developed PE features (new-onset hypertension and proteinuria and/or thrombocytopenia and/or elevated liver enzymes), requiring antihypertensive

drugs in all of them. No cases with diagnostic criteria for PE were found among the 34 non-severe COVID-19 women (Table 1).

Evolution of clinical and laboratory findings in the severe cases of COVID-19

Before severe pneumonia, all eight women were normotensive, had normal platelet count, liver enzymes, LDH and proteinuria, and only one case with UtAPI above the 95th centile was identified. During severe pneumonia, the most frequent findings were: elevated liver enzymes to twice normal concentrations (87.5%), proteinuria >300 mg/g (75.0%) and hypertension (62.5%) (Figure 1). No cases with creatinine >1.1 mg/dl or platelet count <100 000/ μ l were found; nevertheless, one case presented mild thrombocytopenia (platelet count <150 000/ μ l). sFlt-1/PlGF \geq 85/110 and UtAPI >95th centile were present in only one woman. Only one case with LDH >600 IU/l was identified. Based on these findings, five women (62.5%) had diagnostic criteria of PE and/or HELLP syndrome. Caesarean delivery was performed during ICU stay in four cases. HELLP syndrome was the indication for delivery in case 1 (at a GA of 30⁺¹) and worsening of SARS in cases 3, 4 and 7 (at a GA of 37⁺⁶, 36⁺⁶ and 28⁺³, respectively). After recovery from severe pneumonia, hypertensive therapy was no longer required in all cases and only the woman who had presented with sFlt-1/PlGF >110, LDH >600 and UtAPI above the 95th centile, still met PE diagnostic criteria (more details on clinical and laboratory findings and their evolution in severe cases can be seen in Table 2 and Figure 1).

Discussion

Main findings

This study shows that 11.9% of COVID-19 pregnant women develop PE features; however, they only appeared in COVID-19 cases complicated by severe pneumonia. In this situation, PE/HELLP diagnostic criteria were found in five (62.5%) of the cases; nevertheless, abnormal angiogenic status, increased LDH and placental underperfusion could only be confirmed in one of them, which indicates that this case was probably an actual PE. These findings suggest that the signs and symptoms compatible with PE/HELLP present in four of these five cases, could be derived from the complex polypharmacy administered or from the renal and cardiovascular dysfunction for severe SARS-CoV-2 infection. In our cohort, only one of these five cases remained pregnant after severe pneumonia recovery, and then all PE/HELLP features recovered spontaneously. PE and HELLP syndrome do not resolve spontaneously and delivery is the only definitive cure. For these reasons, we believe that the four women with PE/HELLP signs and symptoms, and normal sFlt-1/PlGF, UtAPI and LDH <600, had developed a PE-like syndrome.

Strengths and limitations

To our knowledge, this is the first study to describe the incidence of signs and symptoms of PE in a relatively large cohort of pregnancies with COVID-19 and to show that a PE-like syndrome could be induced by severe COVID-19. Furthermore, our findings are of great value to improve

Table 1. Maternal characteristics in pregnant women with COVID-19

	All patients (n = 42)	Nonsevere patients (n = 34)	Severe patients (n = 8)	P
Maternal age (years)	32.0 (26.0–37.5)	30.9 (25.0–41.8)	39.4 (34.2–44.5)	0.006
Pre-pregnancy BMI (kg/m²)	26.2 (23.5–29.3)	26.1 (22.8–29.3)	27.9 (25.4–30.6)	0.378
Gestational age (weeks)	31.6 (25.9–36.1)	32.8 (26.7–36.1)	28.6 (22.3–32.4)	0.211
Ethnicity				
White	22 (52.4%)	19 (55.9%)	3 (37.5%)	0.304
Latin American	17 (40.5%)	12 (35.3%)	5 (62.5%)	
Others	3 (7.1%)	3 (8.8%)	0	
ART	4 (9.5%)	2 (5.9%)	2 (25.0%)	0.158
Smoking	2 (4.8%)	1 (2.9%)	1 (12.5%)	0.348
Nuliparous	20 (47.6%)	16 (47.1%)	4 (50.0%)	1.0
History of PE	0	0	0	1.0
Pre-pregnancy HTN	0	0	0	1.0
Pre-pregnancy diabetes	1 (2.4%)	1 (2.4%)	0	1.0
Chronic kidney disease	0	0	0	1.0
PE diagnostic criteria during COVID-19	5 (11.9%)	0	5 (62.5%)	<0.001

ART, assisted reproductive technology; BMI, body mass index; HTN, hypertension; PE, pre-eclampsia.

