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ORIGINAL RESEARCH

Cerebral oxygen saturation monitoring in preeclamptic pregnant women undergoing cesarean section with spinal anesthesia: a prospective, observational study

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Abstract
It has been suggested that cerebral oximetry can detect acute and chronic changes in cerebral oxygen saturation due to pregnancy related complications. Furthermore, regional cerebral oxygenation saturation ($rcSO_2$) decreases were obtained during spinal anesthesia for cesarean section. The aim of this prospective observational study is to compare the effects of spinal anesthesia on $rcSO_2$ in preeclamptic and normotensive pregnant women. Preeclamptic (Group P, n = 24) and normotensive (Group N, n = 25) women with gestational week 32 and above, and scheduled for cesarean section under spinal anesthesia were included in this study. In addition to routine monitoring, $rcSO_2$ values obtained with right and left frontal cerebral sensors ($rcSO_2$right and $rcSO_2$left) were recorded before (baseline) spinal injection and during the surgery. The baseline $rcSO_2$ values were similar in both groups. In Group P, $rcSO_2$left values were higher than Group N only 3 and 5 min after spinal injection. In Group N, $rcSO_2$ values decreased from baseline 1, 3, 5, and 10 min after spinal injection. In Group P, $rcSO_2$ values decreased from baseline 1, 3, 5, 10, 30 and 35 min after spinal injection and at the end of the operation. There was no difference between the number of declines and the patients with $rScO_2$ below the cerebral hypoxic threshold. There was a positive correlation between $rcSO_2$ and blood pressure only 5 min after spinal injection, but no correlation with peripheral oxygen saturation was detected during the operation. There is decrease in $rcSO_2$ values after spinal anesthesia correlating with hypotension in preeclamptic women. However, the decrease is less than that of normotensive pregnant women, especially the first 5 min after spinal injection when the blood pressure is lowest. The clinical impact of these results and the relationship between cerebral desaturation and neurological complications remain to be determined.

Keywords Cesarean section · Anesthesia · Spinal · Pre-eclampsia · Spectroscopy · Near-infrared

1 Introduction

Near-infrared spectroscopy (NIRS) is a noninvasive monitoring modality, used to continuously screen regional cerebral oxygen saturation ($rcSO_2$) and cerebral perfusion adequacy. NIRS reflects the regional blood (arterial, venous, and capillary) hemoglobin and oxygen saturation that is influenced by cerebral cortex presentation and consumption, using two wavelengths (700 and 900 nm). Knowledge of oxygen saturation in this region provides advance warning of potential cerebral ischemia [1, 2]. Clinical use of cerebral oximetry is rapidly increasing due to its potential ability to identify changes during surgery and to prevent postoperative neurocognitive sequelae [2, 3].

Systolic velocity and resistance index in the middle cerebral artery decreases by approximately 20%, cerebral perfusion pressure increases by 50% and cerebral blood flow index increases by 10% in normal pregnancy. Cerebral autoregulation is sufficient and despite a significant increase in perfusion pressure, there is little change in cerebral blood flow during pregnancy [4]. However, during cesarean section, one of the most frequently performed surgical procedures, pregnancy-specific complications that may affect the maternal cerebral blood flow have been encountered. These complications may occur suddenly even in low-risk

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pregnancies; they include hypertensive encephalopathy due to pregnancy, intracerebral hemorrhage, amniotic fluid embolism, obstetric hemorrhage and disseminated intravascular coagulopathy [1]. In hypertensive diseases due to pregnancy, central nerve system (CNS) symptoms such as severe headache, visual impairment, hyperreflexia and convulsions occur.

In a small number of studies conducted during pregnancy, it has been suggested that cerebral oximetry could detect acute and chronic changes in cerebral oxygen saturation due to pregnancy-related complications (including hypertensive encephalopathy and massive hemorrhage) and is a promising new device for monitoring the mother during cesarean section [1, 2, 5–7]. There was a reduction in $rcSO_2$ values after spinal anesthesia in cesarean section [2]. In another study, sudden hypotension due to spinal anesthesia during cesarean section was predicted with NIRS [5].

The primary aim of this prospective, observational study was to compare the effects of spinal anesthesia on $rcSO_2$ in preeclamptic and normotensive pregnant women. Values below the cerebral hypoxic limit were compared between the groups, and the correlation between blood pressure and peripheral oxygen saturation and the $rcSO_2$ values were also evaluated as secondary outcomes.

