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ORIGINAL ARTICLE

Transcranial Doppler role in prediction of post-dural puncture headache in parturients undergoing elective cesarean section: prospective observational study

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Abstract

Purpose Post-dural puncture headache (PDPH) may be resulted from significant changes in cerebral blood flow, which could be visualized by Transcranial Doppler (TCD). This study was performed to investigate if TCD can be used to predict the occurrence of PDPH in high-risk patients.

Methods This prospective observational study was conducted on ninety ASA I and II pregnant females undergoing elective cesarean section (CS) under spinal anesthesia. TCD was performed to all patients within 24 h before the operation, at 24 h and 48 h in the post-operative period to measure mean velocity (MV) and Gosling pulsatility index (PI) in the right middle cerebral artery. For 5 days postoperatively, all patients were assessed and the PDPH patients were identified, their pre- and post-puncture TCD measurements were compared with the corresponding measurements of PDPH-free patients and ROC analysis was done to evaluate the predictive value of TCD parameters.

Results 17 patients (18.8%) developed PDPH. PDPH group was significantly higher regarding MV and significantly lower with regard to PI at all times except for the pre-spinal PI. The MV values in all patients showed statistical significant increase within the first 48 h after CS as compared with those before delivery. In PDPH group there was high statistical significant decrease in PI values at 24 h and 48 h compared to the pre-puncture values. The pre-puncture MV was the parameter of the best accuracy for predicting PDPH with a cutoff of MV > 68.4 cm/s and the post-puncture PI at 24 h was the best predictive of PDPH with a cutoff value of < 0.75.

Conclusion TCD might prove a useful tool in predicting PDPH suggesting that higher pre-puncture MV with a cutoff value > 68.4 cm/s and post-puncture lower PI at 24 h with a cutoff < 0.75 are the best predictive parameters.

Trial registration This clinical trial was registered with ClinicalTrials.gov (NCT03464253).

Keywords Transcranial Doppler · Post-dural puncture headache · Cesarean section · Spinal anesthesia

Introduction

Post-dural puncture headache (PDPH) is a well-recognized complication and is found to be the most common iatrogenic pain after cesarean section (CS) in young parturients [1], and this may be due to their young age, sex, widespread application of spinal or epidural anesthesia and associated dilutional anemia and low hematocrit value [2]. The incidence of PDPH following epidural analgesia and spinal anesthesia is 1% and 0.5–2%, respectively [3, 4]. PDPH has a negative impact on patient satisfaction, quality of life and the postpartum experience with the mother's inability to bond with and care for her baby [5]. Also, it increases the economic burden associated with childbirth [6].

The exact etiology of PDPH is unknown; there are two hypotheses that tried to elucidate the cause. First, it's recognized that dural tear results in cerebrospinal fluid (CSF) leak and intracranial hypotension which cause pain sensitive intracranial structures to become stretched when assuming upright position resulting in headache. Second, intracranial volume is constant and equal to the sum of intracranial blood, CSF, and brain matter. After loss of CSF a compensatory reflex vasodilatation occurs in pain-sensitive blood vessels and this result in pain [7].

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The association of common risk factors such as female gender, mostly females during pregnancy, age groups of 20–40 years, a prior history of chronic headache, and a lower body mass index expose the patient to PDPH. The identification of factors that predict the likelihood of PDPH is important so that measures can be taken to minimize this painful complication resulting from spinal anesthesia [8].

Transcranial Doppler ultrasound (TCD) is a portable, safe, non-invasive and real-time tool for assessing intracranial hemodynamics. It was first described by Rune Aaslid in early 20th century, and it has gained increasing acceptance as an accurate diagnostic and therapeutic tool in both cerebrovascular disease and neurocritical care. TCD allows measuring the blood flow velocity in intracranial arteries and several studies have shown that its parameters are affected by both fluctuations in intracranial pressure and changes in cerebral vessel diameters [9, 10]. Hence, PDPH may be due to significant changes in cerebral blood flow, it could be visualized by TCD.

