Perfusion index derived from a pulse oximeter can predict the incidence of hypotension during spinal anaesthesia for Caesarean delivery

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Editor’s key points
- Hypotension is common during spinal anaesthesia for Caesarean delivery.
- The authors evaluated the relationship of this hypotension with resting vascular tone.
- The vascular tone was assessed by a perfusion index (PI) as derived using a pulse oximeter.
- Importantly, higher PI was associated with increased risk of hypotension.

Background. Hypotension during spinal anaesthesia for Caesarean delivery is a result of decreased vascular resistance due to sympathetic blockade and decreased cardiac output due to blood pooling in blocked areas of the body. Change in baseline peripheral vascular tone due to pregnancy may affect the degree of such hypotension. The perfusion index (PI) derived from a pulse oximeter has been used for assessing peripheral perfusion dynamics due to changes in peripheral vascular tone. The aim of this study was to examine whether baseline PI could predict the incidence of spinal anaesthesia-induced hypotension during Caesarean delivery.

Methods. Parturients undergoing elective Caesarean delivery under spinal anaesthesia with hyperbaric bupivacaine 10 mg and fentanyl 20 μg were enrolled in this prospective study. The correlation between baseline PI and the degree of hypotension during spinal anaesthesia and also the predictability of spinal anaesthesia-induced hypotension during Caesarean delivery by PI were investigated.

Results. Baseline PI correlated with the degree of decreases in systolic and mean arterial pressure (r=0.664, P<0.0001 and r=0.491, P=0.0029, respectively). The cut-off PI value of 3.5 identified parturients at risk for spinal anaesthesia-induced hypotension with a sensitivity of 81% and a specificity of 86% (P<0.001). The change of PI in parturients with baseline PI<3.5 was not significant during the observational period, while PI in parturients with baseline PI>3.5 demonstrated marked decreases after spinal injection.

Conclusions. We demonstrated that higher baseline PI was associated with profound hypotension and that baseline PI could predict the incidence of spinal anaesthesia-induced hypotension during Caesarean delivery.

Keywords: anaesthesia, obstetric; anaesthetic techniques, subarachnoid; complications, hypotension; equipment, pulse oximeters; measurement techniques, plethysmography

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Methods

After approval of the study by the Institutional Ethics Committee (Teikyo University Chiba Medical Center, Chiba, Japan), parturients undergoing Caesarean delivery were included consecutively between January 2010 and March 2011. The exclusion criteria were emergency cases, placenta praevia, preeclampsia, cardiovascular or cerebrovascular disease, morbid obesity with a BMI ≥40, gestational age <36 or >41 weeks, and contraindications to spinal anaesthesia. Eighty-three parturients underwent Caesarean delivery during this period; of which, 24 were emergency cases, 11 were excluded for various other reasons (two for general anaesthesia, eight for placenta praevia, and one for morbid obesity), and nine did not consent. The remaining 39 parturients were enrolled in this prospective observational study. Written informed consent was obtained from each parturient in the study.

Study protocol

Each parturient was given an infusion of 500 ml of 6% hydroxyethyl starch 70/0.5 (HES) (Salinhes®, Fresenius Kabi, Tokyo, Japan) for prehydration before spinal anaesthesia via an i.v. cannula. A fixed volume of fluid was given in this study because the variability of parturient weight was not large [63 (11) kg, mean (standard deviation, so)] since morbidly obese parturients were excluded from the study. After the prehydration, lactated Ringer’s solution was infused until the end of surgery. Standard monitoring with electrocardiography, automated non-invasive arterial pressure (NIAP) measurement, and pulse oximetry was performed. The cuff of an automated NIAP device (Philips Electronics Japan, Tokyo, Japan) was attached to the right arm, and systolic arterial pressure (SAP) and diastolic arterial pressure (DAP) were monitored. The mean arterial pressure (MAP) was calculated from the equation: MAP = SAP + (DAP – DAP)/3. The pulse oximeter probe (Mashimo Radical 7; Mashimo Corp., Irvine, CA, USA) was attached to the left index finger. Baseline NIAP, heart rate (HR), and PI were recorded in the supine position. The anaesthesiologists in this study were blinded to the value of PI.