2 Materials and methods

This study was approved by the Ethics Committee (2014/209), and written informed consent was obtained from the patients. Pregnant patients aged 18–45 years, ASA (American Society of Anesthesiology) physical class II–III, gestational week 32 and above, and scheduled for cesarean section under spinal anesthesia were included in the study. Fifty preeclamptic (Group P, n = 25) and normotensive (Group N, n = 25) women were included in the study between July 2014 and 2016 in a 1:1 ratio. The exclusion criteria were as follows: mothers with multiple gestations; severe cardiac, neurological, or pulmonary disease [peripheral oxygen saturation (SpO_2) < 92%]; body mass index more than 40 kg/m^2; urgent level 1 cesarean section due to severe fetal bradycardia, ablatio placenta, cord prolapse or massive hemorrhage, and coagulopathy.

2.1 Monitoring and anesthesia technique

Before surgery, 50 mg of ranitidine and 10 mg of metoclopramide were administered intravenously. Without premedication, patients were placed on an operating table that was tilted 15° to the left and were covered with a heated blanket. In addition to routine monitoring, $rcSO_2$ monitoring was performed with two disposable INVOS sensors (INVOS™ 5100 Cerebral/Somatic Oximeter, Somanetics, Troy, USA). Two cerebral sensors (Adult SomaSensor, Covidien, Mansfield, MA, USA) were placed on the right and left frontal areas under the hairline and were covered with adhesive tape to eliminate light interference. If needed, invasive artery monitoring was planned to implement. The physician who managed the anesthesia started crystalloid and/or colloid infusion and adjusted the infusion rate according to the patient's renal, cardiovascular, and pulmonary comorbidities. All pregnant women were treated with prophylactic antibiotics prior to the skin incision.

All patients were placed in the right lateral decubitus position and after skin disinfection a 25-gauge Quincke spinal needle was inserted into the subarachnoid space in L3–4 or L4–5. After confirming the free flow of cerebrospinal fluid, 12 mg of hyperbaric bupivacaine and 25 µg of fentanyl were administered intrathecally. Subsequently, the patient was placed in the supine position with a tilt of 15° to the left, and mask oxygen support was initiated. Sensory block level was controlled by pin-prick testing, and when the block level reached the T4–T5 dermatome, surgery was allowed. In cases of inadequate or unsuccessful block, general anesthesia was applied, and patients were excluded from the study. When systolic blood pressure (SBP) fell more than 20–25%, IV ephedrine was given, and if the heart rate dropped below 50 beats/min, IV atropine was given.

After removal of the placenta, oxytocin was slowly injected in 3 IU/10 mL saline for 3 min, followed by 15 IU/h in 1000 mL Ringer's lactate infusion. When necessary, 3 IU of oxytocin was repeated every 3–5 min. At the end of the operation, the patients were taken to the recovery room or intensive care unit according to their requirements, and were monitored for side effects in the first 48 h.

2.2 Measurements

On preoperative evaluation, demographic data, indications of cesarean, preoperative medications (antihypertensives, magnesium and others), laboratory values (hemoglobin, hematocrit, platelets, urine protein), and presence of neurological and systemic symptoms (including headache, visual impairment, epigastric pain) were recorded. $RcSO_2$right and $rcSO_2$left values obtained from the intraoperative right, and left cerebral sensors were measured. Three measurements were performed before spinal injection, and the average score was recorded as baseline value. Measurements were repeated at 1, 3, and 5 min after spinal injection and subsequently every 5 min until the end of the operation. Due to differences in operation times, comparisons between groups were recorded as the first 35 min and the end of the operation. Similar to the study of Fassoulaki et al. the cerebral hypoxic threshold was considered to be 20% or lower than the baseline value and less than the 50% value [2].

We recorded all declines in $rcSO_2$ values calculated by the device during the operation.

Simultaneous SBP, diastolic blood pressure (DBP), mean blood pressure (MBP), heart rate (HR), and peripheral oxygen saturation (SpO_2) values were recorded with $rcSO_2$ measurements. Total amounts of ephedrine, total amount of bleeding and the complications encountered during the operation were recorded. Furthermore, skin incision-delivery time and uterine incision-delivery time, APGAR scores at 1st and 5th min, and umbilical cord blood gases values were recorded.

2.3 Statistical evaluation

Statistical Package for Social Sciences (SPSS) for Windows version 22.0 software was used for statistical evaluation. Mean ± standard deviation (SD) or median [min–max], was used for identifying quantitative data; number and percentage were used to identify qualitative data. The Shapiro Wilk normality test was used to test whether the data of quantitative variables showed a normal distribution. According to the results of these variables, a paired *t* test was used in the analysis of intragroup variation, and an unpaired *t* test and Mann–Whitney U test were used in the intergroup comparisons. Statistical evaluation of qualitative variables was performed by using Pearson Chi square analysis and Fisher's exact Chi square analysis. Relationships between quantitative variables at all time points were tested by Pearson correlation analysis. $p < 0.05$ was considered statistically significant.

