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ORIGINAL ARTICLE

Changes in the corrected carotid flow time can predict spinal anesthesia-induced hypotension in patients undergoing cesarean delivery: an observational study

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Abstract

Purpose Spinal anesthesia is a standard technique for cesarean delivery; however, it possesses a risk of hypotension. We hypothesised that the changes in the corrected flow time induced by the Trendelenburg position could predict the incidence of hypotension after spinal anesthesia for cesarean delivery.

Methods Patients undergoing elective cesarean delivery under spinal anesthesia were enrolled. Before anesthesia induction, corrected flow time was measured in the supine and Trendelenburg positions (FTc-1 and FTc-2, respectively). Additionally, a percent change in corrected flow time induced by the Trendelenburg position was defined as ΔFTc. The primary endpoint was to investigate the ability of ΔFTc to predict the incidence of spinal anesthesia-induced hypotension until delivery. The receiver operating characteristics curves to assess the ability of FTc-1, FTc-2, and ΔFTc to predict the incidence of hypotension were generated.

Results Finally, 40 patients were included, and of those, 26 (65%) developed spinal anesthesia-induced hypotension. The areas under the curve for FTc-1, FTc-2, and ΔFTc were 0.591 (95% CI: 0.424 to 0.743) (P = 0.380), 0.742 (95% CI: 0.579 to 0.867) (P = 0.004), and 0.882 (95% CI: 0.740 to 0.962) (P < 0.001) respectively, indicating ΔFTc as the best predictor among these three parameters. The best threshold for ΔFTc was 6.4% (sensitivity: 80.8% (95% CI: 53.8 to 96.2), specificity: 85.7% (95% CI: 42.9 to 100.0)).

Conclusions This study demonstrated that changes in the corrected carotid flow time induced by the Trendelenburg position could serve as a good predictor of spinal anesthesia-induced hypotension for cesarean delivery.

Keywords Cesarean delivery · Hypotension · Corrected flow time

Introduction

Spinal anesthesia is a standard technique for cesarean delivery because it can avoid the risks of general anesthesia, including difficult airway management in parturients [1, 2]. Spinal anesthesia-induced hypotension remains a critical problem, which causes undesirable maternal symptoms including nausea, vomiting and dyspnoea, and adverse outcomes for the fetus such as umbilical acidosis and decreased Apgar scores [3]. The incidence of hypotension is exaggerated by an aortocaval compression and an increased sensitivity of the parturient against local anesthetic drugs [4, 5]. Some clinical approaches have been conducted to prevent its occurrence, such as preoperative volume expansion, administration of vasopressors, and lower limb compression; however, the incidence of hypotension during cesarean delivery still remains around 50% [6]. Consequently, it is essential for anesthesiologists to predict the incidence of hypotension during spinal anesthesia for cesarean delivery.

Dynamic fluid indicators, such as stroke volume variation, perfusion index, and pleth variability index, are recently used for predicting fluid responsiveness during mechanical ventilation [7–11]. Similarly, these indices have been investigated as predictors of spinal anesthesia-induced hypotension during cesarean delivery with conflicting results [5, 12–14]. However, the hemodynamic monitors that display these dynamic indices are usually costly, and some need

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cannulation into an artery causing complications such as nerve injury, hematoma, and peripheral ischemia. Therefore, non-invasive and emerging techniques to predict the incidence of hypotension are required.

Ultrasound imaging is a common and non-invasive method to evaluate the volume status that is widely used perioperatively. In particular, the flow time measured by Doppler ultrasound in the carotid artery has been used to assess the changes in stroke volume (SV) [10]. Flow time is normally corrected for heart rate variability as 'corrected flow time (FTc)'. A recent study [15] has suggested that the change in FTc induced by passive leg raising can predict fluid responsiveness in critically ill patients. Therefore, we hypothesised that the changes in FTc against hemodynamic interventions would reflect the maternal hemodynamic conditions and could discriminate the parturient at a higher risk of spinal anesthesia-induced hypotension. A previous study [4] has already investigated the reliability of FTc for predicting hypotension. However, in this study, pre-anaesthetic FTc alone was evaluated, and hemodynamic interventions were not performed. Considering the variability of FTc in each patient, some interventions against FTc should be performed. To test the hypothesis, this study aimed to assess the reliability of the change in FTc induced by the Trendelenburg position in predicting the incidence of hypotension after spinal anesthesia for cesarean delivery.

