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ORIGINAL RESEARCH

Tricuspid annular plane systolic excursion as a predictor of arterial hypotension induced by spinal anesthesia in cesarean section

Ferdi Gülaştı[1,*], Sevil Gülaştı[2], Eray Çağlayan Çelik[3], Sinem Sarı[1,4]

[1]Department of Anesthesiology and Reanimation, Faculty of Medicine, Adnan Menderes University, 09000 Aydin, Turkey
[2]Department of Cardiology, Faculty of Medicine, Adnan Menderes University, 09000 Aydin, Turkey
[3]Department of Anesthesiology and Reanimation, Aydin Maternity and Child Health Hospital, 09000 Aydin, Turkey
[4]Outcomes Research Consortium, Houston, TX 77001, USA

***Correspondence**
ferdi.gulasti adu.edu.tr
(Ferdi Gülaştı)

Abstract

Background: Severe hypotension is a common complication following spinal anesthesia in cesarean section surgery due to the combined effects of spinal anesthesia and the gravid uterus compressing the inferior vena cava. This study aimed to evaluate the role of tricuspid annular plane systolic excursion (TAPSE) in predicting hypotension after spinal anesthesia in cesarean sections. **Methods**: This observational study included 60 pregnant women aged 20 to 35 years with an American Society of Anesthesiologists physical status of Class I scheduled for elective cesarean section under spinal anesthesia who provided informed consent. Preoperative TAPSE was assessed using transthoracic echocardiography. Intraoperative hemodynamic parameters were recorded, with non-invasive blood pressure measurements taken every two minutes. **Results**: TAPSE was an important predictor of hypotension following spinal anesthesia with the optimal cut-off value being $\leq$2.59 cm, with a sensitivity of 66.7% and a specificity of 73.9%. **Conclusions**: A TAPSE value of $\leq$2.59 cm, measured preoperatively using transthoracic echocardiography, was predictive of intraoperative hypotension in this study. Preoperative TAPSE assessment shows promise for predicting intraoperative hypotension, optimizing fasting durations, and guiding fluid management. To ensure the accuracy of these findings, additional studies are needed. **Clinical Trial Registration**: The study was registered with ClinicalTrials.gov as NCT05874687, Date: 25 May 2023.

Keywords

Tricuspid annular plane systolic excursion (TAPSE); Cesarean section; Spinal anesthesia; Hypotension; Volume

1. Introduction

When a pregnant woman is in the supine position, the uterus can exert pressure on the inferior vena cava (IVC), reducing venous return and leading to hypotension. This condition, known as Aortocaval Compression Syndrome, occurs in approximately 8–10% of pregnant women, with onset as early as the 16th week of pregnancy [1, 2]. During cesarean section (CS) under spinal anesthesia (SA), several factors including supine hypotension syndrome, decreased sympathetic tone, reduced systemic vascular resistance, and vasodilation below the level of block further increase the risk of hypotension [3]. This condition is highly prevalent, occurring in nearly 70% of cases, and can result in adverse maternal and fetal outcomes, such as maternal nausea, vomiting, dyspnea, neonatal depression with low Apgar scores, and fetal acidosis [4–10]. Given the potential complications, the prediction of maternal hypotension is of significant clinical importance.

In order to predict hypotension after spinal anesthesia in a CS, various studies have explored different measurements, including the internal jugular vein collapsibility index, inferior vena cava (IVC) collapsibility, transverse diameter of right common femoral vein, carotid flow, and peripheral perfusion index [11–14]. However, the search continues for a practical, easily measurable, and reliable predictor of hypotension following spinal anesthesia in CS. While IVC collapsibility index (IVC-CI), primarily reflects intravascular volume status, it does not account for the peripheral distribution of blood volume reaching the heart. Similarly, the perfusion index provides insight into peripheral blood distribution but does not directly assess cardiac function. The tricuspid annular plane systolic excursion (TAPSE), on the other hand, is influenced not only by the systolic power of the right ventricle (RV) but also by venous return, making it a more comprehensive indicator. TAPSE is thought to be a strong predictor of hypotension as it reflects both cardiac function and circulatory dynamics. Additionally, its ease of application and minimal operator dependency make it a promising and practical tool for clinical use.

TAPSE is a widely used parameter for evaluating right ventricular (RV) systolic function. It provides a simple and

reliable measurement of apex-basal shortening, offering valuable insight into global RV function. Compared to other RV function assessments, TAPSE is less dependent on optimal image quality and easier to measure, making it a practical tool in clinical settings [15]. Studies conducted in recent years showed that TAPSE is not only a marker of RV function but also positively correlates with intravascular volume status [16].

Given this association, TAPSE may serve as a predictor of post-spinal hypotension in CS, particularly in patients without pre-existing cardiac disease. The aim of this study was to evaluate TAPSE as a potential screening tool for identifying patients at risk of developing hypotensive events following spinal anesthesia in CS.

2. Materials and methods

This study was conducted with approval from the Non-Invasive Clinical Research Ethics Committee of Adnan Menderes University (Protocol No: 2023/185, No: 17, approved on 24 May 2023). The study took place between June 2023 and October 2023, and was registered in the ClinicalTrials.gov database on 25 May 2023 (Principal investigator: Ferdi Gülaştı), (NCT05874687). The study was conducted in accordance with the principles set forth in the Declaration of Helsinki, and written informed consent was acquired from all participants prior to the commencement of any procedures.