Continuous data are given as median and interquartile range. Categorical data as frequency and percentage. *P*-values denoted the comparison between non-severe and severe subgroups.

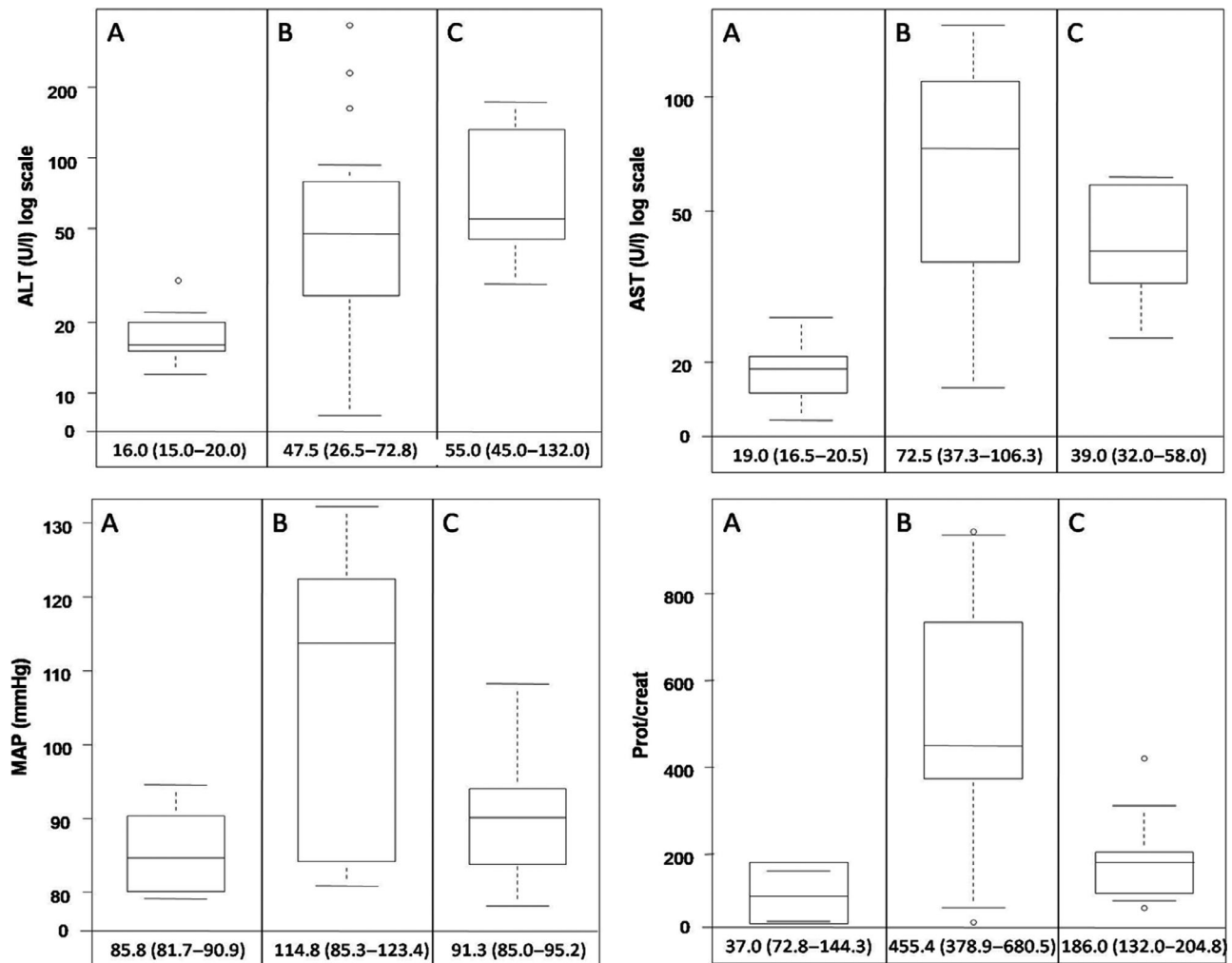


Figure 1. Evolution of ALT, AST, proteinuria and mean arterial blood pressure in pregnant women with COVID-19 before (A), during (B) and after (C) severe pneumonia. The bottom and top edges of each box represent the first and third quartiles, respectively, the band within the box represents the median value and the whiskers represent values that are 1.5 times the interquartile range. Median values and interquartile range of each variable are displayed.

maternal care of pregnancies with severe pneumonia due to COVID-19.