Methods

Enrolled patients

Ethical approval for this study (Ethical Committee Number 2021–38) was given by the Ethical Committee of Osaka City University Graduate School of Medicine, Osaka, Japan (Chairperson Prof. Norifumi Kawada) on 6th May 2021. This study was registered at UMIN clinical trials registry (UMIN00044229). After receiving the institutional review board approval from our hospital, patients undergoing elective cesarean delivery were enrolled in this study. Written informed consent was obtained from all patients. Patients with atrial fibrillation and those who could not keep the Trendelenburg position were excluded. Additionally, we excluded patients with non-reassuring fetal status.

Flow of the study

The flow of the study is shown in the Supplemental Fig. 1. The duration of the study was set from the inception of anesthesia until delivery

Pre-anaesthetic management

All the patients fasted from 9 pm before the operation and took clear liquids (up to 200 mL) until 3 h before surgery. Lactate Ringers' solution was administered at a rate of 80 ml/h from 3 h before the operation. Following arrival at the operating room, all patients were laid on an operating table, and hemodynamic monitoring, including non-invasive blood pressure, electrocardiogram, pulse oximetry (IntelliVue MP70; Philips Electronics Japan Corp., Tokyo, Japan), and the ClearSight system (Edwards Lifesciences, Irvine, USA) was attached. After the initiation of hemodynamic monitoring using the ClearSight system (systolic arterial pressure (SAP), diastolic arterial pressure (DAP), mean arterial pressure (MAP), SV, stroke volume variation (SVV)), patients rested in a supine position for 5 min. The hemodynamic variables measured by the ClearSight system after the 5 min rest were defined as the baseline.

Measurement of corrected flow time

After the baseline hemodynamic measurements, the measurement of flow time was performed. We obtained the

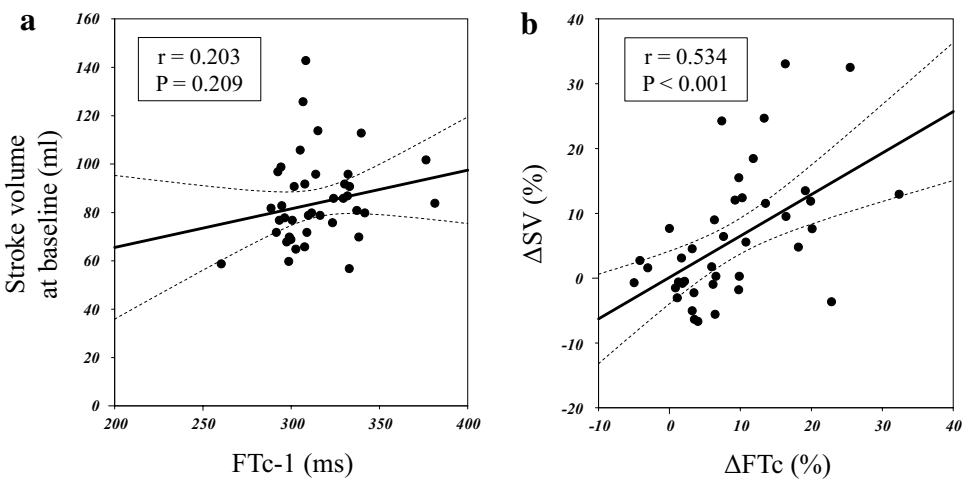

Fig. 1 FTc-1: Corrected flow time in the supine position. ΔFTc: Percent changes in the corrected flow time induced by the Trendelenburg position. ΔSV: Percent changes in stroke volume induced by the Trendelenburg position. **a** Correlation between FTc-1 and stroke volume at baseline (in the supine position). **b** Correlation between ΔFTc and ΔSV.

ultrasound images of the carotid artery in a long-axis view using a 12-MHz linear-array probe (Vivid S6; GE Healthcare, Chicago, IL, USA). The flow time was measured using pulse Doppler waveforms of the right common carotid artery. The position of the measurement was around 3 cm proximal to the carotid bulb in the longitudinal plane [10]. The researchers set the cursor angle parallel to the blood flow direction, and the angle of insonation was set to less than 60° (Supplemental Fig. 2). The Wodey's formula was used for the calculation of FTc as follows:

FTc = measured flow time + [1.29 (HR − 60)].

