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ORIGINAL RESEARCH

Comparison of volume assessment methods in transurethral resection of the prostate

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Abstract

To compare the value of inferior vena cava (IVC) variation, thoracic fluid content (TFC), and central venous pressure (CVP) in transurethral resection of the prostate (TURP) for systemic volumetric load. Eighty male patients who had undergone TURP at our hospital from July to August 2021 were enrolled. Before and after anesthesia induction, IVC variation and TFC were recorded every 15 min and then 15 min after surgery. The ability of IVC variation, TFC, and CVP to predict fluid responsiveness was assessed using receiver operator characteristic (ROC) curves. The Pearson correlation test was used to analyze the correlations among intraoperative IVC variation, TFC, CVP and the stroke volume index (SVI). ROC curve evaluation: the area under the ROC curve (AUC) of IVC variation was 0.82 ($p < 0.01$), while that of CVP and TFC was 0.61 ($p = 0.16$) and 0.45 ($p = 0.28$), respectively. Since the operation began, ΔIVC variation showed a significant negative correlation with ΔSVI at different time points. ΔCVP and ΔTFC showed a poor correlation with ΔSVI. IVC variation was superior to TFC and CVP to predict fluid responsiveness and assess the volume status and volume responsiveness of patients undergoing TURP.

Keywords

Transurethral resection of the prostate; IVC variation; Thoracic fluid content; Central venous pressure; Systemic volumetric load

1. Introduction

As China transitions to an aging society, the number of clinically benign prostatic hyperplasia patients is increasing. Transurethral resection of the prostate (TURP) is considered the gold standard treatment for benign prostatic hyperplasia. Prohibiting drinking and fasting before surgery can lead to an insufficient effective circulating blood volume, which is likely to cause hemodynamic fluctuations during anesthesia induction. Additionally, lavage fluid easily enters the blood vessels during TURP, causing circulation overload, which may aggravate the original heart and lung disease of elderly patients. In severe cases, complications such as cerebral edema and pulmonary edema can result.

Therefore, perioperative volume assessment is particularly important for TURP patients. Classic methods for clinical assessment of the patient capacity status, such as central venous pressure (CVP) monitoring, the Flotrac/Vigileo system (software version 4.0; Edwards Lifesciences, Irvine, CA, USA), are all invasive and carry risks such as hematoma, pneumothorax, infection, and embolism. In recent years, some noninvasive capacity assessment techniques have been gradually applied in the clinic, such as IVC variation and thoracic fluid content (TFC). Many studies have shown that IVC variation and the TFC volume status are closely related and have certain guiding significance for clinical fluid replacement [1–3]. This study aimed to compare the accuracy of IVC variation and TFC in evaluating liquid responsiveness in TURP to provide a reference for clinical noninvasive volume monitoring method selection.

2. Methods

We included 80 elderly male patients who had undergone TURP at our hospital from July to August 2021, were aged 60 to 70 years, and had an American Society of Anesthesiologists (ASA) grade of II to III. The cardiopulmonary, liver and kidney function of all the patients was generally normal, and no other disease in important organs was noted. Patients whose ultrasound did not clearly show the inferior vena cava (IVC) or who had contraindications to arterial and central venipuncture catheterization were excluded. The anesthesia program consisted of intravenous anesthesia for tracheal intubation. All the included patients fasted for 8 hours, followed by preoperative preparations according to the specialty requirements.

Before anesthesia, right subclavian central venous catheterization and radial artery catheterization was prepared under local anesthesia, the Flotrac/Vigileo system (software version 4.0; Edwards Lifesciences, Irvine, CA, USA) was connected, and Electrocardiogram (ECG), invasive blood pressure, oxy-

gen saturation (SpO_2) and the bispectral index (BIS) monitoring was established. Before the induction of anesthesia, sodium lactate Ringer's solution was used to perform compensatory expansion at 6 mL/kg [1, 4], and the infusion was completed within 30 min. The method for general anesthesia induction was as follows: midazolam was administered at a dose of 0.05 mg/kg, sufentanil at a dose of 0.6–0.8 μg/kg, etomidate at a dose of 0.15–0.3 mg/kg, and fensulfonate-atracurium at a dose of 0.2 mg/kg via intravenous injection. Anesthesia was continually supplemented according to the physiological requirements of the patient and cumulative loss with lactated Ringer's solution at a rate of 4 mL/kg/h. When the BIS was between 40 and 60, tracheal intubation was performed, and the ventilation mode was controlled using the following parameters: tidal volume, 8 to 10 mg/kg; respiratory rate, 12 to 16 breaths per minute; inhalation ratio, 1:2; inhaled oxygen concentration, 50%; flow of fresh air, 2 L/min; peak airway pressure, within 30 cm H_2O. Patient end-tidal carbon dioxide ($PETCO_2$) was maintained at 35~45 mmHg during anesthesia. For maintenance medication, a continuous constant-speed intravenous injection of propofol (4~6 $mg{\cdot}kg^{-1}{\cdot}h^{-1}$) and remifentanil (0.2~0.3 $\mu g{\cdot}kg^{-1}{\cdot}min^{-1}$) was administered to maintain the BIS between 40 and 60. After the operation time reached 60 min, furosemide (20 mg) was administered intravenously.