Transthoracic echocardiography (TTE) measurements were performed in the preoperative observation room on patients scheduled for CS under spinal anesthesia (SA). Echocardiographic evaluation was performed 10–30 minutes before spinal anesthesia was administered in the operating room, and hemodynamic parameters were recorded intraoperatively. No preoperative hydration was administrated to the patients. After echocardiographic evaluation, spinal anesthesia was performed in the operating room, and hemodynamic parameters were recorded. Patients were classified into two groups: those who developed hypotension and those who did not. The predictive value of preoperative TAPSE for spinal anesthesia-induced hypotension in CS was then statistically analyzed.

2.1 Study participants

This study included adult pregnant women aged 20 to 35 years who were scheduled for elective CS under subarachnoid block. Eligible participants had a Body Mass Index (BMI) of 20–35 kg/m^2, a Class II of American Society of Anesthesiologists (ASA) physical status classification, and a singleton pregnancy between 37 and 42 weeks of gestation. Written informed consent was obtained from all participants. Exclusion criteria were a TAPSE value $\leq$1.7 cm, known heart disease, arrhythm, multiple pregnancies, expected massive intraoperative blood loss (such as placenta accreta or placenta previa), severe pulmonary hypertension, wall motion abnormalities, severe valvular disease, and cardiomyopathy. Patients with emergency conditions requiring urgent surgical intervention, and those with uncontrolled systemic comorbidities (*e.g.*, respiratory, renal conditions) were excluded from the study.

2.2 Transthoracic echocardiography

Transthoracic echocardiography (TTE) was performed on all patients in the left lateral decubitus position using a Toshiba Aplio 300 Echocardiography Device (Toshiba Aplio 300, Toshiba Medical System Corporation, Tokyo, Japan). Echocardiographic evaluation was performed by a single investigator. For accuracy, all parameter values were calculated as the average of five cardiac cycle measurements. The measurements were carried out in accordance with the American Society of Echocardiography guidelines. M-Mode, 2-Dimensional (2D) images, color Doppler, pulse Doppler, continuous wave Doppler, and tissue Doppler measurements were obtained from all participants who adhered to standard echocardiography protocols.

Fractional area change and TAPSE were utilized to assess Right Ventricular (RV) systolic function. To evaluate RV diastolic function, Tricuspid E and A wave velocities and the E/A ratio were measured. TTE was conducted on all patients by a single clinician. In the apical four-chamber view, TAPSE values were assessed by placing an M-mode cursor across the tricuspid annulus and measuring the longitudinal displacement at peak systole. The measurements were then averaged over five cardiac cycles for recording (Fig. 1).

2.3 Spinal anesthesia

After TTE measurements, spinal anesthesia was administered at the L3–4 or L4–5 intervertebral space, identified using an imaginary line between the iliac crests. A 25-gauge spinal needle was used in the sitting position to inject 2.1 mL of 0.5% hyperbaric bupivacaine into the subarachnoid space. Simultaneously, all patients received Ringer's lactate solution (10 mL/kg over 15 minutes) for fluid loading. Surgery was started when the sensory block reached the T6 level. Blood pressure was measured every 2 minutes during the first 15 minutes. Hypotension, defined as a decrease in mean arterial pressure (MAP) of more than 30% from baseline, a systolic pressure drop below 90 mmHg, or a MAP of 65 mmHg, was treated with ephedrine and an isotonic balanced crystalloid solution (250 mL bolus). Bradycardia, defined as a Heart Rate of less than 50 beats per minute, was treated with intravenous atropine (0.5 mg).

2.4 Sample size

The sample size was determined using the G*Power software (Version 3.1.9.4; Heinrich-Heine-Universitat Dusseldorf, Dusseldorf, NRW, Germany). The study "Gülaştı F., Gülaştı S., Sarı S. (2023), Tricuspid annular plane systolic excursion to predict arterial hypotension caused by general anesthesia induction, Minerva Anestosilogica" was used as the reference. The effect size was calculated based on the TAPSE means between patients with and without hypotension, and was found to be 2.60 using the *t* test. To achieve sufficient statistical power, the effect size was set as 0.80, with a power of 80%, a 5% margin of error, and a 10% dropout rate. Based on these parameters, a total of 59 patients were planned for inclusion in the study.