The measurement of flow time was performed in the supine and subsequently in the Trendelenburg positions (15 degrees) (Supplemental Figure). The original passive leg raising test typically involves elevating the legs to a 45-degree angle [16]. However, in our study setting, this procedure was impractical due to the limitations of the beds in our operating rooms. Moreover, for pregnant patients, a 45-degree leg elevation can cause abdominal compression and discomfort. Therefore, we referred to a previous study and opted for a 15-degree Trendelenburg position, which is less burdensome for pregnant patients [17]. To eliminate the possibility of anesthesiologists altering their interventions based on the FTc values, the measurement of FTc was conducted by dedicated measurement personnel (K.S. or T.J.), and these results were kept concealed from the anesthesiologists. The average of the three measurements was used in the analysis. The FTc values measured in the supine and Trendelenburg positions were defined as FTc-1 and FTc-2, respectively. A per cent change in FTc induced by the Trendelenburg position was defined as ΔFTc, which was calculated as follows:

ΔFTc = [(FTc-2–FTc-1)/FTc-1] × 100.

Along with the FTc measurements, the values of SV (by the ClearSight system) were also recorded in the supine and Trendelenburg positions. Percent changes in SV induced by the Trendelenburg position were defined as ΔSV, which was calculated as follows:

ΔSV = [(SV in the Trendelenburg position–SV in the supine position)/SV in the supine position] × 100.

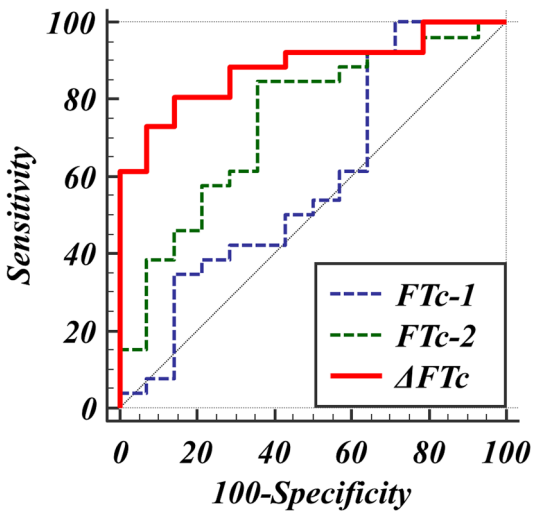

Fig. 2 FTc-1: Corrected flow time in the supine position. FTc-2: Corrected flow time in the Trendelenburg position. ΔFTc: Percent changes in the corrected flow time induced by the Trendelenburg position. Receiver operating characteristic curves for FTc-1, FTc-2, and ΔFTc to predict hypotension after spinal anesthesia

Anesthesia and surgery

After the FTc measurement, patients were returned to the supine position. Spinal anesthesia was performed using 0.5% hyperbaric bupivacaine (11 mg) and fentanyl (10 μg) in the third lumbar intervertebral space. Following the induction of anesthesia, patients were laid in the supine position. A colloid solution (6% hydroxyethyl starch 130,000: Voluven®, Fresenius Kabi, Bad Hamburg, Germany) was administered with a goal of approximately 500 mL until delivery. Blood pressure (SAP, MAP, and DAP) was continuously monitored using the ClearSight system throughout the procedure. When hypotension (i.e., SAP less than 90 mmHg or 80% of the baseline) occurred, vasoactive drugs (phenylephrine 50 μg or ephedrine 5 mg) were administered. The choice of vasoactive drugs depended on the attending anesthesiologists. The level of the upper sensory block was evaluated at 5 and 10 min after induction of anesthesia by a loss of cold sensation. If the sensory block did not reach the Th6 level even at 10 min after spinal anesthesia, we excluded the patient from this study. The surgical procedure was performed in a normal way. The Apgar scores (at 1 and 5 min) of the newborns were evaluated by the pediatricians.