All patients underwent monopolar TURP with 5% mannitol as the irrigation solution. The irrigation reservoir was set at a height of 60 cm from the patient's bed.

2.1 Observation indexes

(1) Indicators collected by the monitor were the mean arterial pressure (MAP), SpO_2, heart rate (HR), and CVP at time points of T0 (before expansion), T1 (after expansion), T2 (15 min after the start of surgery), T3 (30 min after the start of surgery), T4 (45 min after the start of surgery), T5 (60 min after the start of surgery), T6 (80 min after the start of surgery/20 min after diuresis), T7 (105 min after the start of surgery), T8 (120 min after the start of surgery), T9 (135 min after the start of surgery), and T10 (150 min after the start of the operation).

(2) Indexes collected by the Flotrac/Vigileo system were the stroke volume (SV), cardiac output (CO), and stroke volume index (SVI) at the specified acquisition times (T0, T1, T2, T3, T4, T5, T6, T7, T8, T9, and T10).

(3) Ultrasound measurement indexes were obtained using a Sonosite M-Turbo type ultrasound machine, a 3.5-MHz microconvex array probe, and two-dimensional ultrasound-namely, longitudinal detection of the posterior hepatic IVC under the xiphoid process, and the arteries and veins were distinguished by the frequency spectrum. Using the M-mode, the diameter of the IVC 2–3 cm from the right atrium was selected. During the measurement, the plane for the hepatic vein was selected, with the sampling line perpendicular to the long axis of the IVC as much as possible, and measurements were collected for approximately 10 s (including 2–3 breathing cycles) from the inner edge of the blood vessel wall to the inner edge of the other side. The diameter of the IVC during inspiration (IVCi) and during expiration (IVCe) were measured three times each, and the average value was taken as the final measurement value. The IVCi and IVCe were recorded, and IVC variation=(IVCi–IVCe) $\div$ IVCe $\times$ 100%. The measured time points were T0, T1, T2, T3, T4, T5, T6, T7, T8, T9, and T10.

(4) The CSM3000 noninvasive blood flow system monitoring index was the TFC. The measured time points were T0, T1, T2, T3, T4, T5, T6, T7, T8, T9, and T10.

2.2 Statistical analysis

All data were analyzed using SPSS 19.0 (SPSS Inc, Chicago, Il, USA) statistical software. Measurement data with a normal distribution are expressed as the mean $\pm$ standard deviation (x $\pm$ s). Paired *t* tests were used to compare the results before and after expansion and before surgery. The difference between each monitoring index was calculated at every two time points ($\Delta T1 = T2-T1$, $\Delta T2 = T3-T2$, *etc.*), and Pearson correlation analysis was used to evaluate the correlation between ΔSVI and other hemodynamic variables. Receiver operating characteristic (ROC) curve analysis was used to evaluate the ability of IVC variation, CVP, and TFC to predict liquid reactivity, and the area under the ROC curve (AUC) was calculated to establish the best predictor.

If an increase in the stroke index (ΔSVI) $\geq$15% occurred after expansion, we considered it due to fluid reactivity; these patients were regarded as responsive, and patients with ΔSVI $<$15% were regarded as nonresponsive [4, 5].

3. Results

In the present study, 4 patients whose IVC was not clearly shown on ultrasound were excluded. The remaining 76 patients comprised the study group. After volume expansion and fluid replacement, there were 62 patients in the responsive group and 14 patients in the nonresponsive group. No differences in the demographic characteristics of the groups were observed (Table 1).

TABLE 1. Baseline patient characteristics of the two group.