A combined spinal–epidural procedure was performed with the parturient in the right lateral decubitus position. An epidural catheter was inserted at the L1–2 or L2–3 interspace. After a negative test dose with 3 ml of 1.0% lidocaine plus 1:100 000 epinephrine, spinal anaesthesia was induced with a total of 10 mg of 0.5% hyperbaric bupivacaine (Marcaine®; AstraZeneca, Osaka, Japan) and 20 μg fentanyl (total volume 2.4 ml) at the L3–4 interspace. Immediately after the epidural catheter was taped into place, the parturient was returned to the supine position with a left lateral tilt of 15° to facilitate left uterine displacement. The upper sensory block level was checked 5 min after the spinal injection by assessing the loss of cold sensation from alcohol swabs. If a Th6 sensory block level was not achieved, an epidural supplement of 2% lidocaine (with sodium bicarbonate 1 mEq 10 ml⁻¹) was administered in 5–10 ml increments to attain a Th6 sensory block level, and these parturients were excluded from the study.

Maternal NIAP, HR, and PI were recorded at 1 min intervals between the spinal injection and delivery and then at 2.5 min intervals until the end of surgery. Hypotension was defined as a decrease in SAP >25% from baseline. This definition was based on a previous study. When SAP decreased to this level, a bolus of 50 μg phenylephrine was given as a rescue medication, keeping the decrease within SAP ≤25% from baseline. Rescue phenylephrine was given in the same manner if the patient complained of faintness, dizziness, nausea, or vomiting even if the decrease in SAP from baseline was ≤25%. A bolus of 0.5 mg atropine was to be given if hypotension occurred in combination with bradycardia (HR <55 beats min⁻¹). Oxygen was not routinely given unless the arterial oxyhaemoglobin saturation obtained from pulse oximeter decreased to <95%. Hypotensive events were not treated by additional fluid loading.

Arterial blood gas samples were obtained from the umbilical cord. Apgar scores at 1 and 5 min after delivery were recorded by the midwife.

Statistical analysis

Patient characteristic data are presented as mean (sd) or median (range) where appropriate. Since a literature search found no data on the strength of correlation between baseline PI and change in SAP from baseline, a correlation hypothesis of a correlation coefficient ($r$) = 0.50 was assumed in this study based on a study that showed $r$ = 0.541 ($P$ <0.001) between baseline HR and the sd of MAP during spinal anaesthesia for Caesarean delivery. To measure such a correlation coefficient at the desired power of 0.8 and two-tailed $\alpha$ of 0.05, this study required a sample size of 35 parturients. To allow for a possible dropout rate of 10%, we needed 39 parturients in this study.

Spearman’s rank correlation was used to assess the correlations between parturient characteristics or baseline parameters and the per cent decrease in arterial pressure from baseline. Multiple linear regression analysis was performed to assess the relationships between parturient characteristics and baseline parameters with a decrease in SAP and MAP from baseline. Because multicollinearity among the covariates can give spurious results, backward stepwise procedures were performed to identify the independently associated variables.

To test the abilities of baseline PI, parturient characteristics (height and weight)19 20 parturient baseline HR18 to predict spinal anaesthesia-induced hypotension in Caesarean delivery, and areas under the receiver operating characteristic (ROC) curves of hypotension were calculated. The area under the curve (AUC) is a measure of the parameter’s accuracy (AUC = 0.5: no better than chance, no prediction possible; AUC = 1.0: best possible prediction). The optimal cut-off point is the one that has the smallest false-positive and false-negative rates across a range of cut-off points.
Patient characteristic data were analysed by unpaired Student’s t-test, Mann–Whitney U-test, or Fisher’s exact probability test, as appropriate. The perioperative haemodynamic parameters and PI were assessed by two-way analysis of variance with the Bonferroni post hoc test. Statistical significance was defined as \( P < 0.05 \). The SigmaPlot statistical software package for Windows (version 11.0, Systat, San Jose, CA, USA) was used for statistical analysis.

**Results**

No parturients presented signal quality that was inadequate for measurement of PI. Four parturients were excluded from the study because their upper sensory block levels did not reach Th6. These parturients did not develop hypotension. The analysis was based on the remaining 35 data sets. Patient characteristic and obstetric characteristics are presented in Table 1. Baseline PI ranged from 0.7 to 8.6, with a mean value of 4.0 (2.3). Twenty-one parturients (60%) developed hypotension; the maximum decrease in SAP from baseline ranged from 9.1–55.1%, with a mean value of 28.7 (11.5)%. Two of these parturients complained of nausea without a decrease in SAP; one of these parturients did not develop hypotension. The anaesthesia requirement was 200 (50–600) \( \mu \text{g} \). Atropine was not administered to any parturients.