Statistical analysis

All patients were divided into two groups: with and without hypotension after spinal anesthesia until delivery. Receiver operating characteristic (ROC) analyses were performed for ΔFTc, FTc-1, and FTc-2 to predict the incidence of spinal anesthesia-induced hypotension. The area under the curve (AUC) and the best threshold were calculated in each variable, as shown in a previous paper [18]. The best threshold was set as the point of minimising the distance from the upper-left corner of the ROC curve [19]. The P values in the ROC analyses were calculated by testing against the hypothesis of AUC = 0.50 [9].

Furthermore, the grey-zone analysis was performed for ΔFTc, FTc-1, and FTc-2. The grey-zone analysis, previously described by Cannesson et al. [20], is a method to assess an inconclusive range to make a clinical decision. Briefly, the grey zone was calculated as follows: in the first step, a

bootstrap re-sampling was performed for ΔFTc, FTc-1, and FTc-2. The inconclusive range for each variable was calculated using the 95% confidence interval (CI) of each best cut-off threshold analysed from 1000 bootstrapped populations (sampling with replacement) [10]. This was automatically calculated using the MedCalc Statistical Software (MedCalc Software Ltd., Ostend, Belgium). In the second step, the inconclusive range for each variable was calculated using the cut-off values with a sensitivity of less than 90% or a specificity of less than 90% from each ROC analysis [10]. The larger range obtained in these two steps was defined as a grey zone.

An intergroup comparison was performed between the non-hypotension and hypotension groups of patients using the Student t-test and Mann–Whitney U test. Shapiro–Wilk test was used for assessing normality. A correlation between ΔFTc and the number of doses of vasoactive drugs or the duration until the occurrence of hypotension after spinal anesthesia was analysed using the Pearson correlation coefficient. Additionally, correlations between SV at baseline (in the supine position) and FTc-1, as well as ΔSV and ΔFTc, were also analysed with the Pearson correlation coefficient. The Kaplan–Meier method followed by the generalised Wilcoxon test was used to analyse patients with lower (< the threshold calculated from the ROC analysis) and higher (≥ the threshold calculated from the ROC analysis) ΔFTc regarding the duration from the induction of spinal anesthesia to the onset of hypotension.

An intra-observer variability of flow time was evaluated with intraclass correlation coefficients [21]. The sum of squares (SS) was obtained using a one-way ANOVA to calculate intraclass correlation coefficients. The intraclass correlation coefficient was calculated as follows:

Intraclass correlation coefficient = (n × SS subjects − SS total)/[(n − 1) × SS total],

where 'n' means the number of repeated measurements (three in this study).

A previous study [15] revealed that the change in FTc induced by passive leg raising could discriminate fluid responders with a high AUC of 0.88, whereas FTc without intervention could not predict fluid responsiveness. Therefore, in this study, we hypothesised that the AUC of ΔFTc and FTc-1 were 0.85 and 0.6, respectively. Power analysis was performed as follows: H0: AUC of FTc-1 = 0.6 versus H1: AUC of ΔFTc > 0.6 with α = 0.05 and power = 0.80, estimating that the ratio of patients with and without spinal-anesthesia induced hypotension would be 2:1, referring to a previous study [5]. Based on the power analysis, 35 patients were required. Considering a dropout rate of around 10%, we finally included 40 patients in this study.

All the results were expressed as mean (SD) or median (IQR [range]) unless otherwise indicated. For all the analyses, p-values < 0.05 were considered statistically significant. We performed the statistical analysis using the software of Medcalc version 14.8.1 (MedCalc Software Ltd., Ostend, Belgium) and StatFlex version 6.0 (Artech. Co., Ltd., Osaka, Japan).

Results

Patient characteristics and perioperative data

In this study, 43 patients were assessed for eligibility. Of those, 3 patients were excluded (declined to participate: n = 2, non-reassuring fetal status: n = 1). No patient was excluded due to inadequate sensory levels. Finally, 40 patients were analysed; of those, 26 (65%) developed spinal anesthesia-induced hypotension. Patients were divided into two groups according to the incidence of hypotension after spinal anesthesia (non-hypotension and hypotension groups). Patient characteristics and perioperative data in both groups are shown in Table 1. There were no differences between the two groups except for the intraoperative dose of vasoactive drugs.