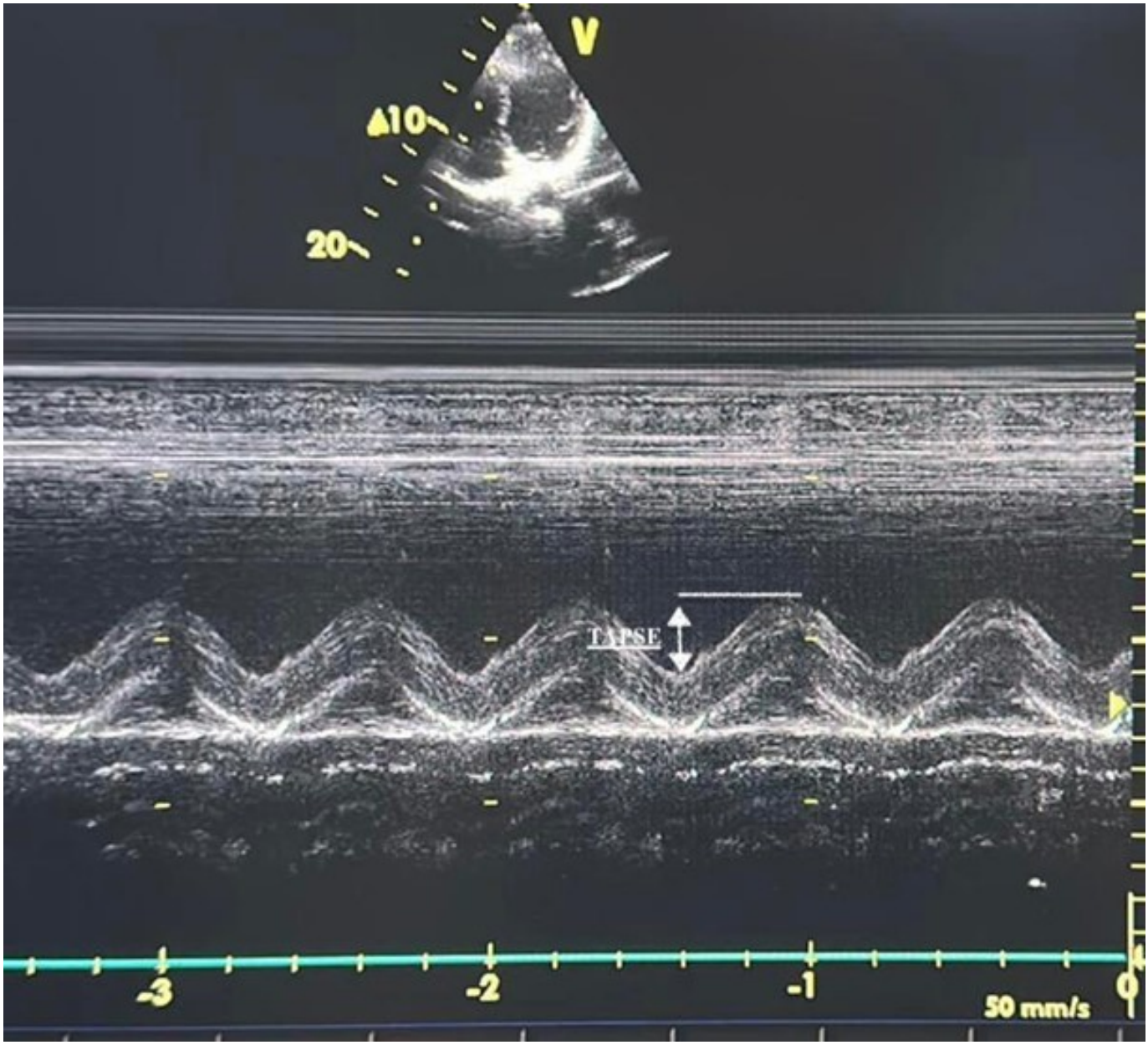

FIGURE 1. TTE image of TAPSE. TAPSE: tricuspid annular plane systolic excursion.

2.5 Statistical analysis

Continuous variables were presented as mean ± standard deviation (SD) or median (range) based on normality of their distribution. Categorical variables were summarized as counts (n) and percentages (%). The normality of continuous variables was tested using the Shapiro-Wilk, Kolmogorov-Smirnov, and Anderson-Darling tests. Groups with normally distributed numerical variables were compared using the independent samples *t*-test, whereas the Mann-Whitney U test was applied to variables that did not meet normal distribution assumptions. Pairwise comparisons over time were performed using the Durbin-Conover test to identify significant intervals. The Pearson Chi-Square and Fisher's Exact tests were applied for categorical variables in 2 × 2 tables, and the Fisher-Freeman-Halton test was used for R × C contingency tables.

Receiver Operating Characteristic (ROC) analysis was conducted to determine the cut-off value of TAPSE for predicting hypotension, using the Youden Index and the Delong Method. All statistical analyses were performed using the Jamovi (Version 2.2.5.0) and JASP (Version 0.16.1). Statistical significance was defined as a p-value < 0.05.

3. Results

Sixty patients were initially enrolled in the study. However, one patient was excluded due to conversion to general anesthesia intraoperatively. The final analysis included 36 patients in the hypotension group and 23 patients in the non-hypotension group (Fig. 2). The two study groups were comparable in terms of comorbidities ($p > 0.05$) (Table 1). The average birth weight of newborns was 3298.7 ± 429.7 g in the non-hypotension group and 3237.0 ± 371.1 g in the hypotension group.

Demographic and laboratory data were comparable between the two groups ($p > 0.05$) (Table 2), including age, height, weight, BMI, and neonatal birth weight (Table 2).

