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Carotid Doppler ultrasound data as predictors of fluid responsiveness

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ABSTRACT

Objective. To evaluate sensitivity and specificity of carotid Doppler parameters as predictors of fluid responsiveness after heart valve surgery.

Material and methods. A prospective study enrolled 49 adults after elective heart valve surgery. On the first day after surgery, all patients underwent passive leg-raising test (PLR) during mechanical ventilation (MV) and spontaneous breathing (SB). We estimated hemodynamic parameters using prepulmonary thermodilution before and after the test. Carotid Doppler indices such as absolute (ΔFTc, ms) and relative (ΔFTc, %) change in corrected flow time were calculated. Responders had cardiac output (ΔCO) increase >10%.

Results. There was a moderate relationship between ΔCO and ΔFTc during PLR test under MV (r=0.551, p<0.0001) and SB (r=0.510, p<0.0001). Sensitivity and specificity of FTc-based PLR test in mechanically ventilated patients were 87% and 70%, respectively (ΔFTc threshold value 16.4 ms), during spontaneous breathing — 88% and 79%, respectively (ΔFTc threshold value 19.4 ms). Similar results were obtained for the relative increase of ΔFTc (%).

Conclusion. The FTc-based PLR test has moderate sensitivity and specificity for analysis of fluid responsiveness after elective heart valve surgery. Further studies are required to demonstrate significant of carotid Doppler measurements as predictors of fluid responsiveness.

Keywords: *fluid responsiveness, carotid Doppler ultrasound, passive leg raising test, cardiac surgery.*

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Introduction

Patients after heart valve surgery require extended hemodynamic monitoring. Infusion therapy is the first step to optimize cardiac output (CO) and oxygen delivery. Traditionally, we can estimate susceptibility to infusion load using either static indicators (central venous pressure (CVP), pulmonary artery wedge pressure (PAWP), indexed global end-diastolic volume (iGEDV)) or dynamic indicators. In case of dynamic indicators, preload changes occur spontaneously (respiratory variability of stroke volume, pulse arterial pressure) or follow certain intervention (dynamic tests: passive leg raising test (PLR), end expiratory occlusion test). It is reasonably believed that dynamic tests, in particular PLR test, are the most objective [1]. This test is used in routine practice and researches [2]. In clinical practice, there are several methods for assessment of cardiac output. Thermodilution methods are the most accurate, but they require invasive procedures and sterile disposable supplies. Moreover, they are associated with some complications. Transthoracic echocardiography in these patients has some limitations [3]. Therefore, searching for more accessible, but equally accurate and significant methods for assessing susceptibility to infusion load is ongoing. Moreover, current trends are aimed at minimizing the invasiveness of hemodynamic monitoring [4].

Carotid Doppler indices may be used as predictors of fluid responsiveness in dynamic tests [5]. These indicators are volumetric blood flow velocity in common carotid artery (CCA) and corrected flow time. Among static tests, we can distinguish respiratory variability of peak blood flow velocity in CCA. Sensitivity and specificity of these tests have been analyzed in few studies. Moreover, their objectivity varied widely (AUROC 0.55-1, sensitivity and specificity 45-95% and 22-95%, respectively) [5].

The purpose of the study was to evaluate sensitivity and specificity of carotid Doppler parameters as predictors of fluid responsiveness after heart valve surgery.

Material and methods

A single-center observational cohort study was carried out between April 2022 and December 2023 and approved by local ethics committee (protocol No. 4 dated 04/12/2023). The study was conducted in accordance with ethical principles of the Declaration of Helsinki. All patients signed an informed consent. We prospectively included 53 adults who underwent elective on-pump heart valve surgery. Four patients were excluded due to necessary temporary postoperative cardiac pacing. A total of 49 patients were finally included in the study. In-