Hemodynamic data in non-hypotension and hypotension groups

Table 2 shows the hemodynamic data in non-hypotension and hypotension groups. Among the baseline hemodynamic variables, baseline SV in the non-hypotension group was significantly higher than that in the hypotension group (P < 0.001). The change in SV induced by the Trendelenburg position was significantly lower than that in the hypotension group (− 0.7 vs 9.5%, P < 0.001). The onset time and duration of hypotension in the hypotension group were 4.0 ± 2.2 and 5.9 ± 3.9 min, respectively.

Corrected flow time in the carotid artery

There were significant differences between the non-hypotension and hypotension groups in baseline FTc-1 and FTc-2. ΔFTc was significantly higher in the hypotension group than that in the non-hypotension group (12.6 vs 2.5%, P < 0.001). As shown in Fig. 1a, FTc-1 was not significantly correlated with SV at baseline (P = 0.209), whereas there was a significant correlation between ΔFTc and ΔSV (r = 0.534 (95% CI: 0.267–0.725), P < 0.001) (Fig. 1b). Additionally, ΔFTc was significantly correlated with both the duration of hypotension and number of doses of vasoactive drugs before delivery (r = 0.641 (95% CI: 0.411–0.794) and 0.613 (95% CI: 0.373–0.777) respectively, P < 0.001 for both) (Supplemental Fig. 3a and b, respectively).

The reproducibility of FTc was analysed by intraclass correlation coefficient. The intraclass correlation coefficient was

Table 1 Patient characteristics and perioperative data in non-hypotension and hypotension groups

Factor	Non-hypotension (n = 14)	Hypotension (n = 26)	P value
Age (years)	32.9 (4.3)	34.7 (5.8)	0.345
Height (cm)	157.9 (6.9)	158.7 (4.9)	0.685
Weight (kg)	65 (13.4)	68.6 (11.1)	0.383
BMI (kg/m^2)	26.1 (13.4)	27.2 (4.4)	0.460
Gestational age (weeks)	38 [38–38]	38 [37–38]	0.750
Indication for cesarean delivery			
Threatened rupture of the uterus	8	18	0.481
Breech presentation	4	4	
Placenta previa	2	2	
After open surgery	9	2	
Sensory block level	T4 [T3-T5]	T4 [T2-T5]	0.639
Delivery time (min)			
From the start of anesthesia	20.9 (5.1)	22.8 (5.5)	0.296
From the start of operation	9.5 (2.9)	10.8 (4.3)	0.328
Apgar 1 min	8 [7, 8]	8 [8, 9]	0.176
Apgar 5 min	9 [9, 9]	9 [8, 9]	0.195
Blood loss (mL)	770 [630–1190]	855 [640–1250]	0.379
Fluid volume (mL)			
Before delivery	600 [500–700]	600 [500–650]	0.414
Total	1325 [1200–1500]	1275 [1150–1400]	0.550
Vasopressor			
Ephedrine(mg)			
Before delivery	–	5 [0–10]	–
Total	0 [0–5]	10 [5–15]	0.003*
Phenylephrine(μg)			
Before delivery	–	150 [100–300]	
Total	125 [0–400]	350 [250–600]	– 0.014*

Data are presented as mean (SD) or median [IQR]

BMI body mass index

*Statistically significant (P < 0.05)

0.896 and 0.825 for FTc-1 and FTc-2, respectively, which indicated good producibility of FTc measurements.

Reliability of ΔFTc in predicting the incidence of hypotension after spinal anesthesia

The ROC curves to assess the ability of FTc-1, FTc-2, and ΔFTc to predict the incidence of hypotension after spinal anesthesia are shown in Fig. 2. The AUC for FTc-1, FTc-2, and ΔFTc were 0.591 (95% CI: 0.424–0.743) (P = 0.380), 0.742 (95% CI: 0.579–0.867) (P = 0.004), and 0.882 (95% CI: 0.740–0.962) (P < 0.001) respectively, indicating that ΔFTc was the best predictor among these three parameters (P = 0.001 for FTc-1 versus ΔFTc, P = 0.172 for FTc-2 versus ΔFTc). The best threshold for ΔFTc was 6.4% (sensitivity: 80.8% (95% CI: 53.8–96.2), specificity: 85.7% (95% CI: 42.9–100.0)).