This study has several limitations. First, this is a small series and the results should be considered with caution. Further research is needed to better understand the systemic consequences of COVID-19 in pregnant women. Second, only four women with PE-like syndrome are reported, which could mean that our findings are not applicable to all pregnancies with severe pneumonia due to COVID-19. Third, only one of the four women who developed a PE-like syndrome remained pregnant after severe pneumonia and despite the PE-like syndrome recovering spontaneously, we cannot affirm that the three other cases did not improve due to delivery. Nevertheless, we believe that the PE-like syndrome alone may not be an obstetric indication for delivery, as it seems that it might not be a

placental complication itself, but one of the clinical manifestations of severe COVID-19. Finally, although UtAPI and sFlt-1/PIGF ratio have a high negative predictive value to predict the short-term absence of PE, they are not diagnostic criteria of PE;^{20,21} thus, we cannot categorically state that the case with PE features and elevated UtAPI and sFlt-1/PIGF was an actual PE and not a PE-like syndrome.

Interpretation

Several disorders have previously proved to imitate PE because they share some of the clinical and laboratory findings of patients with PE. The pathophysiologic causes of these conditions include vasospasm, platelet activation or destruction, microvascular thrombosis, endothelial cell dysfunction and reduced tissue perfusion. Some of these disorders include gestational hypertension, chronic kidney

Table 2. Clinical and biochemical pre-eclampsia-related findings in pregnant women with COVID-19 before, during and after severe pneumonia

	Variables	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Before severe pneumonia	GA (weeks)	30 ⁺⁰	22 ⁺⁶	37 ⁺⁵	36 ⁺⁴	32 ⁺⁰	20 ⁺³	27 ⁺⁴	20 ⁺¹
	SBP (mmHg)	130	120	123	117	104	135	107	116
	DBP (mmHg)	74	72	74	67	71	76	67	63
	MAP (mmHg)	92.7	88.0	90.3	83.7	82.0	95.7	80.3	80.7
	Prot/creat (mg/g)	37	180	—	—	—	—	—	—
	AST (U/l)	17	19	15	20	26	19	23	14
	ALT (U/l)	16	30	13	26	20	12	14	22
	Platelets/ μ l	158 000	242 000	402 000	210 000	275 000	234 000	319 000	242 000
	LDH (U/l)	—	—	—	—	—	—	—	—
	D-dimer (mg/ml)	—	—	—	—	—	—	—	—
	Creatinine (mg/dl)	0.63	0.49	—	0.79	0.74	0.36	0.45	0.66
	UtAPI >95th centile	No	No	Yes	No	No	No	No	No
	PE/HELLP diagnostic criteria	No	No	No	No	No	No	No	No
During severe pneumonia	GA (weeks)	30 ⁺¹	24 ⁺⁴	37 ⁺⁶	36 ⁺⁵	32 ⁺¹	20 ⁺⁴	28 ⁺³	20 ⁺²
	SBP (mmHg)	145	168	156	155	116	115	140	108
	DBP (mmHg)	90	116	98	108	70	68	105	69
	MAP (mmHg)	108.3	133.3	117.3	123.7	85.3	83.7	116.7	82.0
	Prot/creat (mg/g)	855	622	378	514	396	49	948	130
	AST (U/l)	153	122	104	62	38	52	138	113
	ALT (U/l)	170	136	52	39	38	14	65	230
	Platelets/ μ l	324 000	160 000	279 000	231 000	336 000	243 000	108 000	505 000
	LDH (U/l)	482	370	672	555	517	176	463	312
	D-dimer (mg/ml)	457	2129	5065	1800	326	119	514	376
	Creatinine (mg/dl)	0.34	0.42	0.85	0.88	0.42	0.20	0.39	0.26
	Hidralazine	Yes	Yes	Yes	Yes	No	No	No	No
	Labetalol	Yes	Yes	Yes	Yes	No	No	Yes	No
	sFlt-1/PIGF	9.40	20.24	378.90	49.36	24.78	4.60	7.60	5.19
	UtAPI >95th centile	No	No	Yes	No	No	No	No	No
PE/HELLP diagnostic criteria	Yes	Yes	Yes	Yes	No	No	Yes	No	
After severe pneumonia	GA at delivery (weeks)	30 ⁺¹	Not delivered	37 ⁺⁶	36 ⁺⁶	Not delivered	Not delivered	28 ⁺³	Not delivered
	Reason for delivery	HELLP	—	SARS	SARS	—	—	SARS	—
	GA (weeks)	—	25.5	—	—	33.2	21.5	—	21.3
	SBP (mmHg)	123	132	142	115	116	108	109	110
	DBP (mmHg)	83	75	93	68	79	62	75	64
	MAP (mmHg)	96.3	94.0	109.3	83.7	91.3	77.3	86.3	79.3
	Prot/creat (mg/g)	210	183	426	83	115	83	189	128
	AST (U/l)	39	32	56	43	58	—	23	61
	ALT (U/l)	45	132	41	29	55	—	29	172
	Platelets/ μ l	312 000	218 000	232 000	258 000	292 000	169 000	364 000	762 000
	LDH (U/l)	222	277	692	325	211	—	353	192
	D-dimer (mg/ml)	617	1745	3258	—	454	—	347	470
	Creatinine (mg/dl)	0.25	0.3	0.58	—	0.41	—	0.42	0.65
	UtAPI >95th centile	—	No	—	—	No	No	—	No
	PE/HELLP diagnostic criteria	No	No	Yes	No	No	No	No	No