clusion criteria: informed consent, age over 18 years, elective heart valve surgery for acquired defects. Non-inclusion criteria: previous cardiac surgery, morbid obesity (body mass index > 40 kg/m^2), inclusion in any other previous clinical trial (within 30 days), severe atherosclerosis of lower limb arteries, severe stenosis or occlusion of supra-aortic arteries, left bundle branch block, permanent pacemaker. Exclusion criteria: need for cardiac pacing, severe stenosis or occlusion of CCA. Mean age of patients was 65 years, men-to-women ratio — 29/20. Valve lesions included rheumatism (3 patients), degeneration (44 patients) and infective endocarditis (2 patients). Twenty-four (49%) patients suffered from coronary artery disease. Of these, 18 (37%) ones underwent simultaneous coronary artery bypass grafting. There were the following surgical interventions: isolated aortic valve replacement with or without coronary artery bypass grafting (32 patients), isolated mitral valve repair / replacement with or without coronary artery bypass grafting (10 patients), combined interventions on two valves (6 patients) and three-valve correction (1 patient). Induction of anesthesia implied intravenous fentanyl and propofol. Muscle relaxation for tracheal intubation was provided by intravenous rocuronium bromide, maintenance of myoplegia — bolus intravenous administration of pipecuronium bromide. Anesthesia was maintained by inhalation of sevoflurane and fractional administration of fentanyl. Intraoperative mechanical ventilation was carried out using Aisys CS2 ventilator (GE Healthcare Technologies Inc., USA) with the following parameters: FiO2 50-60% for SpO2 ⩾94%, tidal volume 6-8 ml/kg, PEEP 5-7 cm H_2O, respiratory rate 10—14/min for normocapnia.

Cardiopulmonary bypass was performed using Terumo Advanced Perfusion 1 device (Terumo Cardiovascular Systems Corporation, USA) and SKIPPER membrane oxygenator (Eurosets S.r.l., Italy). We applied standard non-pulsatile perfusion with extracorporeal circuit between the right atrium and ascending aorta under moderate hypothermia (34 °C) (perfusion index 2.5 L / min / m). Myocardial protection was achieved by cold crystalloid cardioplegia (Custodiol). Weaning from CPB was gradual. Reduced left ventricular (LV) contractility according to transesophageal echocardiography data required inotropic support, preserved LV systolic function and arterial hypotension (mean blood pressure <65 mm Hg) — norepinephrine infusion. Norepinephrine was preferable for arterial hypotension in early postoperative period.

Upon admission to intensive care unit, we analyzed fluid responsiveness using passive leg raising test (PLR) at four stages (immediately upon admission, after 4, 18 and 24 hours). At baseline, we elevated the head of functional bed by 35° and measured central hemodynamic parameters including CO. At the second stage, we elevated legs by 35° and lowered head end to horizontal position. Next, we measured central hemodynamic parameters including CO within 2 minutes. In parallel, Doppler assessment of blood flow in CCA was carried out. The patient was sensitive to infusion load (responder) if CO increased by more than 10%. Doses of inotropes/vasopressors and ventilation parameters were the same throughout PLR test. The first two stages were performed under mechanical ventilation, the 3rd and 4th stages — under spontaneous breathing. Central hemodynamics was monitored by using of prepulmonary thermodilution. We estimated central hemodynamics (CVP, PAWP, pulse pressure, dynamics of cardiac output and cardiac index), corrected flow time (absolute difference of ΔFTc in ms and relative difference in percentage). The equation is identical to Bazett's formula for QTc. CCA Doppler ultrasound was performed using GE Healthcare LOGIQ E scanner. Pulse pressure (PP) and its changes were calculated as follows:

$$PP=BP_{syst} - BP_{diast} \quad (1)$$

$$\Delta PP=100\times(PP_{after}-PP_{before})/PP_{before} \quad (2),$$

where BP_{syst} — systolic blood pressure; BP_{diast} — diastolic blood pressure; PP_{before} — pulse pressure before PLR test; PP_{after} — pulse pressure after PLR test.

Measurement of indicators in common carotid artery

A linear 4.5-12.0 MHz sensor was placed near the lower edge of the thyroid cartilage to obtain longitudinal image of the left CCA in B-mode. After that, we placed control volume at the center of lumen approximately 2 cm proximal to CCA bifurcation. A pulsed wave Doppler flow trace through the artery was obtained with angle correction. Cycle time was analyzed considering the interval between heartbeats, systolic flow time — between curve elevation and dicrotic notch **(Fig. 1)**. FTc was calculated through dividing the flow time by square root of cycle time. Mean value of 3 consecutive measurements was entered into the study protocol.

$$FTc=FT(ms)/\sqrt{time\ of\ one\ cycle\ (s)} \quad (3)$$

$$\Delta FTc=FTc_{after\ infusion\ load}-FTc_{before\ infusion\ load} \quad (4)$$

$$\Delta FTc(\%)=100\cdot(FTc_{after\ infusion\ load}- -FTc_{before\ infusion\ load})/FTc_{before\ infusion\ load} \quad (5)$$

We considered duration of ventilation, vasopressor and inotropic support, SOFA scores one day after surgery and ICU-stay.