3 Results

Demographic data (age, weight, and height), gestational ages, indications of cesarean section, and preoperative laboratory values are presented in Table 1. In Group P, one patient was excluded from the study because general anesthesia was administered due to inadequate spinal anesthesia. The mean ages and heights were similar in both groups. The weights and body mass indexes were higher in Group P ($p = 0.03$, $p < 0.001$, respectively). The mean gestational age in Group P was 34.69 ± 3.18, while in Group N it was 37.61 ± 1.41 ($p < 0.001$). The decision to perform cesarean section was made in Group P due to fetal distress or non-reactive non-stress test; in Group N, the decision was most often repeated cesarean section. There was no difference in preoperative hemoglobin, hematocrit, and platelet counts between the groups.

In Group P, 13 women had preeclampsia without severe features, and 11 women had severe features of preeclampsia according to the American College of Obstetricians and Gynecologists classification [8]. Five women complained of headache and one complained of visual disturbance. In the preoperative period, oral antihypertensive agents (methyldopa and nifedipine) were given to all preeclamptic women for blood pressure control. However, only nine preeclamptic pregnant women received preoperative $MgSO_4$ infusion that was stopped intraoperatively.

Table 1 Demographic data [mean ± standard deviation; number (%)]

	Group N n = 25	Group P n = 24	p values
Age (year)	30 ± 4	31 ± 7	0.63
Weight (kg)	73 ± 10	82 ± 10	0.03*
Height (cm)	161 ± 5	159 ± 5	0.09
Body Mass Index ($kg \cdot m^{-2}$)	27.98 ± 4.23	32.53 ± 4.30	< 0.001*
Gestational week	37.61 ± 1.41	34.69 ± 3.18	< 0.001*
Gestational history			
Chronic hypertension	1 (3.8%)	5 (19.2%)	0.08
Diabetes mellitus	4 (15.4%)	5 (19.2%)	
Intrauterine growth retardation	2 (7.7%)	7 (26.9%)	
Oligohydroamnios	1 (3.8%)	2 (7.7%)	
Polihydroamnios	1 (3.8%)	–	
Anhydroamnios	–	1 (3.8%)	
Fetal abnormality	1 (3.8%)	–	
Rh incompatibility	2 (7.7%)	–	
Indication of cesarean delivery			
Fetal distress	1 (3.8%)	14 (53.8%)	< 0.001*
Preterm labor	2 (7.7%)	–	0.14
Non-progressive labor	2 (7.7%)	1 (3.8%)	0.55
Previous cesarean delivery	20 (76.9%)	8 (30.8%)	0.001*
Dystocia	7 (26.9%)	3 (11.5%)	0.159
Non-reactive NST	1 (3.8%)	18 (69.2%)	< 0.001*
Rh incompatibility	3 (11.5%)	–	0.07
Fetal abnormality	1 (3.8%)	–	0.31
Preoperative laboratory values			
Hemoglobin (g/dL)	11.65 ± 1.17	11.81 ± 1.64	0.69
Hematocrit (%)	35.38 ± 2.78	35.48 ± 4.36	0.64
Platelet	252 ± 69	233 ± 62	0.31

Group N normotensive, *Group P* preeclamptic, *NST* nonstres test

*p < 0.05

The $rcSO_2$left and $rcSO_2$right values obtained from right and left frontal cerebral sensors during the operation are shown in Table 2. The mean baseline values of the $rcSO_2$right and $rcSO_2$left values were similar between preeclamptic and normotensive pregnant women. In a subgroup analysis, the mean baseline values of rSO_2right and rSO_2left were 67.45 and 68.60, respectively, in severe preeclamptic pregnant women, while the values were 61.51 and 63.45, respectively, in preeclamptic women without severe features. Furthermore, the mean baseline values of rSO_2right and rSO_2left were 72 and 73.5, respectively in preeclamptic

Table 2 Values of right and left frontal regional cerebral oxygen saturations ($rcSO_2$) (mean ± standard deviation)