The per cent decrease in SAP from baseline was correlated with baseline PI (\( r = 0.664, P < 0.0001 \); Table 2 and Fig. 1) and parturient height (\( r = -0.369, P = 0.029 \); Table 1). The per cent decrease in MAP from baseline also correlated with baseline PI (\( r = 0.491, P = 0.0029 \); Table 2). Multiple linear regression analysis confirmed that baseline PI and parturient height significantly contributed to the per cent decrease in SAP from baseline (predicted per cent decrease in SAP from baseline = 99.369 + 2.772 × baseline PI − 0.516 × parturient height; \( R^2 = 0.46, P < 0.001 \)), and baseline PI contributed to the per cent decrease in MAP from baseline (predicted per cent decrease in MAP from baseline = 33.446 + 2.209 × baseline PI; \( R^2 = 0.15, P < 0.001 \)). Phenylephrine requirement correlated with baseline PI (\( r = 0.585, P < 0.0001 \)).

**Table 2** Correlations between the degree of decrease in arterial pressure and obstetric variables. Data are determined by Spearman’s rank correlation. *Degree of decrease in SAP after spinal injection: (baseline SAP–lowest SAP)/baseline SAP. †Degree of decrease in MAP after spinal injection: (baseline MAP–lowest MAP)/baseline MAP. HR, heart rate; PI, perfusion index

<table>
<thead>
<tr>
<th>% SAP decrease *</th>
<th>% MAP decrease †</th>
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<tr>
<td>( r )</td>
<td>( P )-value</td>
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**Fig 1** The correlation between baseline PI and the degree of decrease in SAP during spinal anaesthesia for Caesarean delivery (% SAP decrease = (baseline SAP–lowest SAP)/baseline SAP) (\( r = 0.664, P < 0.0001 \)). The solid line represents the linear regression line and the dotted lines represent the 95% CIs.
The ROC analysis revealed that baseline PI was suitable for detecting parturients at risk for hypotension (AUC = 0.866, P = 0.0003; Fig. 2). Parturient height (AUC < 0.5) and weight (AUC = 0.696, P = 0.0529) and baseline HR (AUC < 0.5) could not predict hypotension. The baseline PI cut-off point that predicted hypotension as determined by the ROC analyses was 3.5 with a sensitivity of 81% [95% confidence intervals (CI) 58–95%], a specificity of 86% (95% CI 57–98%), a positive predictive value of 89%, and a negative predictive value of 75% (P < 0.001).

The patient characteristic and obstetric characteristics were compared according to the baseline PI cut-off point of 3.5 determined by the above ROC analysis. Nineteen parturients (54%) had high baseline PI (PI ≥ 3.5) and hypotension was observed in 17 of those parturients (82%), whereas 16 parturients (46%) had low baseline PI (PI < 3.5) and hypotension was observed in four of those parturients (25%). The median (range) gravidity and parity were 2 (0–4) and 1 (0–3) in parturients with high baseline PI, which were greater than those in parturients with low baseline PI [1 (1–3), P = 0.015 and 1 (0–2), P = 0.046, respectively]. The median (range) preoperative fasting time was 7 (3–11) h in parturients with high baseline PI, which was not different to that in parturients with low baseline PI [8 (3–11) h, P = 0.247]. The mean (SD) (range) total amount of fluid was 29 (11) (14–52) ml kg⁻¹ in parturients with high baseline PI, which was not different to that in parturients with low baseline PI [31 (10) (19–50) ml kg⁻¹, P = 0.456]. In addition, the groups were not different with respect to parturient height and weight, gestational age, upper sensory block level, neonatal body weight, indication for Caesarean delivery, and preoperative laboratory data (haemoglobin and albumin).

Although SAP decreased significantly after spinal injection in parturients with both high and low baseline PI, parturients with high baseline PI had larger decreases in SAP 4, 5, and 6 min after spinal injection than those with low baseline PI (P = 0.049, 0.007, and 0.034, respectively; Fig. 3a). The median (range) time to hypotension was 5 (4–9) min in parturients with high baseline PI and 8 (5–15) min in those with low baseline PI (P = 0.002). While parturients also showed marked decreases in MAP after spinal injection in parturients with both high and low baseline PI, parturients with high baseline PI had a larger decrease in MAP 5 min after spinal injection than those with low baseline PI (P = 0.020; Fig. 3b).