Statistical analysis

Statistical analysis was carried out using the SPSS 23.0 software. Data distribution was assessed using the Kolmogorov–Smirnov test and the Lilliefors test. We used means and standard deviations for data with normal distribution, median and interquartile range — for non-normal distribution. Correlations were assessed using the Spearman coefficient (r). We used nonpara-

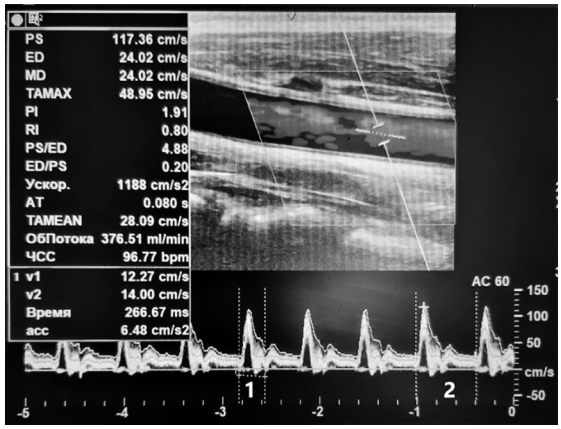

Fig. 1. **Calculation of the corrected flow time (FTc) parameter.**
1 — duration of systolic flow time in the CCA; 2 — duration of the cardiac cycle time.

Table 1. **Demographic, clinical and intraoperative parameters**

Variable	Value
Weight, kg	82±16
Diabetes mellitus, %	22
Coronary artery disease, %	49
Chronic kidney disease, %	49
Chronic obstructive pulmonary disease, %	53
Hypertension stage III, %	76
Preoperative NYHA class of heart failure	2 [2—3]
LV ejection fraction, %	67 [54—71]
Preoperative serum creatinine, μmol/L	98±20
Preoperative hemoglobin, g/L	136±16
Preoperative troponin T, pg/ml	17 [12—22]
Surgery time, min	290 [245—360]
CPB time, min	110 [98—135]
Aortic cross-clamping time, min	76 [63—90]
Intraoperative crystalloid infusion, ml	1500 [1000—1600]
Intraoperative fluid balance, ml	2665±1246

Note. data are presented as relative values (%), mean and standard deviation *M*±*SD*, Me [Q_1—Q_3].

Table 2. **Patient characteristics in postoperative period**

Variable	Value
Crystalloid infusion volume, ml	1500 [1000—2300]
Colloid infusion volume, ml	500 [500—500]
Postoperative blood loss, ml	600 [500—750]
Urine output, ml	1600 [1300—2300]
Overall fluid balance after 1 postoperative day, ml	3470 [2100—4470]
Vasopressor support, %	76
Inotropic support, %	41
Vasopressor support time, hours	15 [5—41]
Inotropic support time, hours	18 [8—29]
Postoperative serum troponin, pg/ml	645 [363—1149]
Paroxysmal AF, *n* (%)	13 (27)
Postoperative packed RBC transfusion, %; ml	27; 644±104
Postoperative packed FFP transfusion, %; ml	35; 1170±335
Postoperative ventilation time, hours	4,5 [2,8—10,1]
SOFA score after 1 postoperative day	3 [3—7]
ICU-stay, hours	44 [39—75]

Note. FFP — fresh frozen plasma; ICU — intensive care unit; SOFA — Sequential Organ Failure Assessment score. Data are presented as mean±standard deviation, median [25th and 75th percentiles].

metric (Mann—Whitney test) and parametric methods (Student's t test). Within-group comparisons between two stages were performed using the Wilcoxon test. Regression logistic and ROC (receiving operator curve) analysis was used to assess predictive value of dynamic tests. Threshold values with maximum sensitivity and specificity were calculated for ΔFTcc, ΔFTcc (%) and PP changes (ΔPP). Differences were significant at $p<0.05$.