ALT, alanine aminotransferase; AST, aspartate aminotransferase; DBP, diastolic blood pressure; GA, gestational age; LDH, lactate dehydrogenase; MAP, mean arterial pressure; PE, pre-eclampsia; PIGF, placental growth factor; prot/creat, urine protein to creatinine ratio; SARS, severe acute respiratory syndrome; sFlt-1, soluble fms-like tyrosine kinase-1; UtAPI, uterine artery pulsatility index.

disease, acute fatty liver of pregnancy, thrombotic thrombocytopenic purpura, haemolytic uremic syndrome, acute exacerbation of systemic lupus erythematosus, severe hypothyroidism and sepsis.^{17,22,23} Differential diagnosis may be a challenge to caregivers due to the overlap of diagnostic criteria among them. Additionally, some of them are potentially life-threatening for both the mother and the fetus; thus, accurate diagnosis is important, as the management and prognosis of these conditions differ widely. Recent studies have shown that angiogenic factors support the differential diagnosis between PE and some of its imitators.^{17,24,25} PlGF and sFlt-1 are placenta-related angiogenic factors that are highly specific to placental insufficiency.²⁶ In PE, the placenta fails properly to invade and remodel maternal uterine spiral arteries, leading to impaired perfusion and placental oxidative stress.^{27,28} This condition leads to increased UtAPI and to an antiangiogenic status with increased sFlt-1/PlGF ratio due to up-regulation of sFlt-1 and down-regulation of PlGF.^{9,20} The identification of an sFlt-1/PlGF imbalance is detectable in the maternal circulation at least 5 weeks before the onset of clinical PE.²⁶ Thus, COVID-19 patients with normal early phase of placental implantation should have normal values of sFlt-1/PlGF and UtAPI in spite of proteinuria, thrombocytopenia, elevated liver enzymes or hypertension. This hypothesis, however, had not been previously investigated due to the very recent outbreak of the SARS-CoV-2 infection.

This study has important clinical implications, as we show that sFlt-1/PlGF, UtAPI and LDH allow PE to be differentiated from the PE-like syndrome present in some of the pregnant women with severe COVID-19. This knowledge could improve management and reduce misdiagnosis in pregnancies with severe COVID-19. In our cohort, case 1 was probably misdiagnosed as HELLP syndrome; this, in addition to the concurrence of SARS, influenced the indication of delivery. The fact that the sFlt-1/PlGF results were not available at the time of worsening of the maternal condition, and the scarce evidence available at that time of the consequences of COVID-19 during pregnancy, prompted the delivery indication at 30⁺¹ weeks. After the experience with this first case, a more conservative management was adopted in the following cases that developed PE-like syndrome. Fortunately, they completely recovered after severe pneumonia and became normotensive again without any antihypertensive drugs and without being delivered.

Conclusion

Pregnant women with severe COVID-19 could develop a PE-like syndrome, which might be distinguished from actual PE by sFlt-1/PlGF, LDH and UtAPI assessment. Therefore, healthcare providers should be aware of its existence and monitor pregnancies with suspected PE with

caution. PE-like syndrome might not be an indication for earlier delivery in itself, as it might not be a placental complication and could resolve spontaneously after recovery from severe pneumonia.