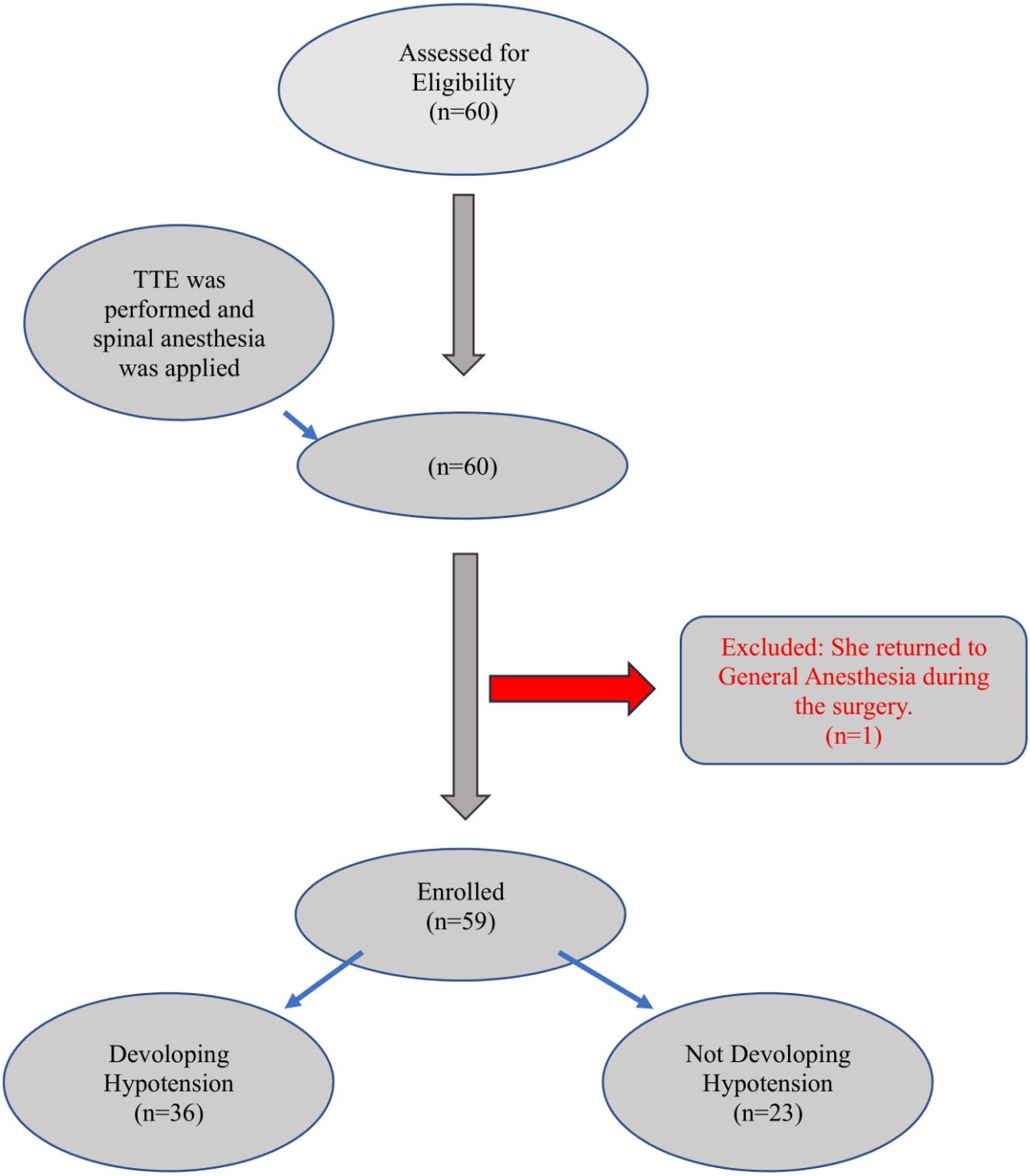

FIGURE 2. Flow chart diagram for patient selection. TTE: Transthoracic echocardiography.

TABLE 1. Comorbidities of the patients with and without hypotension.

	Hypotension		*p*
	Without (n = 23)	With (n = 36)	
Diabetes mellitus	0 (0.0)	2 (5.6)	0.516
Hypothyroid	1 (4.3)	1 (2.8)	1.000
Other	2 (8.7)	5 (13.9)	0.694

TABLE 2. Demographic and laboratory data of the patients with and without hypotension.

	Hypotension						*p*
	Without (n = 23)			With (n = 36)			
	Mean ± SD	Median	Min–Max	Mean ± SD	Median	Min–Max	
Age (yr)	27.2 ± 3.4	27.0	21.0–35.0	27.8 ± 4.5	27.5	20.0–35.0	0.584
ASA physical status class	2.0 ± 0.0	2.0	2.0–2.0	2.0 ± 0.0	2.0	2.0–2.0	1.000
Length (cm)	164.1 ± 6.0	165.0	152.0–173.0	162.0 ± 7.4	162.0	150.0–175.0	0.269
Weight (kg)	74.3 ± 11.9	72.0	57.0–94.0	79.5 ± 13.1	80.0	50.0–105.0	0.128
WBC ($\times 10^3/\mu L$)	10.2 ± 2.2	9.7	6.7–15.4	10.8 ± 2.7	10.2	5.7–17.2	0.393
HB (g/dL)	16.6 ± 24.6	11.7	8.5–124.0	15.5 ± 22.4	11.8	8.4–136.0	0.514
Platelet ($\times 10^3/\mu L$)	229.6 ± 66.2	237.0	157.0–309.0	214.1 ± 82.4	216.0	225.0–361.0	0.526
AST (U/L)	18.9 ± 5.9	17.5	11.0–35.0	18.1 ± 8.4	16.5	10.0–52.0	0.346
ALT(U/L)	12.4 ± 5.4	11.5	5.0–25.0	12.1 ± 4.6	12.0	7.0–27.0	0.961
Urea (mg/dL)	7.5 ± 3.0	6.7	3.5–12.5	6.5 ± 1.9	6.4	3.9–10.2	0.290
Creatinine (mg/dL)	0.5 ± 0.1	0.5	0.4–0.6	0.5 ± 0.1	0.5	0.3–0.9	0.336
APTT (s)	24.6 ± 1.6	24.2	21.7–27.6	24.2 ± 5.7	25.5	2.7–30.3	0.237
INR	0.9 ± 0.1	0.9	0.8–1.0	1.1 ± 0.6	0.9	0.8–4.1	0.067
Neonatal body weight (g)	3298.7 ± 429.0	3250.0	2725.0–4145.0	3237.0 ± 371.1	3157.5	2725.0–3970.0	0.656

ASA: American Society of Anesthesiologists; WBC: White Blood Count; HB: hemoglobin; AST: Aspartate Aminotransferase; ALT: Alanine Aminotransferase; APTT: activated partial thromboplastin time; INR: international normalized ratio; SD: standard deviation; Min–Max: Minimum–Maximum.

Intraoperative findings comparing the groups are summarized in Table 3. No significant differences were observed between the groups in terms of baseline (0th minute) hemodynamic and respiratory parameters (Table 3). Significant differences in systolic, diastolic, and mean arterial pressure values were found at the 4th and 6th minutes ($p < 0.05$) (Table 3). The time-related changes in systolic blood pressure (SBP) and diastolic blood pressure (DBP) values are presented in Fig. 3a,b.