Results

Demographic, preoperative clinical characteristics and intraoperative parameters of patients are presented in **Table 1**, postoperative clinical characteristics — in **Table 2**. PLR-based distribution of responders and non-responders to infusion load is presented in **Fig. 2**. Upon admission to ICU, 55% of patients were responders. One day after surgery, only 23% of patients were susceptible to infusion load. Serum troponin T in early postoperative period was 645 [363—1149] pg/ml, while preoperative levels did not exceed threshold values (17 [12—22] pg/ml).

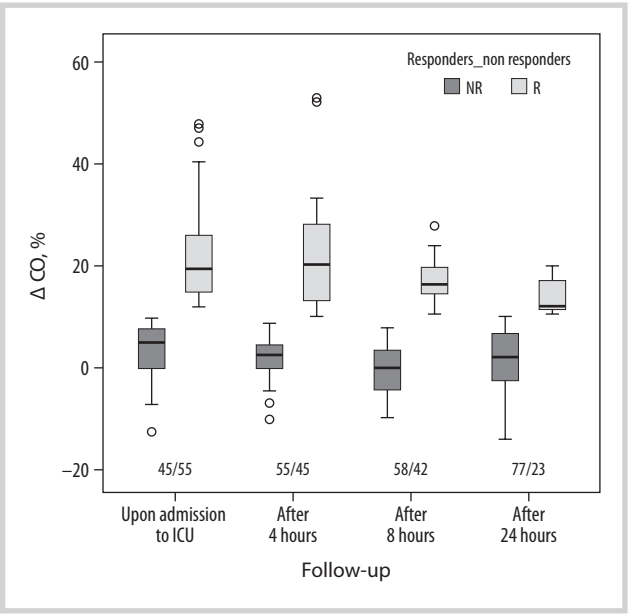

Fig. 2. **Distribution of responders and non-responders at each stage of the study and the value of the increase in CO in each group of patients.**
ΔCO — change in cardiac output during passive leg raising test; NR — non-responders; R — responders. Above each period is the percentage of non-responders/responders

Considering 93 measurements, we established moderate relationship between cardiac output (ΔCO) and FTc changes in PLR test in mechanically ventilated patients (r=0.551, $p<0.0001$). Moderate relationship between these indicators was also revealed under spontaneous breathing after 92 measurements (r=0.510, $p<0.0001$). This relationship persisted at all stages of the study **(Table 3)**.

Correlation coefficients between ΔCO and preload indicators are presented in **Table 3**, i.e. static (CVP, PAWP and FTc before infusion load) and percentage change after infusion load (ΔCVP, ΔPP, ΔFTc and ΔFTc %) at each stage of the study. Only corrected flow time changes (absolute and relative) demonstrated a moderate relationship with ΔCO. PP increment when PLR test revealed a moderate relationship with CO increment. However, this relationship was not significant at every stage of the study. None static preload indicators demonstrated a relationship with ΔCO in PLR test **(Table 3)**.

Static and dynamic parameters of preload in responders and non-responders before and after PLR test at each stage of the study are demonstrated in **Table 4**. Between-group comparison of responders and non-responders revealed significant differences of CVP, PAWP and ΔPP, but not at every stage of the study. We can note lower absolute FTc in responders before PLR test. This difference was significant only at the second stage of the study. At the same time, CVP, PAWP and FTc significantly increased after PLR test in both groups. Responders and non-responders did not differ significantly in PP increment at every stage **(Table 4)**.

AUROC for ΔFTc-based PLR test was 0.868 (95% CI 0.792-0.945, $p<0.0001$) in patients under mechanical ventila-

Table 3. **Relationship between various preload measures and changes of cardiac output before and after the PLR test at each stage of the study**