The possibility of equipment mobilization, the opportunity of repeated bedside technique together with the non-invasive nature, makes TCD measurements attractive in the attempt to estimate cerebral blood flow (CBF) and offers potential application to predict and follow patients with PDPH.

We hypothesized that patients with multiple risk factors to develop PDPH may have changes in CBF. So, comparing the pre- and post-puncture CBF mean velocity and pulsatility index detected by TCD in patients who developed PDPH with the respective values of PDPH-free patients, could help in the prediction of PDPH occurrence in this high-risk patients group.

The aim of this study was to investigate if TCD is able to predict the occurrence of PDPH in female patients undergoing spinal anesthesia for elective cesarean section.

Patients and methods

Study population and design

This prospective observational clinical study was conducted in Zagazig University Hospitals from April to October 2018 on ninety ASA I and ASA II pregnant females aged between 18–40 years and undergoing elective cesarean section under spinal anesthesia. Approval of Institutional Review Board (IRB) and the patient's informed written consent were obtained. Our clinical study was registered with ClinicalTrials.gov (NCT03464253).

Exclusion criteria included patient refusal, ASA Grade III and IV patients, emergent cesarean section, any neurological, psychiatric, or muscular disorder, any contraindication to regional anesthesia as local infection at the site of injection, coagulopathy, history of allergy to local anesthetics used, hypertensive disorders of the pregnancy, atrial fibrillation, significant fetal illness, and inadequate temporal window.

All enrolled cases undergone.

Preoperative assessment

- Preoperative visit to all participating patients during their preoperative preparation to discuss the goal and endpoints of the study, to clarify the advantages and possible side effects of the spinal anesthesia, the importance of using TCD as a predictor and to take a written informed consent regarding the procedure from every patient.
- On physical examination, special attention was given to document vital signs, cardiac, chest condition and exclude contraindications and all patients were investigated by complete blood count, coagulation profile, liver function tests and kidney function tests.
- All patients were instructed about the Crocker scale for severity of headache.
- Pregnant females were allowed for oral solid or liquid intake till 6–8 h and for clear fluid till 2 h before the surgery.
- Performance of the transcranial Doppler:

  Within 24 h before the operation, TCD was performed using Siemens Acuson X300 machine with ultrasound frequency of 1–5 MHz probe. All patients were examined in the supine position. After application of contact gel, the transducer was placed between the ear and lateral orbital margin above the zygomatic bone on the temporal squma (temporal window), then the middle cerebral artery (MCA) was identified. The probe was placed to record peak possible velocity of the vessel. The measurements were repeated three times while the probe is fixed in the same position (the third reading was recorded). These measurements include mean velocity (MV), and the Gosling pulsatility index (PI) in the right MCA. All the measurements were taken by the same anesthesiologist who is experienced in neurosonology.

  Measured TCD indices include mean flow velocity (cm/s) = [peak systolic velocity + (end diastolic velocity *2)]/3 and pulsatility index = (peak systolic velocity − end diastolic velocity)/mean flow velocity [11].

Intraoperative

On entering the patient to the operating room, standard monitors such as electrocardiogram, pulse oximetry, and non-invasive blood pressure monitor were attached and baseline parameters were recorded. An anesthetic machine was always at hand, tested and ready, airway management devices and resuscitation drugs were also ready, prepared and available.

A suitable peripheral intravenous line was established before any injection of local anesthetic and all patients were premedicated with IV midazolam 0.03 mg/kg. All patients received an intravenous preload of 15 ml/kg lactated Ringer's solution before subarachnoid block. O_2 supplementation (4–6 L/min) is administered via nasal cannula throughout the time of surgery.

In the sitting position and under complete aseptic technique, sterilization of the back was done with a solution of povidone iodine, and sterile drapes were applied, followed by local anesthetic skin infiltration with 3 ml lidocaine 2% then spinal anesthesia was performed using 25 gauge disposable Quinke spinal needle at L3–L4 or L4–L5 spinal intervertebral space by paramedian approach. Following free flow of CSF the drugs (2.5 ml of hyperbaric bupivacaine 0.5% (12.5 mg) and 25 μg fentanyl were injected. The injection was made over 10 s with no barbotage. The patients were placed supine immediately after injection with left uterine displacement and slight elevation of the head.