	Responsive group	Nonresponsive group	*p*
No. of patients	62	14	
Sex, M/F, n	62/62	14/14	
Mean age (year)	66.32 $\pm$ 2.21	65.75 $\pm$ 1.92	0.524
ASA class (II/III)	54/8	12/2	0.346
Height (cm)	167.58 $\pm$ 3.32	168.42 $\pm$ 2.76	0.671
BMI (kg/m^2)	21.45 $\pm$ 1.66	22.14 $\pm$ 1.28	0.263

Data represents the number of patients or the mean $\pm$ SD. M, male; F, female; ASA, American Society of Anesthesiologists; BMI, Body Mass Index.

3.1 Hemodynamic parameters in patients before and after fluid challenge

Paired *t* tests were used to compare the results of various hemodynamic indicators before and after expansion. The difference in HR and TFC between before and after expansion

was not statistically significant (Table 2).

TABLE 2. Hemodynamic indexes before and after expansion.

Item	Before expansion	After expansion	*p*
HR (beats/min)	72.02 ± 6.96	69.42 ± 5.71	0.324
MAP (mmHg)	70.24 ± 8.15*	78.52 ± 10.18*	0.000
IVCi (cm)	1.47 ± 0.26*	1.85 ± 0.32*	0.000
IVCe (cm)	1.28 ± 0.21*	1.39 ± 0.24*	0.000
IVC variation (%)	44.37 ± 15.64*	24.48 ± 12.16*	0.000
CO (L/min)	4.27 ± 0.28*	5.12 ± 0.25*	0.000
SV (mL/beat)	52.44 ± 8.52*	68.57 ± 7.63*	0.000
SVI (mL/beat/m^2)	33.27 ± 5.73*	39.80 ± 3.84*	0.000
CVP (cmH_2O)	5.37 ± 0.46*	6.78 ± 0.39*	0.000
TFC (1/Ω)	0.043 ± 0.005	0.044 ± 0.003	0.512

** means the indicators are compared with those before expansion, $p < 0.05$.*
HR, heart rate; MAP, mean arterial pressure; IVCi, the diameter of the inferior vena cava in inspiration; IVCe, the diameter of the inferior vena cava in expiration; IVC variation, inferior vena cava variation; CO, cardiac output; SV, stroke volume; SVI, stroke volume index; CVP, central venous pressure; TFC, thoracic fluid content.

After expansion, compared with the responsive group, the ΔSV, ΔCO, and ΔIVC variation in the nonresponsive group was significantly reduced ($p < 0.05$), but there was no significant difference between the two groups in ΔHR, ΔMAP, ΔCVP, or ΔTFC ($p > 0.05$) (Table 3).

TABLE 3. Differences in other hemodynamic indicators between the responsive and nonresponsive groups.

	Responsive group	Nonresponsive group	*p*
ΔSV (mL/beat)	15.56 ± 2.83	10.33 ± 1.75	0.028
ΔCO (L/min)	0.86 ± 0.05	0.53 ± 0.026	0.012
ΔHR (beat/min)	4.42 ± 3.34	4.67 ± 2.58	0.796
ΔMAP (mmHg)	3.67 ± 3.31	2.75 ± 2.22	0.350
ΔIVC variation (cm)	0.05 ± 0.03	0.024 ± 0.03	0.036
ΔCVP (cmH_2O)	0.58 ± 0.32	0.42 ± 0.36	0.773
ΔTFC (1/W)	(1.25 ± 0.14) × 10^{-4}	(3.30 ± 0.56) × 10^{-4}	0.137

3.2 Prediction of fluid responsiveness by the ROC curves of IVC variation, CVP and TFC

IVC variation predicts a critical value of liquid reactivity of 0.44 (sensitivity, 70.83%; specificity, 87.5%), CVP predicts a critical value of fluid responsiveness of 6.2 mmHg (sensitivity, 87.0%; specificity, 37.5%), and TFC predicts a critical value of liquid reactivity of 0.52 1/W (sensitivity, 17.3%; specificity, 12.5%). The AUC of IVC variation was 0.82 ($p < 0.01$; 95% CI, 0.74–0.96, $p = 0.000$), and that of CVP variation was 0.61 ($p = 0.16$; 95% CI, 0.47–0.86, $p = 0.183$). Although TFC predicts liquid reactivity, the AUC was 0.45 ($p = 0.28$), and the 95% CI was not significant (Fig. 1).