Grey-zone analysis for ΔFTc

Figure 3 indicates the grey zone for ΔFTc. The grey zone for ΔFTc was from 2.4 to 10.1%, including 15 patients (38%). The number of patients included in the grey-zone for ΔFTc was significantly fewer compared to those for FTc-1 and FTc-2 (29 patients for FTc-1 [P = 0.002 versus ΔFTc], 26 patients for FTc-2 [P = 0.014 versus ΔFTc]).

Kaplan–Meier analysis regarding the duration from anesthetic induction to the onset of hypotension

Figure 4 shows the duration from anesthetic induction to the onset of hypotension in patients with lower ΔFTc (< 6.4%)

Table 2 Haemodynamic data in non-hypotension and hypotension groups

Factor	Non-hypotension (n = 14)	Hypotension (n = 26)	P value
Baseline			
SAP (mmHg)	132.3 (9.6)	127.5 (10.0)	0.162
DAP (mmHg)	79.0 (7.6)	77.9 (8.2)	0.686
MAP (mmHg)	98.9 (8.2)	96.3 (8.5)	0.371
HR (bpm)	76.4 (14.0)	76.8 (12.6)	0.924
SV (mL)	97.4 (19.7)	76.8 (11.6)	< 0.001*
SVV (%)	9.5 (3.1)	12.3 (4.7)	0.062
ΔSV (%)	− 0.7 (2.2)	9.5 (10.8)	< 0.001*
Corrected flow time			
FTc-1 (ms)	322.6 (28.2)	311.7 (18.2)	< 0.001*
FTc-2 (ms)	329.8 (20.0)	350.2 (23.5)	< 0.001*
ΔFTc (%)	2.5 (4.2)	12.6 (7.9)	< 0.001*
Minimum blood pressure after spinal anaesthesia			
SAP (mmHg)	115.7 (9.0)	83.2 (17.5)	< 0.001*
DAP (mmHg)	67.9 (7.8)	51.6 (6.9)	< 0.001*
MAP (mmHg)	83.8 (7.7)	61.5 (7.5)	< 0.001*
Hypotension after spinal anaesthesia			
Time to event (min)	–	4.0 (2.2)	
Duration time (min)	–	5.9 (3.9)	–

Data are presented as mean (SD)

SAP systolic arterial pressure, *DAP* diastolic arterial pressure, *MAP* mean arterial pressure, *SV* stroke volume, *SVV* stroke volume variation, *ΔSV* percentage increase in stroke volume by Trendelenburg positioning, *FTc-1* corrected flow time in the carotid artery in the supine position, *FTc-2* corrected flow time in the carotid artery in the Trendelenburg position (15 degrees), *ΔFTc* percent increase in corrected flow time by Trendelenburg positioning

*Statistically significant (P < 0.05)

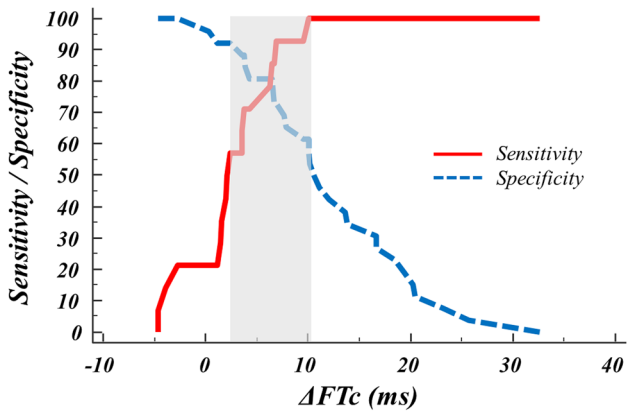

Fig. 3 ΔFTc: Percent changes in the corrected flow time induced by the Trendelenburg position. Grey zone for ΔFTc. The red and blue lines indicate sensitivity and specificity, respectively. The grey zone represents the inconclusive range of ΔFTc

and higher ΔFTc (≥ 6.4%). Patients with higher ΔFTc had a higher incidence of hypotension and a faster onset of hypotension with a statistically significant level (P = 0.022) compared to those with lower ΔFTc.