HR did not differ significantly between parturients with high baseline PI and those with low baseline PI during the hypotensive period after spinal injection (Fig. 3c). PI values were higher in parturients with high baseline PI than those with low baseline PI during the observational period (P < 0.05; Fig. 3a). The change of PI in parturients with low baseline PI was not significant throughout the observational period, while PI in parturients with high baseline PI demonstrated marked decreases after spinal injection (P < 0.01; Fig. 3c). Neonatal outcomes did not differ between parturients with high baseline PI and those with low baseline PI.

**Discussion**

In this prospective observational study, we demonstrated that higher baseline PI was associated with greater decrease in arterial pressure and larger doses of phenylephrine administration, and an ROC analysis showed a high sensitivity and specificity of the baseline PI for prediction of spinal anaesthesia-induced hypotension during Caesarean delivery. Baseline HR and parturient weight and height could not predict hypotension in this study, although these parameters have been reported to be predictors in other studies.18–20

Spinal anaesthesia-induced hypotension is mainly a result of decreased systemic vascular resistance due to blockade of preganglionic sympathetic fibres.1 Spinal anaesthesia also induces blood pooling in blocked areas of the body, leading to reductions in cardiac output and MAP.2–4 Therefore, preoperative sympathetic activity1 18 21 and preoperative volume status5 are known to affect the degree of such hypotension. However, preoperative peripheral vascular tone may also have influence. Healthy pregnancy is characterized by a decrease in systemic vascular resistance and increases in total blood volume and cardiac output,22 and pregnant women, particularly after 30 weeks of gestation, have more blood volume trapped in extremities due to the pregnancy-induced decrease in vascular tone.6 7 Several studies using plethysmography have demonstrated a reduction in peripheral vascular tone during healthy pregnancy.6–9 Consequently, the induction of a sympathectomy by spinal analgesia in healthy pregnant women is thought to further increase the pooling, resulting in more trapped blood in the extremities compared with non-pregnant women.10 and

**Fig 2** ROC curves for the baseline PI during spinal anaesthesia for Caesarean delivery. The optimal cut-off value for predicting the incidence of hypotension in PI was 3.5. AUC, area under the ROC curve, with 95% CIs given in parentheses.
thus colloid preloading,\textsuperscript{3} \textsuperscript{4} \textsuperscript{23} and lower limb compression using mechanical measures\textsuperscript{10} \textsuperscript{26} which increase the central blood volume have been demonstrated to reduce the incidence of hypotension during spinal anaesthesia for Caesarean delivery. However, the degree of decrease in vascular tone in parturients may vary depending on the number of pregnancy and other factors.\textsuperscript{5} \textsuperscript{9} \textsuperscript{22} Therefore, it is likely that parturients with low baseline vascular tone are more at risk to develop hypotension during spinal anaesthesia than those with relatively higher baseline vascular tone. Peripheral vascular tone can be measured by plethysmography, but the technique is invasive and is not readily available for clinical management in the elective settings. In contrast, non-invasive plethysmographic pulse wave monitoring is found in most pulse oximeters and is readily available for routine use. Changes in PI are caused by pulsatile changes in arterial blood volume and changes in venous and non-pulsatile arterial blood volume originated from variations in the tonus of the arterial and venous wall muscles under various conditions.\textsuperscript{11} \textsuperscript{27} Ginosar and colleagues\textsuperscript{13} have demonstrated that an increase in PI was an earlier and more sensitive indicator of the development of epidural-induced sympathectomy compared with an increase in skin temperature. Others have demonstrated that a decrease in PI was an effective indicator for intravascular injection of epinephrine-containing epidural test dose\textsuperscript{12} and was a useful indicator to identify inadequate perfusion in critically ill patients.\textsuperscript{14} From these perspectives, we hypothesized that the relationship between baseline vascular tone and spinal anaesthesia-induced hypotension during Caesarean delivery could be assessed by using PI values derived from a pulse oximeter. To address our hypothesis, we examined whether baseline PI correlates with the degree of decrease in arterial pressure during spinal anaesthesia for Caesarean delivery and whether baseline PI could predict parturients at risk for such hypotension.