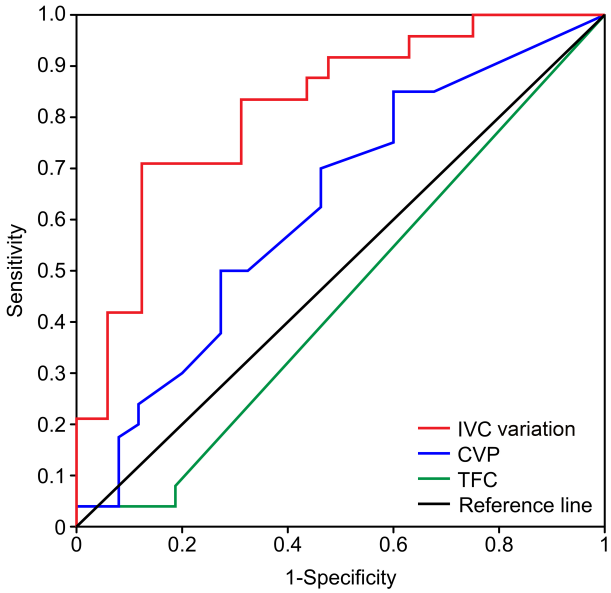

FIGURE 1. ROC curves of IVC variation, CVP and TFC to predict liquid reactivity. IVC variation, inferior vena cava variation; CVP, central venous pressure; TFC, thoracic fluid content.

3.3 Correlation between various indicators and ΔSVI

All the included ΔIVC, ΔCVP, ΔTFC and ΔSVI values were analyzed separately. Among these cases, the operation time was 60–90 min in 51 cases, 90–120 min in 20 cases, and 120–150 min in 9 cases.

After the beginning of the operation, ΔIVC variation and ΔSVI showed a significant negative correlation at different time points (r1 = −0.672, r2 = −0.715, r3 = −0.693, r4 = −0.624, r5 = −0.741, r6 = −0.686, r7 = −0.662, r8 = −0.574, r9 = −0.618). The correlation coefficients of ΔIVC and ΔSVI fluctuated from –0.574 to –0.741 at each time point, and a linear correlation was found between the groups ($p < 0.05$) (Table 4).

During the operation, ΔCVP and ΔSVI were moderately correlated (r1 = 0.425, r2 = 0.393, r3 = 0.452, r4 = 0.418, r5 = –0.442, r6 = 0.527, r7 = 0.483, r8 = 0.561, r9 = 0.450). The correlation coefficient fluctuated between 0.393 and 0.561, and no linear correlation was found between the groups ($p > 0.05$) (Table 5).

TABLE 4. Correlation between ΔIVC and ΔSVI at various time points.

	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5	ΔT6	ΔT7	ΔT8	ΔT9
r	−0.672	−0.715	−0.693	−0.624	−0.741	−0.686	−0.662	−0.574	−0.618
R^2	0.45	0.50	0.48	0.38	0.56	0.46	0.44	0.32	0.37
p	0.014	0.010	0.018	0.025	0.016	0.019	0.037	0.060	0.054

TABLE 5. Correlation between ΔCVP and ΔSVI at various time points.

	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5	ΔT6	ΔT7	ΔT8	ΔT9
r	0.425	0.393	0.452	0.418	–0.442	0.427	0.483	0.561	0.450
R^2	0.181	0.154	0.204	0.175	0.195	0.276	0.233	0.315	0.203
p	0.150	0.182	0.126	0.175	0.144	0.213	0.186	0.152	0.174

TABLE 6. Correlation between ΔTFC and ΔSVI at various time points.

	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5	ΔT6	ΔT7	ΔT8	ΔT9
r	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.033
R^2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
p	0.816	0.822	0.947	0.918	0.894	0.825	0.769	0.528	0.623

No correlation was found between ΔTFC and ΔSVI at various time points during the operation. The correlation coefficient fluctuated from 0.000 to 0.033, and no linear correlation was found between the groups ($p > 0.05$) (Table 6).

4. Discussion

Hypotension is prone to occur after the induction of anesthesia, which can lead to the hypoperfusion of tissues and organs, a condition that is not conducive to the prognosis of patients [6]. Additionally, patients undergoing TURP are older and often have cardiovascular disease. If too much lavage fluid is absorbed during surgery, it can cause an increase in the cardiac preload, elicit pulmonary edema from left heart failure, and even induce myocardial infarction, increasing the length of Intensive Care Unit (ICU) stay and clinical mortality rate [7]. Therefore, exploring excellent and convenient noninvasive capacity evaluation indicators is a crucial clinical issue. This study confirmed that in TURP patients, IVC variation is superior to CVP and TFC in predicting fluid responsiveness. Meanwhile, ΔIVC variation and ΔSVI were significantly negatively correlated at different time points during the operation, while ΔCVP, ΔTFC and ΔSVI were shown to have a poor correlation.