Disclosure of interests

Manel Mendoza and Itziar Garcia-Ruiz received lecture fees by Roche Diagnostics. The other authors have no conflicts of interest to declare. Completed disclosure of interests forms is available to view online as supporting information.

Contribution to authorship

AS and EC had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. EC, AS, MM and IG-R conceived and designed the study. RML-M, JB, NM and NF-H contributed to the literature research. NM, CR, PG-M and BS contributed to data collection and confirmation. MM, IG-R and AS contributed to data analysis, and MM, IG-R, AS, RMLM, JB, NF-H and EC contributed to data interpretation. MM and IG-R were in charge of writing the manuscript draft. AS and EC made substantial revisions to the manuscript. MM and IG-R contributed equally to this article. AS and EC also contributed equally to this article.

Details of ethics approval

This study was approved by the Vall d'Hebron University Hospital Ethics Committee (PR[AMI]181/2020) on 13 March 2020. Written informed consent was waived due to the rapid emergence of this infectious disease. However, verbal informed consent was obtained from all patients, which was included in the patient's medical record.

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References

- 1 WHO Director-General's opening remarks at the media briefing on COVID-19. 2020 [www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020]. Accessed 12 March 2020.
- 2 Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72 314 cases from the Chinese Center for Disease Control and Prevention. *JAMA* 2020; published online Feb 24. <https://doi.org/10.1001/jama.2020.2648>
- 3 Cai Q, Huang D, Yu H, Zhu Z, Xia Z, Su Y, et al. Characteristics of liver tests in COVID-19 patients. *J Hepatol* 2020; published online Apr 13. <https://doi.org/10.1016/j.jhep.2020.04.006>