	Right $rcSO_2$ (%)		Left $rcSO_2$ (%)	
	Group N n = 25	Group P n = 24	Group N n = 25	Group P n = 24
T0	62.11 ± 6.98	64.23 ± 10.85	62.58 ± 7.18	65.81 ± 8.25
T1	60.08 ± 7.16[§]	61.29 ± 10.88[§]	60.52 ± 8.15[§]	62.04 ± 7.54[§]
T3	55.28 ± 8.20[§]	59.33 ± 10.69[§]	55.20 ± 7.46[§]	60.62 ± 8.91*[§]
T5	54.00 ± 9.38[§]	59.37 ± 11.92[§]	53.36 ± 8.96[§]	61.00 ± 10.93*[§]
T10	59.24 ± 8.69[§]	60.75 ± 12.02[§]	59.20 ± 8.79[§]	62.50 ± 10.52[§]
T15	62.00 ± 7.43	63.58 ± 9.22	62.12 ± 7.86	65.12 ± 8.44
T20	62.04 ± 7.78	62.29 ± 9.79	62.00 ± 7.44	64.50 ± 8.76
T25	63.72 ± 8.31	61.87 ± 9.42	62.04 ± 8.32	63.91 ± 8.02
T30	62.76 ± 8.89	60.58 ± 10.25[§]	62.32 ± 8.46	62.54 ± 8.21[§]
T35	61.92 ± 8.22	59.58 ± 9.85[§]	61.80 ± 7.46	61.12 ± 8.80[§]
E.O.	60.84 ± 7.69	58.45 ± 9.60[§]	60.64 ± 7.73	60.37 ± 8.45[§]

Group N normotensive, *Group P* preeclamptic, *T0* baseline, *Tx* x min after spinal injection, *E.O.* end of operation

*Comparison between groups, $p < 0.05$; [§] in-groups comparison, $p < 0.05$

Table 3 Number of declines and number of patients with $rScO_2$ values below 20% of the baseline or below 50% absolute value [numbers (%)]

	Right $rScO_2$ (20%)	Left $rScO_2$ (20%)	Right $rScO_2$ (< 50%)	Left $rScO_2$ (< 50%)
Group N N = 25				
Number of declines	22	29	28	36
Number of patients	8 (32%)	12 (48%)	9 (36%)	9 (36%)
Group P N = 24				
Number of declines	21	17	31	39
Number of patients	8 (33.3%)	8 (33.3%)	8 (33.3%)	8 (33.3%)
P values	0.58	0.22	0.54	0.54

Group N normotensive, *Group P* preeclamptic

women with preoperative neurological symptoms. There was no difference between the groups in terms of the $rcSO_2$right values measured after spinal injection while the $rcSO_2$left values were higher in Group P at 3 and 5 min after spinal injection ($p = 0.02$, $p = 0.01$, respectively).

In intra-group comparisons, in Group P, the $rcSO_2$right and $rcSO_2$left values were found to decrease at the 1st, 3rd, 5th, 10th, 30th and 35th minutes after spinal injection according to baseline values and at the end of the operation ($p < 0.05$). In Group N, the $rcSO_2$right and $rcSO_2$left values were found to decrease at 1st, 3rd, 5th and 10th minutes after spinal injection compared to baseline values ($p < 0.05$). The number of declines and the number of patients with $rScO_2$ values below 20% of the baseline or below 50% absolute value were similar between the groups (Table 3).

Intraoperative hemodynamic data and SpO_2 values are shown in Figs. 1, 2, 3, 4 and 5. There was a significant difference between the two groups in terms of SBP, DBP and MBP at all measurement times ($p < 0.05$). There was no difference between the two groups in terms of HR ($p > 0.05$). SpO_2 values measured at baseline and at the 3rd minute after spinal injection were lower in Group P than those in Group N ($p < 0.05$).

The correlation between $rcSO_2$ values and hemodynamic data was tested at all time points but only statistically significant correlations are given below. In Group N, there was a moderate positive correlation 5 min after the spinal injection between $rcSO_2$right values and SBP ($r = 0.41$; $p = 0.03$), $rcSO_2$left values and SBP ($r = 0.42$; $p = 0.03$), and DBP ($r = 0.43$; $p = 0.03$). There was no significant correlation between MBP and the $rcSO_2$right and $rcSO_2$left values. In Group P, there was a moderate positive correlation 5 min after the spinal injection between $rcSO_2$right values and SBP ($r = 0.44$; $p = 0.03$), and DBP ($r = 0.40$; $p = 0.01$), and $rcSO_2$left values and DBP ($r = 0.43$; $p = 0.03$). There was a moderate positive correlation between $rcSO_2$right values and MBP in the 5th minute after spinal injection ($r = 0.48$; $p = 0.01$) and $rcSO_2$left values and MBP in the 3rd and 5th minutes after spinal injection ($r = 0.46$; $p = 0.02$; $r = 0.41$; $p = 0.04$, respectively). There was no significant correlation between SpO_2 and $rcSO_2$ values in both groups.