The block level is tested with a spirit swab for sensory block to reach to T4–6 sensory dermatome and Bromage motor score for adequate motor block before surgical incision. Heart rate (HR), mean arterial pressure (MAP), ECG and oxygen saturation are monitored intraoperatively, Maintenance fluid at the rate of 10 ml/kg/hour is given throughout the surgery.

Postoperative

All the patients were mobilized after hemodynamic stability and return of sensory and motor power. TCD was performed to all patients in a quiet comfortable place, twice in the postoperative period at 24 h and 48 h after spinal anesthesia, and is used to measure mean flow velocity (MV) and Gosling pulsatility index (PI) in the right MCA.

For 5 days postoperatively, all patients are questioned and assessed clinically for the occurrence of headache. PDPH is diagnosed according to the International Classification of Headache Disorders (ICH-II) guidelines. There are four criteria for PDPH diagnosis that include a headache that develops within 5 days after dural puncture, worsens within 15 min after sitting or standing and improves within 15 min after lying down, accompanied by at least one of the following: neck stiffness, nausea, photophobia, and tinnitus, and resolves either spontaneously within 1 week or within 48 h after effective treatment of the spinal fluid leak [8, 12, 13].

The severity of the headache was analyzed by Crocker scale (1976); and given a score of 1–4 [13].

Score	Symptoms
1	Mild headache which allowed long periods of sitting: no associated nausea or vomiting
2	Moderate headache which made sitting difficult for more than half an hour: occasionally associated with nausea and vomiting
3	Severe headache which made sitting difficult frequently and associated with nausea and vomiting
4	Intense headache even on lying down; nausea and vomiting make feeding impossible

The group of patients who developed PDPH was identified and their pre- and post-puncture cerebral blood flow measurements by TCD were compared with the corresponding measurements of PDPH-free patients to associate the measurements with the occurrence of PDPH.

Sample size calculation

Sample size was calculated to be (90) patients, calculated using (open Epi) program. At confidence interval 95% and power of test 80%, as mean of cerebral arteries' velocity prepuncture was (71.9 ± 24.9 cm/s) and was (58.4 ± 20.2 cm/s) post puncture [10].

Statistical analysis

Collected study data were coded entered and analyzed using Microsoft Excel software. Data were then imported into Statistical Package for the Social Sciences (SPSS version 20.0) (Statistical Package for the Social Sciences) software for analysis. According to the type of data qualitative data were represented as number and percentage, quantitative data were represented by mean ± SD, the following tests were used to test differences for significance; difference and association of qualitative variable by Chi-square test (χ^2). Differences between quantitative independent groups by *t* test, multiple by ANOVA, and paired by paired *t* test. *P* value was set at < 0.05 for significant results and < 0.001 for high significant result. TCD parameters to predict PDPH were studied using receiver operator characteristic (ROC) curves. For each ROC curve, the optimal cutoff point of MV and PI with maximal sensitivity and specificity for predicting PDPH was calculated.

Results

Ninety pregnant female patients undergoing elective cesarean section under spinal anesthesia were enrolled in this study. 17 patients (18.8%) of them developed PDPH during the study; no statistical significant differences were detected between these patients and PDPH-free patients regarding the patients' characteristics (age, weight, and height) as well as the ASA physical status distribution. Also, there was no statistical significant difference regarding the number of spinal attempts, estimated intra-operative blood loss, pre-operative and post-operative hemoglobin levels (Table 1).

Apart from the pre-spinal pulsatility index, all other parameters were statistically highly significant different in PDPH patient group than PDPH-free patients at all times, PDPH group was significantly higher regarding mean velocity and significantly lower with regard to PI at all times except for the pre-spinal PI (Table 2, Figs. 1, 2).

The values of middle cerebral artery mean velocity showed statistical significant increase within the first 48 h after cesarean section as compared with those before delivery. Also, the pulsatility index values showed high statistical significant increase when comparing the pre-puncture to the post-puncture times in PDPH-free patients while in patients who developed PDPH there was high statistical significant decrease in PI values at 24 h and 48 h compared to the pre-puncture values (Table 3).