The preoperative TTE parameters for the study participants are outlined in Table 4. TAPSE values were lower in the hypotension group than the non-hypotension group ($p < 0.001$) (Table 4). There was no significant difference in the Left Ventricular Ejection Fraction (LVEF), Tricuspid E, Tricuspid A, tricuspid regurgitation (TR) peak velocity, Right Ventricular end-diastolic area (RVEDA), Right Ventricular end-diastolic volume (RVEDV), Right Ventricular end-systolic area (RVESA) and Right Ventricular end-systolic volume (RVESV) values ($p > 0.05$) (Tables 4,5).

The optimal TAPSE cut-off value for predicting post-spinal hypotension in CS was determined to be $\leq$2.59 cm (Fig. 4). This threshold had a sensitivity of 66.7% and specificity of 73.9%. The Area Under the Curve (AUC) value was 0.749 (95% confidence interval (CI): 0.626–0.872, $p < 0.001$) (Table 4).

4. Discussion

In this study, TAPSE and RV function were evaluated using TTE before CS. The primary hypothesis was that TAPSE could serve as a predictive marker for hypotension following spinal anesthesia in CS. The results demonstrated that a TAPSE value $\leq$2.59 cm could predict hypotension following spinal anesthesia with 66.7% sensitivity.

Hypotension due to spinal anesthesia in cesarean delivery has been reported in 7.4–74.1% of cases [4]. In the present study, the incidence of hypotension was 61%, consistent with the previously reported rates. This hypotension is primarily caused by vasodilation, reduced preload, decreased cardiac output, and a subsequent drop in arterial blood pressure after spinal anesthesia. These effects persist until the pressure on the IVC is relieved after delivery. As a result, maternal and fetal organ hypoperfusion-related complications may arise. Several risk factors contribute to the development of hypotension after spinal anesthesia. In a study by Yao SF *et al.* [12], neonatal birth weight was found to be higher in mothers who developed hypotension following spinal anesthesia for CS [12]. However, in our study, no significant differences in neonatal birth weight was observed between the hypotension and non-hypotension groups.

TAPSE is a widely used echocardiographic parameter and a key indicator of RV systolic function. Recent studies suggest that TAPSE is also linked to RV volume [15–18]. It is well known that the aortocaval compression in the supine position, combined with the vasodilatory effects of spinal anesthesia, can lead to a relative hypovolemic condition in full term pregnant women. According to Yao SF *et al.* [12], the diameter of the transverse right common femoral vein can predict hypotension following spinal anesthesia in CS surgeries. Likewise, Xu Z *et al.* [5] showed that the Perfusion Index (PI) could predict hypotension caused by spinal anesthesia in CS surgeries. However, the sensitivities and specificities for

TABLE 3. Hemodynamic parameters of the patients with and without hypotension.

	Hypotension								*p*
	Without (n = 23)				With (n = 36)				
	n	Mean ± SD	Median	Min–Max	n	Mean ± SD	Median	Min–Max	
0. min. pulse (bpm)	23	96.4 ± 12.5	99.0	72.0–116.0	36	95.8 ± 15.8	98.0	60.0–134.0	0.878
0. min. SpO_2*	23	99.2 ± 0.8	99.0	97.0–100.0	36	98.4 ± 1.3	99.0	95.0–100.0	0.015
0. min. SBP (mmHg)	23	128.9 ± 14.9	130.0	105.0–149.0	36	131.1 ± 15.1	129.5	103.0–169.0	0.076
0. min. DBP* (mmHg)	23	74.1 ± 13.2	76.0	53.0–93.0	36	81.0 ± 10.0	81.0	58.0–95.0	0.026
0. min. Mean BP (mmHg)	23	91.7 ± 11.4	94.0	72.0–110.0	36	97.1 ± 9.7	98.0	77.0–123.0	0.059
2. min. pulse (bpm)	23	97.5 ± 19.9	98.0	65.0–164.0	36	116.5 ± 102.5	103.0	56.0–703.0	0.320
2. min. SpO_2	23	99.0 ± 1.2	99.0	96.0–100.0	36	98.5 ± 1.4	99.0	95.0–100.0	0.135
2. min. SBP (mmHg)	23	127.4 ± 16.0	129.0	95.0–154.0	36	124.7 ± 25.9	124.0	71.0–177.0	0.657
2. min. DBP (mmHg)	23	75.7 ± 12.9	80.0	51.0–93.0	36	72.9 ± 25.7	73.0	26.0–154.0	0.294
2. min. Mean BP (mmHg)	23	92.2 ± 13.4	96.0	65.0–113.0	36	91.7 ± 24.7	91.0	46.0–163.0	0.479
4. min. pulse (bpm)	23	131.3 ± 171.3	94.0	74.0–914.0	36	87.7 ± 23.4	86.0	42.0–135.0	0.065
4. min. SpO_2*	23	99.2 ± 1.0	99.0	97.0–100.0	36	98.8 ± 1.1	99.0	96.0–100.0	0.153
4. min. SBP* (mmHg)	23	118.8 ± 16.2	122.0	90.0–146.0	36	95.6 ± 25.2	86.0	61.0–173.0	<0.001
4. min. DBP* (mmHg)	23	72.0 ± 18.8	70.0	51.0–142.0	36	46.3 ± 20.8	41.5	17.0–124.0	<0.001
4. min. Mean BP* (mmHg)	23	85.2 ± 13.9	88.0	63.0–108.0	36	64.4 ± 24.6	57.5	35.0–145.0	<0.001
6. min. pulse* (bpm)	23	94.7 ± 13.6	90.0	72.0–125.0	36	81.4 ± 21.3	78.5	40.0–129.0	0.009
6. min. SpO_2*	23	99.2 ± 1.0	99.0	96.0–100.0	36	98.3 ± 1.3	98.0	96.0–100.0	0.002
6. min. SBP* (mmHg)	23	113.0 ± 12.1	112.0	94.0–138.0	36	95.6 ± 21.5	91.5	59.0–151.0	<0.001
6. min. DBP* (mmHg)	23	66.9 ± 25.9	62.0	45.0–176.0	36	50.1 ± 19.4	48.0	25.0–117.0	0.001
6. min. Mean BP* (mmHg)	23	80.5 ± 13.7	76.0	63.0–111.0	36	67.3 ± 19.7	67.5	38.0–133.0	0.002
8. min. pulse (bpm)	23	92.6 ± 17.4	95.0	70.0–132.0	36	83.6 ± 19.1	81.5	44.0–140.0	0.073
8. min. SpO_2*	23	99.3 ± 0.9	99.0	97.0–100.0	36	98.0 ± 2.4	98.0	87.0–100.0	0.008
8. min. SBP* (mmHg)	23	117.7 ± 15.2	118.0	95.0–144.0	36	104.1 ± 25.2	101.0	13.0–155.0	0.010
8. min. DBP* (mmHg)	23	67.8 ± 24.4	62.0	43.0–161.0	36	56.5 ± 18.7	54.5	25.0–131.0	0.041
8. min. Mean BP* (mmHg)	23	82.0 ± 12.9	81.0	64.0–114.0	36	75.2 ± 23.1	69.0	45.0–152.0	0.045
10. min. pulse (bpm)	23	97.5 ± 13.0	96.0	72.0–121.0	36	92.2 ± 17.0	92.0	50.0–120.0	0.208
10. min. SpO_2*	23	99.1 ± 1.1	99.0	96.0–100.0	36	98.3 ± 1.9	98.0	90.0–100.0	0.023
10. min. SBP (mmHg)	23	111.7 ± 25.9	115.0	11.0–145.0	36	111.5 ± 19.5	107.5	71.0–160.0	0.437
10. min. DBP* (mmHg)	23	65.9 ± 20.0	61.0	39.0–140.0	36	58.0 ± 20.7	54.0	32.0–151.0	0.053
10. min. Mean BP* (mmHg)	23	81.1 ± 13.6	79.0	60.0–124.0	36	78.8 ± 27.9	71.5	45.0–186.0	0.084