The duration of operations was similar in both groups. The mean blood loss was 582 ± 214.51 mL in Group N during operation and was 657 ± 251.08 mL in Group P ($p = 0.10$). There was no difference between the two groups in terms of the number of patients given ephedrine and total ephedrine amounts. There was no difference in postoperative hemoglobin values (Table 4). No obstetric (massive bleeding, amniotic fluid embolism) complications were encountered in the perioperative period in any patient and intensive care was not needed. No additional neurological symptoms were seen intraoperatively or in the postoperative period in preeclamptic women.

The fetal parameters are shown in Table 5. The mean weight of newborns was lower in Group P than in Group N. There was no difference between groups in terms of skin incision-delivery time, uterine incision-delivery time, umbilical cord blood gases, or APGAR scores.

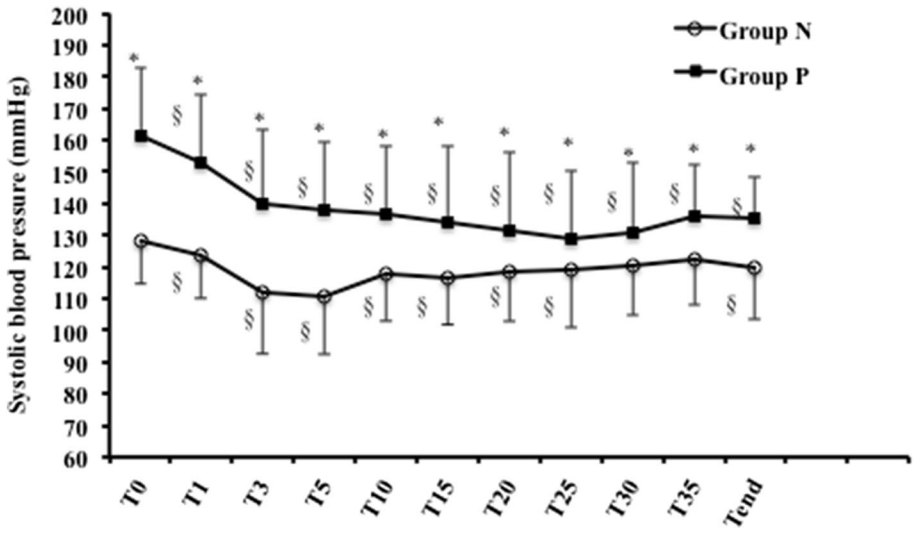

Fig. 1 Systolic blood pressure (mmHg) measurements during the operation. *T0* baseline, *Tx* x min after spinal injection, *E.O.* end of operation. *Comparison between groups, $p < 0.05$; §in-groups comparison, $p < 0.05$

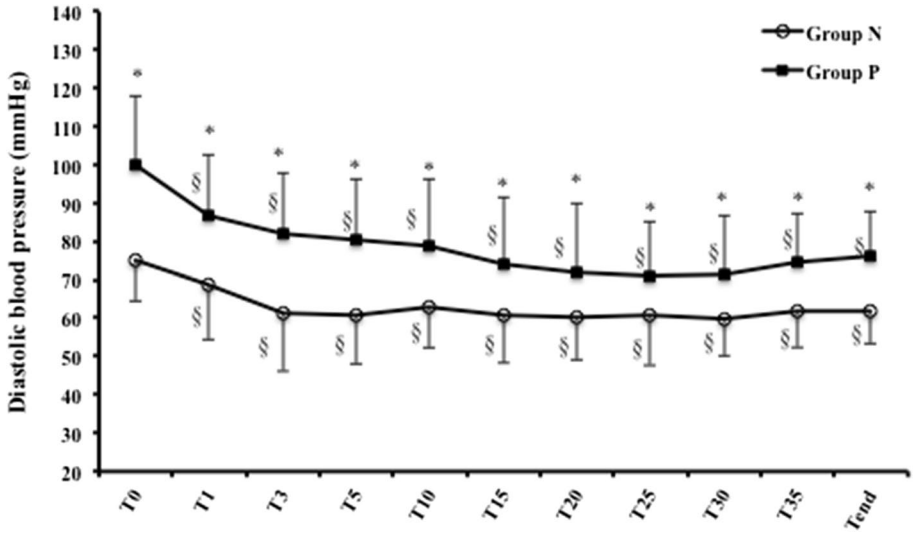

Fig. 2 Diastolic blood pressure (mmHg) measurements during the operation. *T0* baseline, *Tx* x min after spinal injection; E.O.: end of operation. *Comparison between groups, $p < 0.05$; §in-groups comparison, $p < 0.05$