The results of the receiver operating characteristic (ROC) analysis of MV and PI at different times of measurements for predicting PDPH showed that for the pre-puncture measurements within 24 h before dural puncture, the MV resulted in the parameter with the best accuracy for predicting PDPH with a cutoff of MV > 68.4 cm/s yielded 94% sensitivity, and 95% specificity. While evaluating the post-puncture values the PI at 24 h and 48 h were the best predictive of PDPH with a cutoff value of < 0.75 giving 100% sensitivity, and 100% specificity (Table 4, Fig. 3, 4).

Table 2 TCD parameters distribution in both groups

Variables	PDPH-free patients (N=73)	Patients with PDPH (N=17)	P value
Prespinal MV (cm/s)	63.98 ± 2.92	71.52 ± 1.75*	< 0.001
Prespinal PI	0.84 ± 0.055	0.82 ± 0.05	0.068
Postspinal MV at 24 h (cm/s)	71.99 ± 5.44	82.48 ± 4.42*	< 0.001
Postspinal PI at 24 h	0.89 ± 0.054	0.62 ± 0.051†	< 0.001
Postspinal MV at 48 h (cm/s)	73.8 ± 5.33	82.96 ± 3.19*	< 0.001
Postspinal PI at 48 h	0.89 ± 0.06	0.61 ± 0.039†	< 0.001

Quantitative data were expressed as mean ± SD. Independent samples Student's t test. $P < 0.05$ is significant. $P < 0.001$ high significant difference

TCD transcranial Doppler, *PDPH* post-dural puncture headache, *Prespinal MV, PI* mean velocity, pulsatility index measured within 24 h before spinal anesthesia, *Postspinal MV,PI at 24 h* mean velocity, pulsatility index measured 24 h after spinal anesthesia, *Postspinal MV,PI at 48 h* mean velocity, pulsatility index measured 48 h after spinal anesthesia

*MV was significantly higher in PDPH group at all times

†PI was significantly lower in PDPH group at 24 and 48 h

Table 1 Patients' characteristics

Characteristics	PDPH-free patients (N=73)	Patients with PDPH (N=17)	P value
Age/(years)	26.53 ± 5.77	26.76 ± 6.05	0.884*
Weight/(Kg)	85.88 ± 9.23	84.43 ± 9.26	0.561*
Height/(cm)	158.21 ± 5.41	159.82 ± 5.45	0.275*
ASA status			
ASA I number (%)	63 (86.3)	15 (88.2)	0.83◆
ASA II number (%)	10 (13.7)	2 (11.8)	
Number of spinal attempts			
One attempt number (%)	70 (95.9%)	16 (94.2%)	0.74◆
Two attempts number (%)	3 (4.1%)	1 (5.8%)	
Estimated intra-operative blood loss (ml)	989.7260 ± 147.65738	1038.2353 ± 123.14805	0.21*
Pre-operative hemoglobin level (gm/dl)	10.4918 ± 0.77312	10.5176 ± 0.66824	0.89*
Post-operative hemoglobin level (gm/dl)	10.1562 ± 0.69801	10.1235 ± 0.67131	0.86*

Quantitative data were expressed as mean ± SD. Qualitative data were expressed as a number and percentage. $P < .05$ is significant