Variable	Upon admission to ICU (ventilation)	After surgery		
		after 4 hours (ventilation)	after 18 hours (spontaneous breathing)	after 24 hours (spontaneous breathing)
Preload parameters before PLR test				
CVP/ΔCO	*r*=0,029 *p*=0,843	*r*=–0,216 *p*=0,158	*r*=–0,269 *p*=0,065	*r*=–0,160 *p*=0,299
PAWP/ΔCO	*r*=0,018 *p*=0,810	*r*=–0,243 *p*=0,146	*r*=–0,298 *p*=0,055	*r*=–0,141 *p*=0,386
FTc/ΔCO	*r*=–0,172 *p*=0,236	*r*=–0,256 *p*=0,094	***r=–0,337*** ***p=0,019***	*r*=–0,117 *p*=0,451
Preload parameter changes after PLR test				
ΔCVP/ΔCO	*r*=0,205 *p*=0,158	*r*=0,450 *p*=0,002	*r*=0,275 *p*=0,061	*r*= –0,046 *p*=0,765
ΔFTc/ΔCO	*r*=0,568 *p*<0,0001	*r*=0,526 p<0,0001	r=0,509 p<0,0001	***r=0,483*** ***p=0,001***
ΔFTc(%)/ΔCO	*r*=0,558 *p*<0,0001	*r*=0,515 p<0,0001	r=0,537 p<0,0001	r=0,438 *p*=0,001
ΔPP/ΔCO	*r*=0,439 *p*=0,0016	*r*=0,317 *p*=0,039	*r*=0,429 *p*=0,0026	*r*=0,028 *p*=0,859

Note. r — correlation coefficient; ICU — intensive care unit; ΔFTc — corrected systolic flow time change in common carotid artery; ΔCO — cardiac output change; ΔCVP — central venous pressure change; PAWP — pulmonary artery wedge pressure; ΔPP — pulse pressure change. Bold italics indicate significant correlations.

tion **(Fig. 3 a)**, under spontaneous breathing — 0.817 (95% CI 0.719-0.916, *p*< 0.0001) **(Fig. 3 b)**.

This test demonstrated moderate sensitivity and specificity for mechanical ventilation (87% and 70%, respectively, threshold ΔFTc 16.4 ms) and spontaneous breathing (88% and 79%, respectively, threshold ΔFTc 19.4 ms).

AUROC for ΔFTc (%) — based PLR test was 0.868 (95% CI 0.790-0.945, *p*<0.0001) in patients under mechanical ventilation **(Fig. 4 a)**, under spontaneous breathing — 0.827 (95% CI 0.731-0.924, *p*<0.0001) **(Fig. 4 b)**.

This test showed moderate sensitivity and specificity for mechanical ventilation (80% and 85%, respectively, threshold ΔFTc 7.4%) and spontaneous breathing (83% and 79%, respectively, threshold ΔFTc 5.7%).

PP-based PLR test had low sensitivity and specificity for predicting fluid responsiveness. AUROC for mechanical ventilation was 0.679 (95% CI 0.560-0.798, *p*=0.006) **(Fig. 5 a)**, for spontaneous breathing — 0.645 (95% CI 0.529—0.761, *p*=0.026) **(Fig. 5 b)**.

Discussion

Today, cardiac surgery patients are high-risk ones not only due to surgical interventions, but also due to comorbidities. In our study, mean age of patients was 65 years. Comorbidities mainly included diabetes mellitus, chronic kidney disease, chronic obstructive pulmonary disease, coronary artery disease and hypertension **(Table 1)**. Mean ICU-stay was 2 days due to severe comorbidities and advanced age. Such patients require careful monitoring and personalized treatment. Infusion of crystalloid solutions is most often the first step in the treatment of patients with hemodynamic instability. Both fluid overload and hypovolemia lead to tissue hypoperfusion. The last can lead to multiple organ failure if not corrected in a timely manner [6]. Serum troponin T in early postoperative period as one of the predictors of cardiovascular failure and mortality was elevated [7, 8]. High troponin T may be explained by surgical intervention. Indeed, mitral and tricuspid valve surgery, as well as combined interventions (35% in our study) are always accompanied by higher serum biomarkers of myocardial damage compared to coronary artery bypass surgery or aortic valve replacement / repair [8]. Infusion therapy should be personalized after cardiac surgery, since cardiovascular system is compromised in this case. Therefore, PLR-based assessment of sensitivity to infusion load is preferable, since this technique avoids irreversible infusion of solutions and does not lead to excessive hydration [9]. Low cardiac index upon admission (1.7 [1.4—2.2] L/min/m^2) together with positive fluid responsivity tests supported the need for fluid resuscitation. Pulmonary artery catheterization is the most common for advanced hemodynamic monitoring. However, this procedure is highly invasive and associated with certain dangerous complications. Therefore, the role of Swan-Ganz catheter in hemodynamic monitoring is constantly being reviewed [10]. Static indicators (CVP and PAWP) have low sensitivity and wide "gray zone" for predicting fluid responsiveness [11]. According to modern data, CVP and PAWP characterize filling pressure for the right and left ventricles, respectively. Their main role in infusion load tests is analysis of ability of each ventricle to accept additional blood volume. Significantly higher CVP or PAWP after PLR test can indicate that the patient is not a responder [12]. In our study, CVP varied from 5-6 mm Hg at the first two stages up to 8-9 mm Hg in the last two stages, PAWP — from 9-11 to 7-9 mm Hg, respectively. PAWP after PLR test was higher in non-responders compared to responders. This is consistent with this concept. At the same time, borderline values of CVP (<4 and >15 mm Hg) and PAWP (<5 and >20 mm Hg) can quite reasonably be considered triggers for starting or stopping infusion therapy, respectively [11, 12].