Discussion

This study investigated the reliability of ΔFTc in predicting the incidence of spinal anesthesia-induced hypotension in cesarean delivery. ΔFTc could predict the occurrence of hypotension with excellent accuracy (AUC: 0.882, P < 0.001). The best threshold for ΔFTc was 6.4% (sensitivity: 80.8%, specificity: 85.7%). Considering the results of the ROC and grey-zone analyses, ΔFTc was a better predictor compared to FTc-1 and FTc-2. Our hypothesis

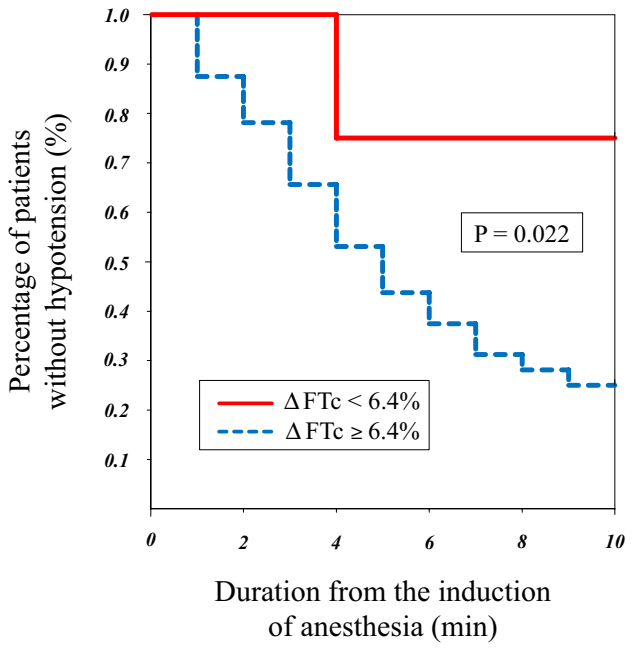

Fig. 4 ΔFTc: Percent changes in the corrected flow time induced by the Trendelenburg position. Time from anesthetic induction to the onset of hypotension analysed by the Kaplan–Meier method. Blue dotted line: Higher ΔFTc group (ΔFTc ≥ 6.4%). Red solid line: Lower ΔFTc group (ΔFTc < 6.4%)

that the intervention of change of body position (Trendelenburg position) could improve the predictability of FTc was confirmed.

Predicting the occurrence of spinal-anesthesia-induced hypotension in cesarean delivery is a major concern for anesthesiologists. Previous studies have investigated the predictability of various hemodynamic variables, including pleth variability index [5, 13], perfusion index [12], and heart rate variability [1, 22]. Pleth variability index showed good predictability with an AUC of ROC curve of 0.791 [5]. Heart rate variability could also forecast the incidence of hypotension after spinal anesthesia with a statistical significance (P = 0.046, odds ratio 1.478) [22]. However, these indices require specific hemodynamic monitors and are not available everywhere. Therefore, non-invasive and emerging techniques to predict hypotension are required.

Ultrasound imaging has been widely available as an emerging method for assessing patients' volume status, especially in the perioperative period. It is commonly used for perioperative hemodynamic management due to its good reproducibility and non-invasiveness. The measurement of diameter in the inferior vena cava is frequently used to discriminate fluid responders in critically ill patients [23], which is difficult to perform during the surgery because of its inaccessibility. Instead, ultrasound imaging in the carotid artery is available for the intraoperative hemodynamic assessment. The carotid artery is easy to access during major surgery, and its flow is quickly measurable by an ultrasound Doppler. In particular, FTc has been recognised as a useful variable to evaluate fluid responsiveness [10]. Previous studies [24, 25] have shown that fluid loading induced a substantial increase in FTc in hypovolaemic status. Furthermore, changes in FTc induced by hemodynamic interventions were suggested to be reliable as a predictor of fluid responsiveness. Barjaktarevic et al. [15] investigated the ability of FTc to discriminate fluid responders in patients with undifferentiated shock. They revealed that changes in FTc induced by passive leg raising manoeuvre could predict fluid responsiveness with excellent reliability (AUC by an ROC analysis: 0.88). FTc can also be used even in patients with spontaneous breathing. Kim et al. [26] assessed the reliability of FTc in predicting fluid responsiveness under spontaneous breathing. The absolute value of FTc (threshold: 349.4 ms) showed an excellent accuracy in evaluating fluid responders (AUC: 0.842, sensitivity: 72.7%, specificity: 83.9%).