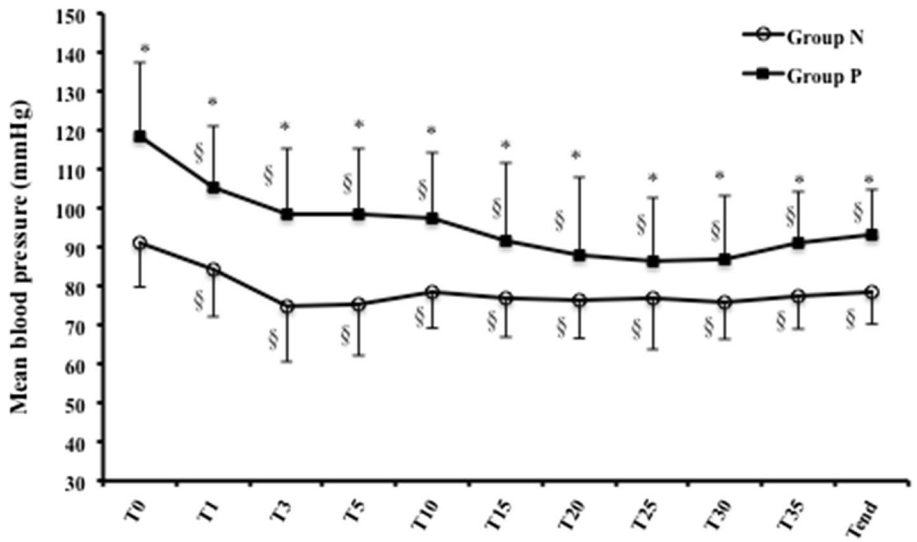

Fig. 3 Mean blood pressure (mmHg) measurements during the operation. *T0* baseline; *Tx* x min after spinal injection; *E.O.* end of operation. *Comparison between groups, $p < 0.05$; §in-groups comparison, $p < 0.05$

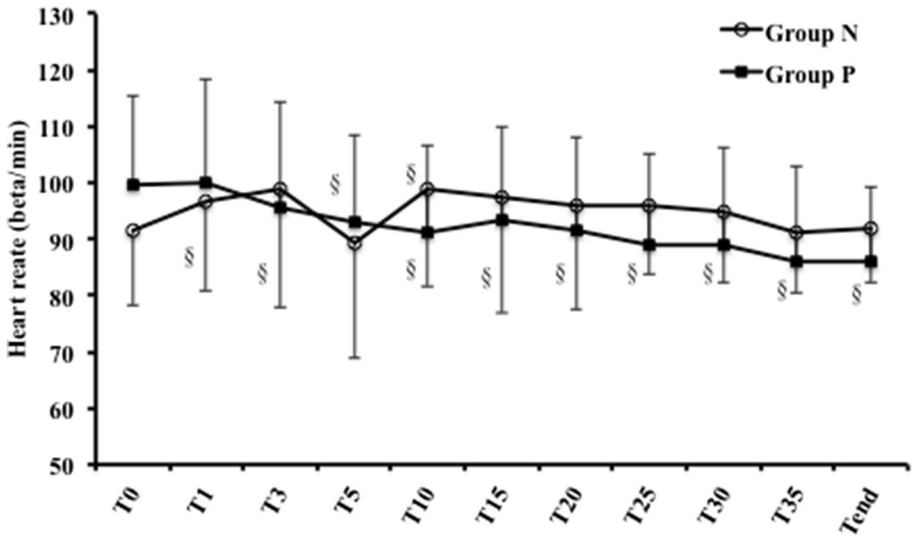

Fig. 4 Heart rate (beat/min^{-1}) measurements during the operation. *T0* baseline; *Tx* x min after spinal injection; *E.O.* end of operation. *Comparison between groups, $p < 0.05$; §in-groups comparison, $p < 0.05$