PDPH post-dural puncture headache, *N* total number of patients in each group

*Independent samples Student's t test

◆Chi-square test

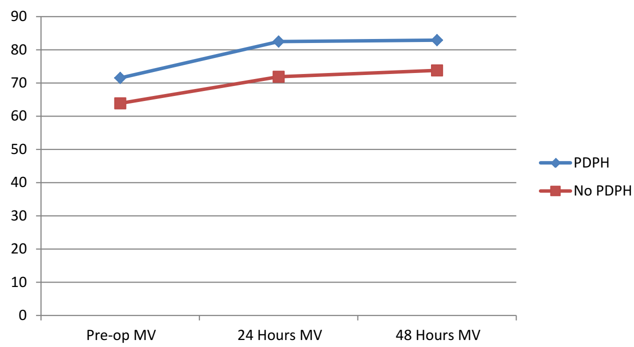

Fig. 1 Mean velocity (MV) measurements at different times

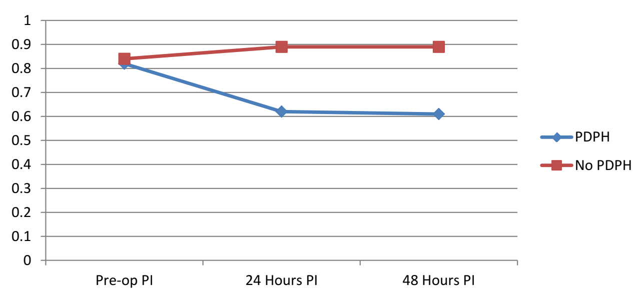

Fig. 2 Pulsatility Index (PI) measurements at different times

Table 3 Parameters change assessment over time in all patients

Variables		Mean ± SD	*P*
PDPH-free patients	MV prespinal	63.9874 ± 2.92619	< 0.001
	MV at 48 h	73.8082 ± 5.33015*	
	PI prespinal	0.8482 ± 0.05529	< 0.001
	PI at 48 h	0.8947 ± 0.06397††	
PDPH patients	MV prespinal	71.5294 ± 1.75420	< 0.001
	MV at 48 h	82.9647 ± 3.19256*	
	PI prespinal	0.8212 ± 0.05036	< 0.001
	PI at 48 h	0.6141 ± 0.03954†	

Quantitative data were expressed as mean ± SD. Paired *t* test. $P < 0.05$ is significant. $P < 0.001$ high significant difference

PDPH post-dural puncture headache, *MV prespinal,PI prespinal* mean velocity, pulsatility index measured within 24 h before spinal anesthesia, *MV 48 h,PI 48 h* mean velocity, pulsatility index measured 48 h after spinal anesthesia

*MV was significantly increased at 48 h after CS compared to the before delivery values

††PI was significantly increased in PDPH-free patients at 48 h after CS compared to the before delivery

†PI was significantly decreased in PDPH group at 48 h after CS compared to the before delivery

Discussion

Subarachnoid block is the most common technique used for cesarean section all over the world. This block was developed in late 1800s and the German surgeon, Karl August Bier in 1898 was the first to report the PDPH symptoms and he assumed that PDPH is due to CSF leak [14]. This distressing complication of spinal anesthesia results in prolongation of hospital length of stay, increasing costs, as well as a negative impact on patient satisfaction [12].

TCD provides non-invasive real-time assessment of cerebral hemodynamics. Therefore, it could be used to visualize the changes in cerebral blood flow resulted from PDPH. We assumed that using TCD parameters (MV, PI) to monitor the changes in cerebral blood flow in patients with multiple risk factors to develop PDPH, young females undergoing spinal anesthesia for elective cesarean section, could be helpful in the prediction of PDPH occurrence in this high-risk patients group.

In our study, 17 patients (18.8%) out of 90 patients who underwent spinal anesthesia for elective cesarean section suffered the symptoms of PDPH, whereas symptoms were not observed in the remaining 73 patients (81.1%). In all PDPH patients, the symptoms were manifested within 2 days following lumbar puncture.

The pre-puncture values of the mean velocity in the right MCA were significantly higher in patients who developed PDPH compared to the unaffected subjects. This is in agreement with the results of Nowaczewska et al., who found that higher baseline values of mean velocity and peak systolic velocity in bilateral MCAs predispose to PDPH. Yet, their results showed low pre-puncture PI values in patients who developed PDPH compared to patients who were free of this syndrome while the results of our study show no difference in pre-puncture PI values this could be explained by the different patient populations included in Nowaczewska et al. study as they did lumbar puncture as a diagnostic procedure for patients with different neurological diseases of both sex not only females as in our study and the mean age of their patients was higher than in the present study [12].

In support of our findings, Gobel et al., in their study found that patients with PDPH showed significantly higher flow velocities before lumbar puncture compared to patients without PDPH [15].