Recently, the usefulness of ultrasound imaging in the carotid artery has been investigated in pregnant women. A previous study by Xu et al. [27] examined whether FTc could serve as a predictor of fluid responsiveness in parturients undergoing cesarean delivery. They revealed that FTc could show a predictive utility for fluid responsiveness (threshold: 313.8 ms, sensitivity: 77%, specificity: 90%, AUC under the ROC curve: 0.846). Multivariate logistic regression analysis also revealed that FTc was an independent factor associated with fluid responsiveness (P value: 0.001, odds ratio: 1.191). Kim et al. [4] investigated the predictability of preoperative FTc for spinal anesthesia-induced hypotension in patients undergoing cesarean delivery. In this study, 35 patients were included, and hypotension occurred in 21 patients (60%). The FTc values were calculated in two ways (Wodey's and Bazett's formulas). FTc calculated in both formulas showed excellent predictability with an AUC higher than 0.9. The results of this study were inconsistent with those of our study. In our study, FTc-1 (FTc values measured in the supine position) could not predict the incidence of hypotension after spinal anesthesia, whereas FTc-2 (FTc values in the Trendelenburg position) and ΔFTc could. The reasons for this discrepancy may be the following: first, in this study, continuous blood pressure monitoring was performed, which enabled us to obtain more accurate data for detecting hypotension; second, there were several methodological differences between the previous study [4] and ours, including inclusion criteria, volume loading after spinal anesthesia, and the definition of hypotension. These differences may have enabled FTc-2 and ΔFTc (not FTc-1) to predict hypotension in this study. Our study indicated that FTc-1 was not significantly correlated with SV at baseline, while there was a significant correlation between ΔFTc and

ΔSV. Considering the correlations between FTc and SV shown in this study, FTc-1 might not be a surrogate for SV.

As indicated in previous papers [8, 28], considering the weakness of dynamic indices, they should not be used as absolute values. The relative changes of dynamic indices induced by hemodynamic interventions should be evaluated. In a previous study [15] investigating the predictability of FTc for fluid responsiveness, the changes in FTc induced by passive leg raising could discriminate fluid responders (AUC: 0.88), whereas, regarding FTc in the supine position, there was no significant difference between responders and non-responders (P = 0.86). Kimura et al. [10] also revealed that hemodynamic intervention (lung recruitment maneuver) could improve the predictability of FTc for fluid responsiveness. In the previous study by Kim et al.[4], pre-anaesthetic FTc alone was evaluated, and hemodynamic interventions were not performed. Considering the variability of FTc in each patient, some interventions against FTc should be performed. Our research uniquely incorporates positional changes as an intervention to enhance the predictive accuracy of non-invasively measured FTc. This approach of manipulating body posture to potentially improve the predictive power of FTc has not been explored in previous studies. To assess fluid responsiveness as well as the incidence of hypotension using FTc, some hemodynamic interventions, including passive leg raising and position changing, should be considered, as shown in our study.

Our study had a limitation. The ClearSight system was used for continuous blood pressure monitoring, which is not a gold standard method. However, the accuracy of this system in blood pressure measurement during cesarean delivery has already been confirmed [29]. For more accurate measurement, insertion of an invasive arterial line is required, which is too invasive for normal cesarean delivery.

In conclusion, this study demonstrated that ΔFTc could serve as a good predictor of spinal anesthesia-induced hypotension for cesarean delivery. Changes in the corrected carotid flow time induced by the Trendelenburg position were a non-invasive method to assess the hemodynamic changes after spinal anesthesia accurately. Additionally, this method was technically easy to perform without specific hemodynamic monitoring and cannulation into the artery.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00540-023-03293-2.

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Data availability Data will be available upon reasonable request to corresponding author.

Declarations

Conflict of interest Koichi Suehiro has received speaker fees from Edwards Lifesciences and Otsuka Pharmaceutical Factory. Other authors have no conflict of interest.

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