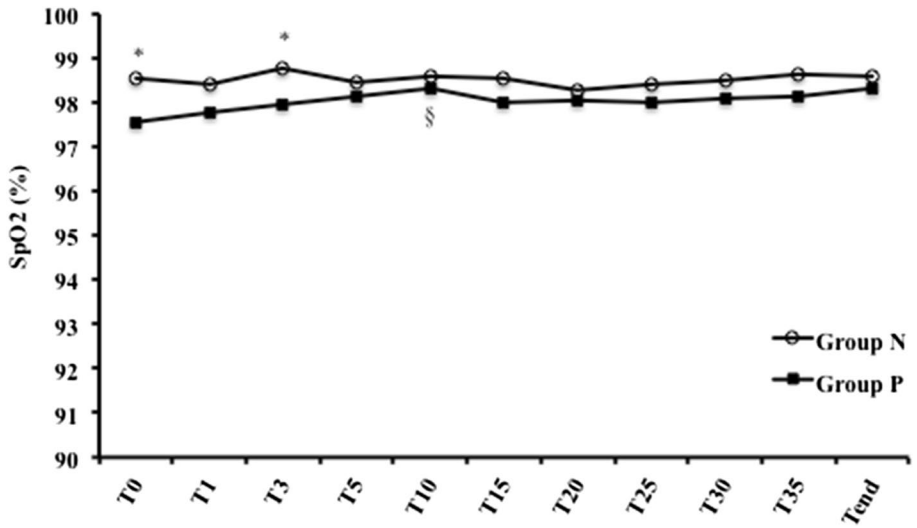

Fig. 5 Peripheral oxygen saturation (SpO_2) (%) measurements during the operation. *T0* baseline; *Tx* x min after spinal injection; *E.O.* end of operation. *Comparison between groups, $p < 0.05$; §in-groups comparison, $p < 0.05$

Table 4 Operative data [mean ± standard deviation; median (min–max)]

	Group N n = 25	Group P n = 24	p values
Operation time (min)	46.60 ± 6.62	49.92 ± 11.63	0.56
Number of patients used ephedrine	14 (56%)	8 (33.3%)	0.11
Ephedrine amount (mg)	5.20 ± 5.67 5 [0–20]	2.29 ± 3.60 0 [0–10]	0.05
Intraoperative blood loss (mL)	582 ± 214.51	657 ± 251.08	0.19
Postoperative hemoglobin (g/dL)	10.59 ± 1.26	10.72 ± 1.61	0.74

Group N normotensive, *Group P* preeclamptic

4 Discussion

To our knowledge, this is the first study to report the intraoperative cerebral oxygen saturation with NIRS in preeclamptic pregnant women undergoing cesarean section with spinal anesthesia, and comparing with the values obtained from normotensive pregnant women. In our study, the baseline mean $rcSO_2$ values in preeclamptic pregnant women significantly decreased after spinal

Table 5 Fetal parameters (mean ± standard deviation)

	Group N n = 25	Group P n = 24	*P* values
Weight (g)	2901 ± 824	2279 ± 866	0.01*
Skin incision-delivery time (min)	5.74 ± 1.47	5.75 ± 2.65	0.98
Uterine incision-delivery time (min)	1.66 ± 0.49	2 ± 0.88	0.19
Umbilical cord blood gases			
pH	7.33 ± 0.10	7.31 ± 0.83	0.07
PO_2	22 ± 7	24 ± 8	0.48
PCO_2	41 ± 9	42 ± 13	0.92
Base excess	− 3.49 ± 4.48	− 3.59 ± 4.30	0.73
APGAR scores			
1 min	7.9 ± 1.9	7.2 ± 2.8	0.69
5 min	9.1 ± 2.5	8.5 ± 2.9	

Group N normotensive, *Group P* preeclamptic

*p < 0.05

injection, similar to normotensive pregnant women. By contrast, lower values continued at the end of the operation. However, the rate of decrease in the preeclamptic group was significantly smaller than that of the normotensive group, especially at the 3rd and 5th min after spinal injection. In terms of $rcSO_2$ values below the cerebral hypoxic limit, there was no difference between the two groups. A correlation between cerebral oxygen saturation and blood pressure values was observed in the first 5 min after spinal injection when the hemodynamic alteration was highest. Intraoperative values of peripheral oxygen saturation ranged from 96 to 100%, and no correlation with $rcSO_2$ values was detected.

High blood pressure may lead to hyperperfusion, excessive distension in cerebral blood vessels, and vasogenic edema by disturbing auto-regulation capacity in preeclamptic women. However, ischemia due to excessive cerebral vasospasm and hypoperfusion may also cause CNS symptoms [4]. Furthermore, conflicting results have been obtained in transcranial doppler studies performed in these patients. For example, middle cerebral artery flow velocity has a wide-ranging spectrum [9–11]. Yamazaki et al. performed cerebral oxygen saturation monitoring with TRS-20 (near-infrared time-resolved spectroscopy), a newer spectroscopy device, in 18 pregnant women undergoing cesarean section. Although only four of the women were preeclamptic, the mean baseline values before anesthesia induction (73.6 ± 4.4) were higher than in normotensive pregnant women (67.2 ± 4.3). They suggested that there might be chronic alterations that accompanied cerebral hyperperfusion tendency and consequent in baseline values of cerebral oxygen saturation, without clinically apparent encephalopathy symptoms, in the majority of preeclamptic pregnant women [1]. By contrast, Guerci et al. found that the mean cerebral oxygen saturation observed in 20 severe preeclamptic pregnancies with neurological symptoms in the obstetric intensive care unit was significantly lower than in the control group. Pregnant women who did not respond to oral antihypertensive treatment and had not yet started $MgSO_4$ treatment were included into the study. After the administration of $MgSO_4$, they found that cerebral oxygen saturation values increased to the values of the control group in a short period of time. The authors suggested that the cerebral oxygenation impairment might occur due to deterioration in microcirculation in severe preeclamptic patients [7]. In our study, there was no significant difference between the two groups, although higher baseline values were observed in preeclamptic women. Nevertheless, baseline values in severely preeclamptic pregnant women were higher than those of preeclamptic women without severe features on subgroup analysis. Furthermore, patients with preoperative neurological symptoms had higher mean baseline values. In several studies, it has been reported that the baseline values might vary between individuals. Various cerebral oximeter devices may be another reason for different baseline values [7]. Apart from these, several factors, including the level of influence of the cerebral microcirculation depending on the severity of preeclampsia, and preoperative $MgSO_4$ treatment, may affect the baseline values.