In our study, the post-puncture mean velocity values were significantly higher in PDPH group compared to patients without PDPH. This finding is somewhat different from the findings of Nowaczewska et al., where no significant differences were observed between the groups regarding post-puncture mean velocity and peak systolic

Table 4 Accuracy of TCD parameters at different times of measurement in predicting PDPH

Variable	Cutoff	AUC	*P*	95% CI		Sensitivity (%)	Specificity (%)
				Lower bound	Upper bound		
MV pre	> 68.4	0.993	0.00	0.981	1.000	94	95
MV 24	> 77	0.921	0.00	0.861	0.981	82	79
MV 48	> 77	0.922	0.00	0.861	0.980	82	79
PI 24	< 0.75	1.000	0.00	1.000	1.000	100	100
PI 48	< 0.75	1.000	0.00	1.000	1.000	100	100

TCD transcranial Doppler, *PDPH* post-dural puncture headache, *MV pre* mean velocity measured within 24 h before spinal anesthesia, *MV 24, PI 24* mean velocity, pulsatility index measured 24 h after spinal anesthesia, *MV 48, PI 48* mean velocity, pulsatility index measured 48 h after spinal anesthesia, *AUC* Area under the curve, *CI* confidence interval

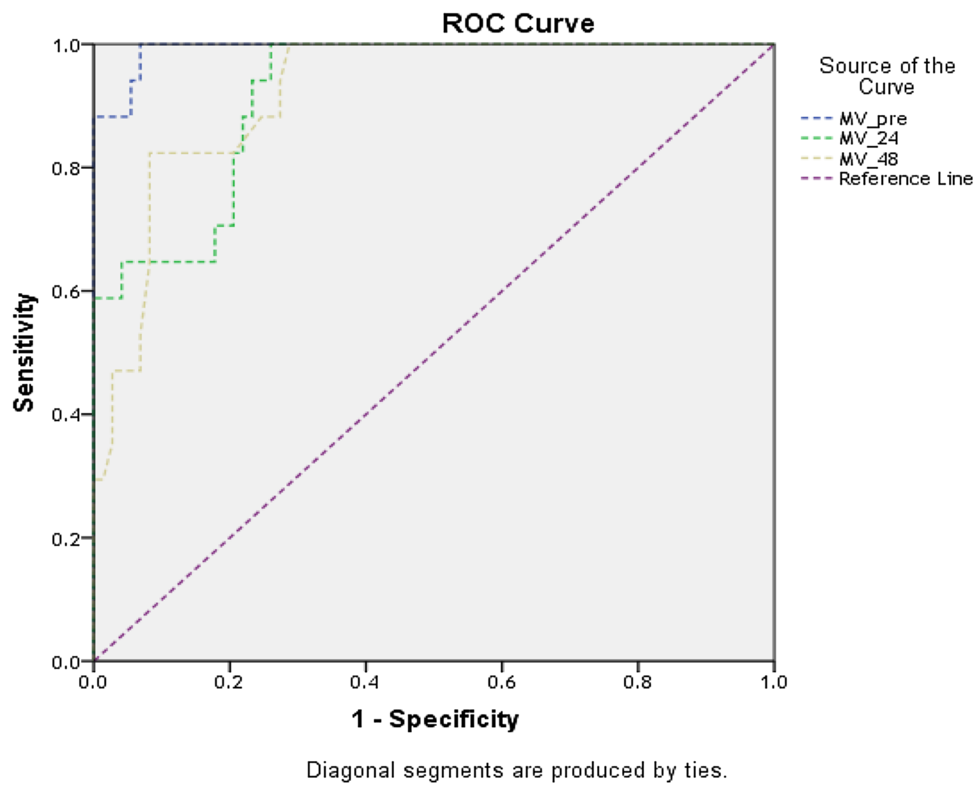

Fig. 3 ROC curve for mean velocity (MV) cutoff regarding PDPH prediction

velocity, the inclusion of only pregnant females in our study and the physiological changes related to pregnancy may provide an explanation of this difference. However, the post-puncture PI was still significantly lower in PDPH patients in our study and on the study conducted by Nowaczewska et al. [12].