Bedside echocardiography, as an alternative to pulmonary artery catheterization, has several advantages. This noninvasive procedure visualizes cardiac chambers and valves. In experienced hands, echocardiography can estimate almost all central hemodynamic parameters similar to prepulmonary thermodilution [13]. Some authors prefer transesophageal echocardiography for optimizing the volumetric monitoring in off-pump CABG [14]. However, this method has certain limitations, i.e. role of physician's experience, impossible continuous hemodynamic monitoring and no acoustic window for transthoracic echocardiography in postoperative period. The latter is fa-

Table 4. **Changes of static and dynamic preload indicators in responders and non-responders at each stage of the study**

Variable		Upon admission to ICU		After surgery					
				after 4 hours		after 4 hours		after 4 hours	
		before PLR test	after PLR test	before PLR test	after PLR test	before PLR test	after PLR test	before PLR test	after PLR test
CVP, mm Hg	Responders	6 [4—7]	9# [6—10]	6 [4—8]	9# [6—12]	5 [3—5,5]	8# [5,5—10]	6 [3—7]	7# [6—9]
	Non-responders	6 [3—7]	7*# [4—8]	5 [4—6]	7*# [5—9]	6 [5—8]	8*# [6—10]	6 [4—7]	8# [6—10]
Mean BP, mm Hg	Responders	76 [61—84]	77# [69—88]	69 [61—77]	78# [65—84]	74 [67—82]	77 [72—85]	69 [64—76]	72# [66—81]
	Non-responders	80 [68—87]	79 [75—89]	75 [66—81]	71# [69—86]	73 [66—83]	76 [68—88]	72 [68—77]	73 [67—80]
ΔPP, %	Responders	—	16* [6—22]	—	14 [3—22]	—	6* [1—11]	—	3 [—5—10]
	Non-responders	—	0 [–3—13]	—	3 [–2—10]	—	–3[–11—9]	—	0 [–3—8]
PAWP, mm Hg	Responders	10 [7—13]	13# [10—15]	10 [6—13]	11 [9—15]	8 [5—12]	11# [8—14]	7 [5—11]	12# [7—14]
	Non-responders	9 [8—13]	11* [8—12]	11 [8—13]	11# [9—13]	10 [8—14]	11*# [9—18]	9 [7—14]	12# [9—16]
FTc, ms	Responders	312 [288—332]	344# [316—374]	300 [290—339]	350# [329—383]	295 [267—338]	339# [311—373]	308 [289—339]	343# [332—362]
	Non-responders	320 [302—336]	329# [311—355]	346* [315—364]	346 [320—368]	321 [307—337]	333# [312—360]	334 [305—352]	348# [308—361]

Note. CVP — central venous pressure; BP — blood pressure; Δ PP — pulse pressure change during PLR test; PAWP — pulmonary artery wedge pressure; FTc — corrected systolic flow time in common carotid artery; PLR — passive leg raising test; ICU — intensive care unit. Data are presented as median [25th and 75th percentiles]. * — $p<0.05$ for between-group comparison; # — $p<0.05$ for within-group comparison with values before PLR test

Fig. 3. **AUROC for the FTc for predicting fluid load response in patients on mechanical ventilation (a) and with spontaneous breathing (b).**

cilitated by forced supine position of patients, drainage tubes in pleural cavities and anterior mediastinum, invasive mechanical ventilation [13]. Therefore, we did not consider this monitoring as a reference one. Moreover, accuracy and reproducibility of Doppler-based CO measurement is limited [15].