Fassoulaki et al. observed that the baseline values of $rcSO_2$ decreased significantly, especially at the 5th and 10th minute after spinal injection in healthy pregnant women undergoing cesarean section under spinal anesthesia, and that this decrease correlated with hypotension developing after spinal injection [2]. Hirose et al. reported a decrease in cerebral blood volume with $rcSO_2$ after spinal injection in healthy pregnant women who underwent cesarean section with spinal anesthesia and reported that the decrease correlated positively with hypotension [6]. In the past, the common belief that spinal anesthesia caused severe hypotension

and reduced peripheral organ perfusion in severe preeclampsia prevented its widespread use. By contrast, subsequent studies have shown that less hypotension develops in these patients than in normotensive pregnant women [12, 13]. In our study, although there was a decrease in $rcSO_2$ values after spinal anesthesia in preeclamptic pregnant women, this rate of decrease was lower than that of normotensive pregnant women. Yamazaki et al. also observed a slight non-significant decrease in spinal anesthesia in preeclamptic pregnant women [1]. These results can be interpreted to the effect that spinal anesthesia does not cause any additional complications in terms of cerebral perfusion in preeclamptic pregnant women.

In our study, no additional neurological or systemic symptoms were observed during the operation or in the first postoperative 24 h, including in severely preeclamptic women. Further research is needed to investigate how the $rcSO_2$ values change in the presence of intraoperative neurological symptoms, as well as to study the efficacy of $rcSO_2$ monitoring to detect cerebral complications.

Posterior cerebral area is more important in complications such as posterior reversible encephalopathy syndrome (PRES) due to preeclampsia [1, 3, 7]. Therefore, it remains debatable as to whether $rcSO_2$ values measured from the frontal area reflect the changes in this area.

Factors such as cardiac output, arterial blood oxygen, hemoglobin level, temperature, hypo/hypercapnia, and vasopressors administration may influence $rcSO_2$ values in addition to cerebral factors [2, 7]. Rokamp et al. concluded that 100% oxygen supplementation before anesthesia increases NIRS-determined cerebral and skeletal tissue oxygen levels; however, increased oxygen delivery during surgery did not sufficiently prevent a critical reduction in cerebral oxygenation [14]. In preeclamptic women during cesarean delivery, giving supplementary oxygen is reasonable, though in healthy pregnant women, it is not generally necessary. In our study, supplementary oxygen was given to all patients after spinal anesthesia to ensure standardization between the two groups. All patients were warmed with heating blankets during surgery. There was no difference between the groups in terms of the use of ephedrine. Regarding this, Foss et al. also showed that phenylephrine reduced rSO_2 values while ephedrine had no effect [15].

One limitation of the study was that carbon dioxide levels (and respiratory rates), important factors regulating cerebral vasomotor activity, were not followed. No cardiac output measurements were made. Information regarding intraoperative hemoglobin levels, another factor affecting $rcSO_2$ values, was obtained indirectly. Furthermore, no treatment protocol has been identified for $rcSO_2$ changes detected in our study, and only observations were made. Therapeutic principles for intraoperative cerebral desaturation and its neurological consequences require further study.

In conclusion, there is a decrease in $rcSO_2$ values after spinal anesthesia correlating with hypotension in preeclamptic women. The decrease is less than that of normotensive pregnant women, especially in the first 5 min after spinal injection when the blood pressure is lowest. The clinical impact of these results and the relationship between cerebral desaturation and neurological complications remain to be determined. Nevertheless, NIRS may be a useful modality for intraoperative cerebral monitoring in preeclamptic women, a complex and risky patient group, and it deserves further research.

Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest.

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