We found a fair correlation between baseline PI and the degree of a decrease in SAP from baseline during spinal anaesthesia for Caesarean delivery, and demonstrated that the number of gravidity and parity was larger in parturients with high baseline PI (PI ≥ 3.5) than those with low baseline PI (PI ≤ 3.5). Since the magnitude of a decrease in systemic

\begin{figure}[h]
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\caption{Summary of the changes in SAP (a), MAP (b), HR (c), and PI (d) from baseline (BL) through 15 min after the induction of spinal anaesthesia (SP). Data are presented as mean (SD). Time, minutes after spinal injection. *P < 0.05 vs the group's baseline value; †P < 0.05 for parturients with baseline PI > 3.5 vs those with baseline PI ≤ 3.5; vs P < 0.01 for parturients with baseline PI > 3.5 vs those with baseline PI ≤ 3.5.}
\end{figure}
vascular resistance secondary to pregnancy is greater in multiparous women compared with nulliparous women. Higher baseline PI in our study may have reflected lower peripheral vascular tone secondary to pregnancy. Another notable finding was that the change of PI in parturients with low baseline PI was not significant throughout the observational period, while PI in parturients with high baseline PI demonstrated marked decreases after spinal injection. Since compensatory increases in sympathetic nervous system activation and systemic vascular resistance in non-blocked areas of the body to maintain systemic perfusion pressures are attenuated under high spinal anaesthesia (sensory block below Th6 or higher as used in the present study), a decrease in PI after spinal injection seen in parturients with high baseline PI likely reflected a decrease in preload due to blood pooling in the lower part of the body rather than an increase in vascular tone due to compensatory sympatheic vasoconstriction. It is therefore suggested that parturients with high baseline PI had lower peripheral vascular tone compared with those with low baseline PI and thus were more at risk of developing spinal anaesthesia-induced hypotension due to more blood pooling in the lower part of the body.

Our study has several limitations. First, we did not measure haemodynamic parameters such as cardiac output and systemic vascular resistance. However, arterial and central venous cannulations are not appropriate in uncomplicated elective Caesarean delivery. Secondly, photoplethysmographic analysis is quite sensitive to patient movement, and PI is also easily decreased by several factors such as stress and anxiety that can induce sympathetic activation, which in turn induces peripheral vasoconstriction. The accuracy of pulse oximeter photoplethysmographic wave analysis has been demonstrated to be greater in patients with higher perfusion status. Although the pulse oximeter used in our study (Mashimo Radical 7; Mashimo Corp., Irvine, CA, USA) is demonstrated to be useful to monitor peripheral perfusion even in neonates and critically ill neonates, these factors may have had a negative effect on the sensitivity and specificity of preoperative PI for predicting hypotension. Thirdly, in our study, baseline values of PI and haemodynamic parameters were obtained with parturients in the supine position, whereas a 15° left lateral table tilt was applied after spinal injection. In pregnant women, the supine position is known to be associated with significant aortocaval compression by the gravid uterus, reducing venous return, cardiac output, and arterial pressure, and we cannot rule out its effect on the baseline values. Despite these limitations, we were able to demonstrate that baseline PI was correlated with the development of hypotension during spinal anaesthesia for Caesarean delivery.

In our study, hypotension could be treated by bolus administrations of phenylephrine without additional volume load after spinal injection, and neonatal outcomes were similar in parturients with high baseline PI and those with low baseline PI. However, Ueyama and colleagues indicated that a large augmentation of blood volume that results in a significant increase in cardiac output is necessary for effective prevention of hypotension during spinal anaesthesia for Caesarean delivery. Thus, our study provides rationale for a prospective study to investigate whether a large augmentation of blood volume that results in a significant increase in cardiac output can reduce the incidence of spinal anaesthesia-induced hypotension in parturients with high baseline PI. On the other hand, phenylephrine has been recently established as a first-line vasopressor during spinal anaesthesia for Caesarean delivery. If low baseline vascular tone, as suggested from this study, is a major factor in producing spinal anaesthesia-induced hypotension during Caesarean delivery, prophylactic phenylephrine infusion that increases vascular tone may be a rational option to prevent spinal anaesthesia-induced hypotension in parturients with high baseline PI. Future studies are warranted that establish preferred preventative measures in these parturients that are predicted to develop hypotension during spinal anaesthesia.

In conclusion, we demonstrated that baseline PI measured at the finger correlated with the degree of decrease in arterial pressure during spinal anaesthesia for Caesarean delivery, and a baseline PI cut-off point of 3.5 could be used to identify parturients at risk for such hypotension. PI may be a very useful tool to predict hypotension during spinal anaesthesia for Caesarean delivery in everyday practice.

**Declaration of interest**

None declared.

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Perfusion index in parturients


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