Our findings may be explained by the theory that the value of PI is an indirect estimation of the intracranial pressure (ICP) as there is a linear relationship between ICP and PI changes. Also, PI represents the vascular resistance in middle cerebral artery examined by TCD. Therefore any decrease in PI may be a consequence of both decreased ICP and decreased vascular resistance (vasodilatation) [16]. Considering that PDPH is due to an excessive CSF leakage leading to a decrease in ICP and PI during early post-puncture period then reactive cerebral vasodilatation leads to further decrease in PI.

Cerebral blood flow velocity is affected by many factors. It is well known that a mean velocity decrease with age and it is established to be higher in females than in males [12]. In this study, the effects of age and gender were eliminated because only females in childbearing age undergoing cesarean section under spinal anesthesia were enrolled. It is also known that MV is negatively correlated with hematocrit and hemoglobin level [12]. In our study there was no significant difference between both groups in pre-and post-operative the hemoglobin level as well as the intra-operative blood loss.

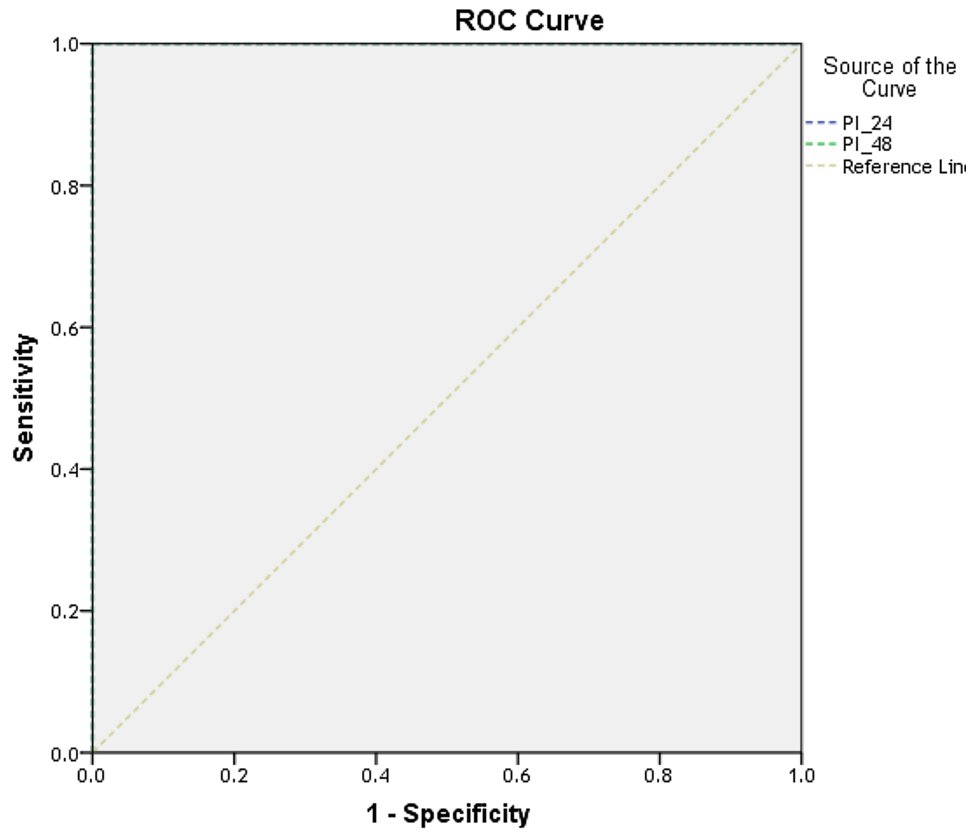

Fig. 4 ROC curve for pulsatility index (PI) cutoff regarding PDPH prediction

During pregnancy, blood flow increases to all organs including the brain. So, an adaptation of cerebral circulation during pregnancy is highly important. Also, in the early post-delivery days, brain circulation undergoes a profound adaptation and gradual return to non-pregnant cerebral hemodynamics [17]. The middle cerebral artery mean flow velocity progressively decreases from the first to the third trimester and this change has been attributed to estrogen mediated vasodilatation of brain arteries. While, after delivery MV progressively and rapidly increases in the first postpartum week, to decrease thereafter to pre-gestational levels by the 40th day post-delivery [18]