Doppler ultrasound of blood flow in great arteries (brachial, radial or carotid arteries) has recently attracted the attention of clinicians [16, 17]. Superficial localization of these arteries facilitates visualization even for poorly trained personnel in contrast to echocardiography or Doppler ultrasound of abdominal aorta. In 2017, Ma I.W.Y. et al. [18] presented one of the first studies devoted to comparison of carotid Doppler measurements and thermodilution-based CO. The authors estimated 51 patients and found no relationship between CO and FTc. However, there was a moderate relationship between blood flow velocity and CO (r=0.44, 95% CI 0.18-0.63, p=0.004). The purpose of our study was not to identify a direct relationship between FTc and CO, especially since other studies have not confirmed these results, especially among cardi-

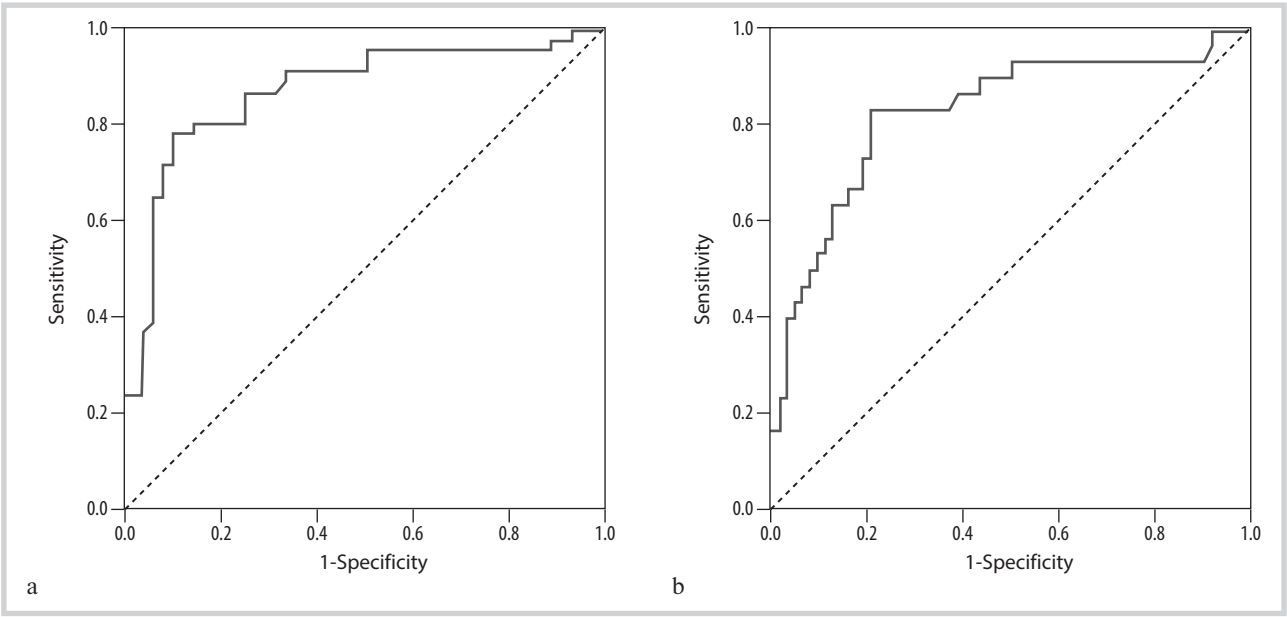

Fig. 4. **AUROC for ΔFTc (%) for predicting fluid load response in patients on mechanical ventilation (a) and with spontaneous breathing (b).**