- 4 Cheng Y, Luo R, Wang K, Zhang M, Wang Z, Dong L, et al. Kidney disease is associated with in-hospital death of patients with COVID-19. *Kidney Int* 2020; published online Mar 20. <https://doi.org/10.1016/j.kint.2020.03.005>
- 5 Kreutz R, Algharably EAE-H, Azizi M, Dobrowolski P, Guzik T, Januszewicz A, et al. Hypertension, the renin-angiotensin system, and the risk of lower respiratory tract infections and lung injury: implications for COVID-19. *Cardiovasc Res* 2020; published online Apr 15. <https://doi.org/10.1093/cvr/cvaa097>
- 6 Lippi G, Plebani M, Henry BM. Thrombocytopenia is associated with severe coronavirus disease 2019 (COVID-19) infections: a meta-analysis. *Clin Chim Acta* 2020;506:145–8.
- 7 Gheblawi M, Wang K, Viveiros A, Nguyen Q, Zhong J-C, Turner AJ, et al. Angiotensin converting enzyme 2: SARS-CoV-2 receptor and regulator of the renin-angiotensin system. *Circ Res* 2020; published online Apr 8. <https://doi.org/10.1161/CIRCRESAHA.120.317015>
- 8 Liu PP, Blet A, Smyth D, Li H. The science underlying COVID-19: implications for the cardiovascular system. *Circulation* 2020; published online Apr 15. <https://doi.org/10.1161/CIRCULATIONAHA.120.047549>
- 9 Turpin CA, Sakyi SA, Owiredu WKBA, Ephraim RKD, Anto EO. Association between adverse pregnancy outcome and imbalance in angiogenic regulators and oxidative stress biomarkers in gestational hypertension and preeclampsia. *BMC Pregnancy Childbirth* 2015;15:189.
- 10 American College of Obstetricians and Gynecologists, Task Force on Hypertension in Pregnancy. Hypertension in pregnancy. Report of the American College of Obstetricians and Gynecologists' task force on hypertension in pregnancy. *Obstet Gynecol* 2013;122:1122–31.
- 11 Di Mascio D, Khalil A, Saccone G, Rizzo G, Buca D, Liberati M, et al. Outcome of coronavirus spectrum infections (SARS, MERS, COVID 1–19) during pregnancy: a systematic review and meta-analysis. *Am J Obstet Gynecol MFM* 2020. 2, 100107<https://doi.org/10.1016/j.ajogmf.2020.100107>
- 12 World Health Organization. Clinical management of severe acute respiratory infection when novel coronavirus (nCoV) infection is suspected: interim guidance. 2020 [<https://apps.who.int/iris/handle/10665/330854>]. Accessed 11 March 2020.
- 13 Haram K, Svendsen E, Abildgaard U. The HELLP syndrome: clinical issues and management. A review. *BMC Pregnancy Childbirth* 2009;9:8.
- 14 Martin AM, Bindra R, Curcio P, Cicero S, Nicolaides KH. Screening for pre-eclampsia and fetal growth restriction by uterine artery Doppler at 11–14 weeks of gestation. *Ultrasound Obstet Gynecol* 2001;18:583–6.
- 15 Schiettecatte J, Russcher H, Anckaert E, Mees M, Leleser B, Tirelli AS, et al. Multicenter evaluation of the first automated Elecsys sFlt-1 and PIGF assays in normal pregnancies and preeclampsia. *Clin Biochem* 2010;43:768–70.
- 16 Gómez O, Figueras F, Fernández S, Bannasar M, Martínez JM, Puerto B, et al. Reference ranges for uterine artery mean pulsatility index at 11–41 weeks of gestation. *Ultrasound Obstet Gynecol* 2008;32:128–32.
- 17 Verlohren S, Herraiz I, Lapaire O, Schlembach D, Moertl M, Zeisler H, et al. The sFlt-1/PIGF ratio in different types of hypertensive pregnancy disorders and its prognostic potential in preeclamptic patients. *Am J Obstet Gynecol*. 2012;206:58.e1–8.
- 18 Stepan H, Herraiz I, Schlembach D, Verlohren S, Brennecke S, Chantraine F, et al. Implementation of the sFlt-1/PIGF ratio for prediction and diagnosis of pre-eclampsia in singleton pregnancy: implications for clinical practice. *Ultrasound Obstet Gynecol* 2015;45:241–6.
- 19 Paules C, Youssef L, Rovira C, Crovetto F, Nadal A, Peguero A, et al. Distinctive patterns of placental lesions in pre-eclampsia vs small-for-gestational age and their association with fetoplacental Doppler. *Ultrasound Obstet Gynecol* 2019;54:609–16.
- 20 Zeisler H, Lurba E, Chantraine F, Vatish M, Staff AC, Sennström M, et al. Predictive value of the sFlt-1:PIGF ratio in women with suspected preeclampsia. *N Engl J Med* 2016;374:13–22.
- 21 Recommendations | PIGF-based testing to help diagnose suspected pre-eclampsia (Triage PIGF test, Elecsys immunoassay sFlt-1/PIGF ratio, DELFIA Xpress PIGF 1-2-3 test, and BRAHMS sFlt-1 Kryptor/BRAHMS PIGF plus Kryptor PE ratio). NICE Guidance. [www.nice.org.uk/guidance/dg23/chapter/1-Recommendations]. Accessed 28 March 2020.
- 22 Sibai BM. Imitators of severe pre-eclampsia. *Semin Perinatol* 2009;33:196–205.
- 23 Inversetti A, Serafini A, Manzoni MF, Dolcetta Capuzzo A, Valsecchi L, Candiani M. Severe hypothyroidism causing pre-eclampsia-like syndrome. *Case Rep Endocrinol* 2012;2012:586056.
- 24 Rolfo A, Attini R, Nuzzo AM, Piazzese A, Parisi S, Ferraresi M, et al. Chronic kidney disease may be differentially diagnosed from preeclampsia by serum biomarkers. *Kidney Int* 2013;83:177–81.
- 25 Hirashima C, Ogoyama M, Abe M, Shiraishi S, Sugase T, Niki T, et al. Clinical usefulness of serum levels of soluble fms-like tyrosine kinase 1/placental growth factor ratio to rule out preeclampsia in women with new-onset lupus nephritis during pregnancy. *CEN Case Rep* 2019;8:95–100.
- 26 Levine RJ, Maynard SE, Qian C, Lim K-H, England LJ, Yu KF, et al. Circulating angiogenic factors and the risk of preeclampsia. *N Engl J Med* 2004;350:672–83.
- 27 Hung TH, Skepper JN, Burton GJ. In vitro ischemia-reperfusion injury in term human placenta as a model for oxidative stress in pathological pregnancies. *Am J Pathol* 2001;159:1031–43.
- 28 Pijnenborg R, Vercruyse L, Verbist L, Van Assche FA. Interaction of interstitial trophoblast with placental bed capillaries and venules of normotensive and pre-eclamptic pregnancies. *Placenta* 1998;19:569–75.