The results of the present study confirm these changes in cerebral hemodynamics before and after delivery. The mean velocity values increase within 48 h after CS when compared to pre-delivery values. This is in line with earlier studies by, Batur Caglayan et al., who studied the physiological changes in middle cerebral artery (MCA) blood flow velocity in healthy pregnant females just before and within 24 h after delivery and concluded that MCA flow velocity decreased in late pregnancy and increased in early post-delivery period to the same level of the non-pregnant females [19]. Also, Anzola et al., assessed the MCA flow velocity on 900 consecutive puerperae to assess normal values and range. They found that MCA mean flow velocity of healthy females in early puerperium was higher than in age-matched non-pregnant females and it may exceed the threshold of 100 cm/s with no evidence of intracranial spasm; this may be due to blood loss during delivery [20].

Williams and Galerneau reported that the mean cerebral blood flow velocity returns to normal level immediately after delivery [21]. While, Demarin et al., found that the changes of mean flow velocity were reversible, and it reaches the normal level 2 months after delivery [22].

Nowaczewska et al., in their study confirmed the theory of cerebral vasodilatation in PDPH patients as they found significant decrease in bilateral MCAs mean velocity of PDPH patients when compared to the pre-puncture values [12]. These findings are inconsistent with our results; we reported an increase in right MCA mean velocity 24 h after spinal anesthesia. Examining only the right MCA as well as the effects of pregnancy and delivery on the mean cerebral blood flow velocity may give an explanation to its increase towards normal levels in early puerperium within 48 h in our study. Supposed mechanisms for this increase in the MV might be mild vasoconstriction caused by the sudden decrease in the estrogen level after delivery, and the hemodilution as well as the blood loss during CS.

In our study, we observed that the pulsatility index remains low after delivery especially in patients who developed PDPH indicating excessive CSF leak and intracranial hypotension as a cause of PDPH and that PI parameter may be useful in predicting PDPH in this group of patients.

On investigating the TCD parameters either pre- and post-puncture values, and their ability to predict PDPH, we found that the post-puncture values of the PI at 24 h were the best predictive of PDPH with a cutoff value of < 0.75 giving 100% sensitivity, and 100% specificity and for the pre-puncture the MV measured within 24 h before lumbar puncture resulted in the parameter with the best accuracy for predicting PDPH with a cutoff of MV > 68.4 cm/s yielded 94% sensitivity, and 95% specificity. The present study is the first study to evaluate TCD parameters in predicting PDPH. Therefore, further studies on larger number of populations are highly required to validate our results.

One of the merits of this study is the inclusion of only young pregnant females undergoing elective CS under subarachnoid block hence eliminating the age and gender factors that may affect cerebral blood flow velocity. Also, performing the block with fixed size needle and performing TCD by the same physician eliminates operator variations.

On the other hand, there were some limitations in our study; there is a limited evidence available regarding cerebral circulation adaptation to pregnancy and labor. So far, studies assessing cerebral hemodynamic variations in puerperium are small studies depending on normative data comparing velocities in normal versus pre-eclamptic and eclamptic subjects. Also, studies assessing cerebral blood flow changes in PDPH patients are scarce and up to our knowledge our study is the first one to evaluate cerebral blood flow mean velocity and pulsatility index as predictors of PDPH. The severity of PDPH needs to be observed and correlated with the changes in TCD parameters.

Conclusion

In conclusion, TCD might prove a useful tool in predicting patients susceptible to PDPH suggesting that higher pre-puncture mean velocity with a cutoff value > 68.4 cm/s and post-puncture lower PI at 24 h with a cutoff < 0.75 are the best predictive parameters for PDPH. It is clear that there is a quest for further large scale studies to verify our results and for "fine tuning" of this new TCD application to improve our patients' care.

Compliance with ethical standards

Conflict of interest There are no conflicts of interest.

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