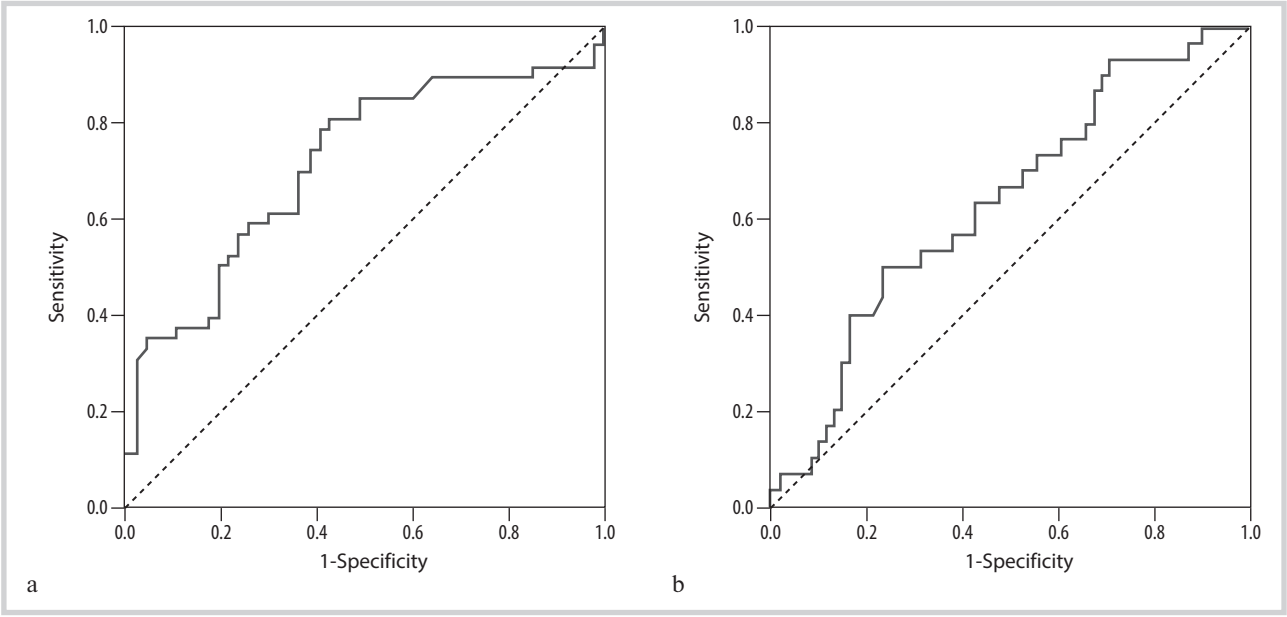

Fig. 5. **AUROC for ΔPP for predicting the fluid load response in patients on mechanical ventilation (a) and with spontaneous breathing (b).**

ac patients [19]. Nevertheless, increase or decrease in this indicator following preload changes is physiologically explainable and confirmed in some studies [20, 21]. Systolic flow time is directly proportional to myocardial contractility and LV preload, as well as inversely proportional to afterload [22]. J. van Houte et al. [20] found high agreement rate (80—100%) between increment of corrected flow time and CO or stroke volume. We found a moderate relationship between these indicators, and there may be several reasons for this. First, we enrolled patients with paroxysmal atrial fibrillation. In these ones, FTc varies from one cardiac cycle to the next. According to our protocol, mean value of 3 consecutive cardiac cycles was considered, but this could affect the relationship with CO increase. Moreover, most previous studies included only patients with sinus rhythm [20, 23]. In our opinion, patients with this complication cannot be excluded from the study, since new-onset paroxysms of AF are common after cardiac surgery. According to our colleagues, incidence of this complication is up to 14% [24]. There were 13 (27%) similar patients in our study. In addition, not only preload, but also LV contractile reserve and afterload influence on FTc. Patients after open heart valve surgery have various hemodynamic profiles (vasoplegia, vasospasm, low CO syndrome, pulmonary hypertension) that could affect sensitivity of tests.

Despite moderate sensitivity and specificity of FTc-based PLR test, its predictive power is higher compared to PP. The latter is often an alternative to analyze susceptibility to fluid load in the absence of cardiac output monitoring. Perhaps, combination of these two indicators will increase sensitivity and specificity of PLR test.

Conclusion

The FTc-based PLR test has moderate sensitivity and specificity for analysis of fluid responsiveness after elective heart valve surgery for both mechanical ventilation and spontaneous breathing. Predictive power of these tests is higher compared to tests based on traditional static (central venous pressure, pulmonary artery wedge pressure) or dynamic indicators (pulse pressure changes). Further studies are required to demonstrate significant of carotid Doppler measurements as predictors of fluid responsiveness.

Author contribution:
Concept and design of the study — Zozulya M.V., Lenkin A.I.
Collection and analysis of data — Zozulya M.V.
Statistical analysis — Zozulya M.V.
Writing the text — Zozulya M.V.
Editing — Lenkin A.I.

No conflict of interests to declare.

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