TABLE 3. Continued.

	Hypotension								*p*
	Without (n = 23)				With (n = 36)				
	n	Mean ± SD	Median	Min–Max	n	Mean ± SD	Median	Min–Max	
12. min. pulse (bpm)	23	97.2 ± 16.9	92.0	72.0–139.0	36	92.9 ± 16.9	92.5	59.0–123.0	0.351
12. min. SpO_2*	23	99.0 ± 1.3	100.0	96.0–100.0	36	98.3 ± 1.5	98.0	95.0–100.0	0.027
12. min. SBP (mmHg)	23	117.2 ± 15.5	118.0	91.0–154.0	36	113.3 ± 18.3	114.0	81.0–157.0	0.398
12. min. DBP (mmHg)	23	55.9 ± 9.0	55.0	36.0–74.0	36	57.6 ± 19.2	55.5	34.0–142.0	0.858
12. min. Mean BP (mmHg)	23	81.1 ± 22.6	74.0	63.0–177.0	36	76.4 ± 22.0	71.0	48.0–169.0	0.228
14. min. pulse (bpm)	23	92.6 ± 11.2	90.0	73.0–116.0	36	93.8 ± 18.0	92.0	52.0–139.0	0.749
14. min. SpO_2*	23	99.1 ± 1.2	100.0	96.0–100.0	36	98.3 ± 1.6	98.5	93.0–100.0	0.029
14. min. SBP (mmHg)	23	113.8 ± 15.5	111.0	81.0–156.0	36	111.4 ± 18.7	115.0	73.0–158.0	0.611
14. min. DBP (mmHg)	23	57.2 ± 12.0	54.0	43.0–96.0	36	60.5 ± 29.1	55.0	29.0–186.0	0.756
14. min. Mean BP (mmHg)	23	81.0 ± 22.3	75.0	57.0–169.0	36	81.0 ± 32.0	75.0	42.0–181.0	0.437
20. min. pulse (bpm)	22	137.0 ± 207.9	90.0	76.0–1066.0	35	93.3 ± 16.2	94.0	60.0–126.0	0.922
20. min. SpO_2*	22	99.0 ± 1.3	99.0	95.0–100.0	35	98.1 ± 1.6	98.0	93.0–100.0	0.022
20. min. SBP (mmHg)	22	110.0 ± 18.4	107.0	81.0–168	34	112.6 ± 15.9	117.0	76.0–151.0	0.075
20. min. DBP (mmHg)	22	48.7 ± 15.7	44.0	25.0–91.0	34	57.6 ± 29.1	51.0	26.0–165.0	0.066
20. min. Mean BP (mmHg)	22	68.0 ± 14.0	64.5	50.0–111.0	34	70.4 ± 10.2	71.0	44.0–85.0	0.068
30. min. pulse (bpm)	17	94.8 ± 14.2	96.0	69.0–113.0	27	92.4 ± 11.8	93.0	73.0–117.0	0.553
30. min. SpO_2	17	98.9 ± 1.1	99.0	97.0–100.0	27	98.1 ± 1.6	98.0	95.0–100.0	0.083
30. min. SBP (mmHg)	17	110.0 ± 14.9	105.0	93.0–155.0	27	115.5 ± 15.6	113.0	80.0–151.0	0.111
30. min. DBP (mmHg)	17	55.1 ± 12.0	55.0	36.0–87.0	27	59.4 ± 20.4	53.0	34.0–139.0	0.571
30. min. Mean BP (mmHg)	17	71.9 ± 11.6	69.0	55.0–104.0	27	77.3 ± 22.8	72.0	52.0–174.0	0.385
40. min. pulse (bpm)	11	94.8 ± 12.5	98.0	72.0–110.0	15	88.6 ± 12.6	89.0	70.0–115.0	0.224
40. min. SpO_2	11	99.0 ± 1.0	99.0	97.0–100.0	15	98.1 ± 1.6	98.0	95.0–100.0	0.119
40. min. SBP (mmHg)	11	117.7 ± 16.4	117.0	97.0–156.0	15	117.7 ± 18.0	112.0	97.0–165.0	0.999
40. min. DBP (mmHg)	11	66.7 ± 32.0	55.0	44.0–154.0	15	54.9 ± 18.9	49.0	34.0–99.0	0.264
40. min. Mean BP (mmHg)	11	75.9 ± 11.2	73.0	58.0–99.0	15	79.3 ± 33.0	70.0	56.0–185.0	0.500

*SpO_2: Peripheral Capillary Oxygen Saturation; SBP: systolic blood pressure; DBP: diastolic blood pressure; BP: blood pressure; SD: standard deviation; Min–Max: Minimum–Maximum. *: student t test.*

FIGURE 3. Blood pressure variations during surgery in patients. (a) Systolic blood pressure variations during surgery in patients with and without hypotension. (b) Changes in mean blood pressure measurements of surgery in patients with and without hypotension.

TABLE 4. A comparison of echocardiographic parameters of patients with hypotension and without hypotension—ROC analysis results based on the TAPSE.

	Hypotension						*p*
	Without (n = 23)			With (n = 36)			
	Mean ± SD	Median	Min–Max	Mean ± SD	Median	Min–Max	
TAPSE* (cm)	2.7 ± 0.3	2.6	2.2–3.3	2.4 ± 0.3	2.4	1.8–31.0	<0.001
LVEF** (%)	67.5 ± 1.8	68.0	65.0–70.0	65.1 ± 12.4	68.0	65.0–70.0	0.786
Tricuspid E** (cm/s)	70.1 ± 16.3	71.2	7.6–95.7	71.4 ± 7.8	70.1	50.2–97.6	0.957
Tricuspid A* (cm/s)	51.4 ± 8.8	50.8	34.7–76.8	51.1 ± 8.5	50.6	29.2–72.8	0.895
TR peak velocity** (m/s)	2.3 ± 0.8	2.1	1.6–5.1	2.1 ± 0.5	2.0	1.3–3.8	0.095
RV end-diastolic area* (cm^2)	26.6 ± 4.7	25.9	18.4–34.4	27.3 ± 8.0	26.4	3.3–48.2	0.681
RV end-systolic area* (cm^2)	15.4 ± 3.0	16.0	8.8–20.5	17.1 ± 4.4	17.1	9.6–28.3	0.090
RV end-diastolic volume* (mL)	63.2 ± 19.1	70.5	25.4–87.2	65.6 ± 25.9	60.9	22.9–120.9	0.703
RV end-systolic volume** (mL)	29.6 ± 9.0	30.1	11.9–44.0	36.7 ± 16.0	34.1	11.8–85.4	0.144

**Student t test; **Mann Whitney U test. TAPSE: tricuspid annular plane systolic excursion; LVEF: Left Ventricular Ejection Fraction; TR: tricuspid regurgitation; RV: right ventricle; SD: standard deviation; Min–Max: Minimum–Maximum.*

TABLE 5. ROC analysis results based on the TAPSE variable of hypotension following spinal anesthesia for cesarean section.

	AUC	95% GA		Sensitivity	Specificity	*p*
TAPSE (Cut-off = 2.59)	0.749	0.626	0.872	66.7	73.9	0.001

TAPSE: tricuspid annular plane systolic excursion; AUC: Area Under the Curve; GA: Confidence Interval (Gaussian Approximation).

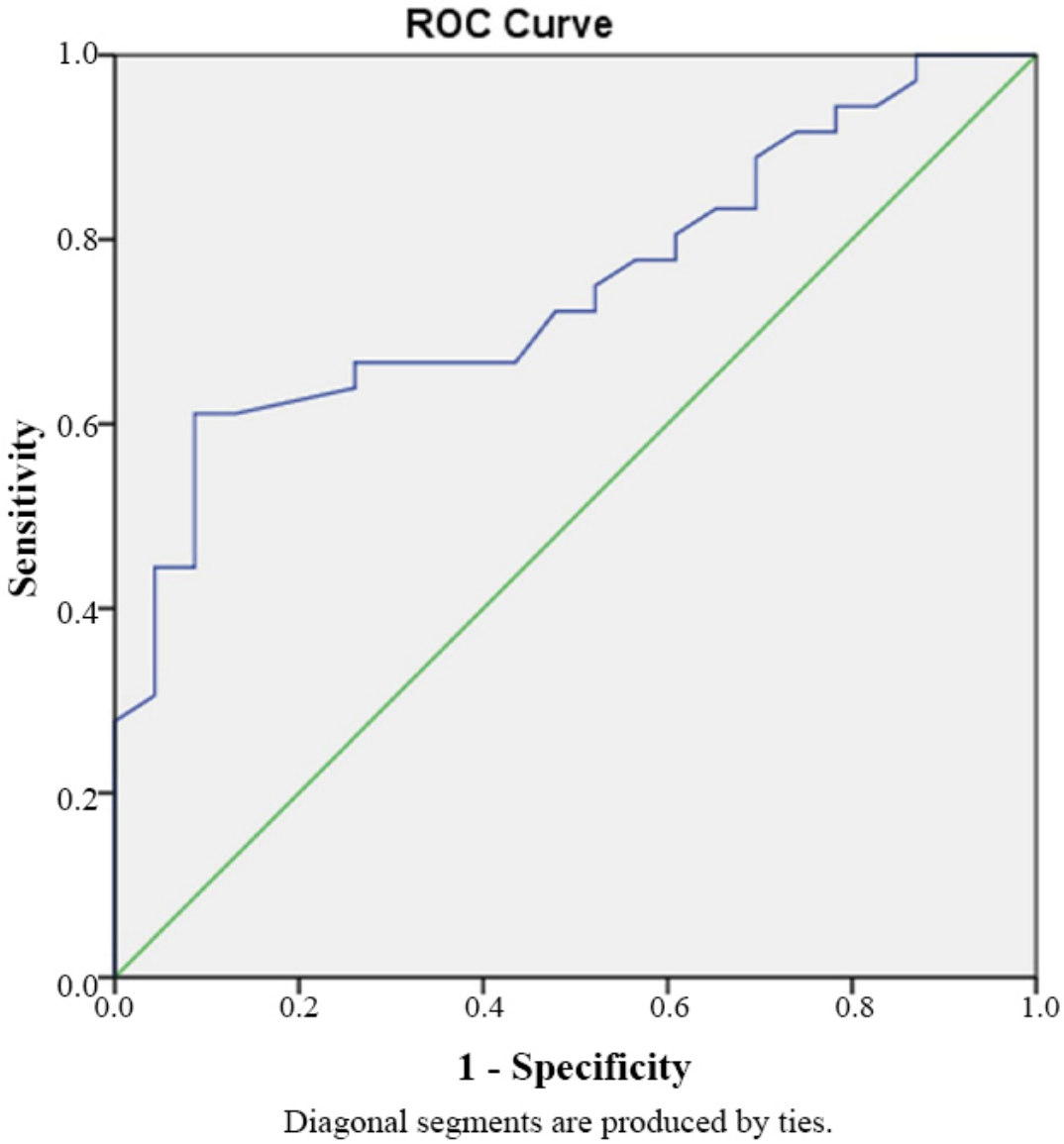

FIGURE 4. The ROC analysis of TAPSE. ROC: Receiver Operating Characteristic.

the Right and Left Toe Perfusion Index were different. In cases where the reliability of the perfusion index is affected, predictive values are still controversial.

Singh Y *et al.* [19] evaluated the Inferior vena cava collapsibility index (IVC-CI) as a predictor, reporting a sensitivity of 60.9% and specificity of 35.5% [19]. In contrast, Nandini MG *et al.* [20] reported that the peripheral perfusion index had a sensitivity of 85.7% and specificity of 60% at a cut-off value of 3.5. A meta-analysis by Hung KC *et al.* [21], which included 12 studies with 2009 patients published between 2017 and 2023, investigated the diagnostic accuracy of the Perfusion Index in predicting perioperative hypotension after spinal anesthesia for CS. The pooled sensitivity and specificity were 0.81 (95% CI = 0.72–0.87) and 0.75 (95% CI = 0.67–0.82), respectively [21]. In our study, TAPSE at a cut-off value of 2.59 cm demonstrated a sensitivity of 66.7% and specificity of 73.9%.

The arterial oxygen saturation (SaO_2) levels were significantly lower at 0, 6, 8, 10, 12, and 14 minutes in the hypotension group compared to the non-hypotension group. This decrease in SaO_2 may be attributed to lower blood pressure and reduced oxygen circulation in the hypotension group when compared to the non-hypotension group at 0, 6, 8, 10, 12, 14 minutes.

TAPSE, an echocardiographic measure, serves as an indicator of right ventricular systolic function by evaluating the longitudinal movement of the lateral tricuspid valve wall during systole. The connection between TAPSE and RV volume load has been investigated in recent studies. Our findings suggest that TAPSE is influenced by RV volume, as it effectively predicts hypotension following spinal anesthesia for CS surgery. A key advantage of TAPSE is its non-invasive nature, making it a simple and user-independent method that does not compromise image quality. Given these advantages, TAPSE may serve as a practical tool for predicting hypotension in CS surgeries under spinal anesthesia.

There were some limitations in our study. The blood pressure was monitored intermittently and non-invasively, with measurements taken every two minutes, which may have influenced the detection of rapid hemodynamic changes. Prophylactic vasoactive drugs were not administrated following spinal anesthesia, as the study aimed to observe the natural course of hypotension without pharmacological intervention. Future interventional studies should include prophylactic vasoactive agents to assess their impact on hypotension prediction. Additionally, as this is the first study to evaluate TAPSE as a predictor of hypotension in CS under spinal anesthesia, further research is necessary to validate these findings and explore its broader clinical applications.

5. Conclusions

In this study, a TAPSE value of $\leq$2.59 cm, measured via TTE before spinal anesthesia, was identified as a predictor of hypotension after spinal anesthesia in CS surgeries. However, further validation studies with larger populations are required to confirm these findings and establish TAPSE as a reliable clinical tool for predicting hypotension in this setting.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

FG—has given substantial contributions to study design, data collection, and analysis, manuscript writing and editing. SG—to study design and manuscript critical revision for important intellectual content. EÇÇ—to data collection. SS—to study design and manuscript critical revision for important intellectual content. All authors read and approved the final version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was conducted with approval from the Non-Invasive Clinical Research Ethics Committee of Adnan Menderes University (Protocol No: 2023/185, No: 17, approved on 24 May 2023). Declaration of Helsinki, and written informed consent was acquired from all participants prior to the commencement of any procedures.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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