A pulse-contour technique called Vigileo/FloTrac was launched to estimate SVI without the need for any calibration [8]. The SVI was calculated as the arterial pulse pressure waveform deviation change by Vigileo's algorithm. Mechanical ventilation induces cyclic cardiac filling changes and produces respiratory changes in SVI [9]. The respiratory changes in SVI unmask fluid responsiveness in patients with sinus rhythm. Zhang X *et al.* [3] have shown that SVV is correlated well with an increase in SVI, and that ROC curves suggested that SVV can predict fluid responsiveness, which are in agreement with the findings in surgical patients. However, SVV only reflect whether the patient's volume status is sufficient with a limit of 13%, but it cannot be quantified, which means that it cannot track the dynamic changes in systemic volumetric load. So we choose SVI but not SVV as the gold standard for judging volume load.

Studies have shown that the function of the two ventricles of patients in the responsive group is on the ascending branch of the Frank-Starling curve. Thus, ΔSVI will increase with increasing systemic blood volume. In the unresponsive group, the maximum compensation of the Frank-Starling curve is exerted. Even if the capacity load is increased again, the SVI does not change significantly [10]. In the present study, when the capacity was insufficient, the difference between IVCmax and IVCmin was significant—that is, greater IVC variation was observed. When the capacity was overloaded, the difference between IVCmax and IVCmin was very small—that is, the variation in IVC decreased, and ΔSVI shifted correspondingly with the capacity state to the right on the Frank-Starling curve until the capacity was saturated. Thus, ΔIVC variation and ΔSVI showed a negative correlation.

The IVC diameter is closely correlated with right-sided cardiac functions [11], and it is not influenced by the body's compensatory vasoconstrictor [12]. However, it can be affected by mechanical ventilation. The pleural pressure increase will lead to higher pressure of right atrium during inspiration if it is underfilled [13]. IVC diameter, as measured by ultrasound, was proved to be valid in guiding fluid challenge in a wide range of patients [14–16]. A recent systematic review revealed that IVC measured with point-of-care ultrasonography is of great value to predict fluid responsiveness in ICU patients with severe organ dysfunction under controlled mechanical ventilation and those resuscitated with colloids [17].

Numerous studies have described that CVP is of little significance in representing the blood volume [18]. If venous return also changes because of the change in blood volume while heart function changes, the relationship between the CVP and blood volume will also change. Sakka *et al.* [19] also found that the CVP is easily influenced by cardiovascular

compliance, intrathoracic pressure, and valve regurgitation and cannot accurately reflect changes in the cardiac preload. In the present study, the CVP increased after expansion, but no correlation was found between ΔCVP and ΔSVI intraoperatively, indicating that CVP indicators have certain limitations in monitoring high blood volume.

The TFC is a hemodynamic parameter that reflects the fluid in the thoracic interstitium, blood vessels and alveoli. Studies have shown that it can be effectively used in acute decompensated heart failure patients, and its effectiveness in evaluating CO and pulmonary capillary wedges is comparable to that of pulmonary artery catheterization [20]. TFC and IVC variation are noninvasive monitoring methods that are simple and convenient to apply. However, the pros and cons of predicting the liquid reactivity performance of the two have not been reported, and there have been concerns about their clinical application. In the present study, TFC showed poor predictive performance. We speculate that the TFC may increase only when volume overloading occurs to a certain extent, such as with pulmonary congestion or pulmonary edema, which is positively correlated with the systemic blood volume. This finding needs further study for clarification.

The limitations of our study are as follows: a small sample size, therefore, larger samples are needed to better assess the ability of SVI and IVC variation to predict fluid responsiveness. Otherwise, ultrasound measurement of IVC is limited to patients undergoing general anesthesia with tracheal intubation. Although TURP is performed under regional anesthesia in some primary hospitals, general anesthesia is still the first choice of anesthesiologists in most major cities in numerous countries, for it is easier to operate and also improve patient comfort and satisfaction.

5. Conclusions

Our study clearly clarified that ultrasound measurement of the IVC has the advantages of being noninvasive, simple and relatively accurate in evaluating high blood volume during TURP. It can be effectively used to evaluate the volume load clinically and has high value for clinical application.

The CSM3000 noninvasive blood flow detection system for TFC monitoring has limited clinical value.

AUTHOR CONTRIBUTIONS

YW helped conceive the study and contributed to the definition of intellectual content, experimental studies, data acquisition, statistical analysis, manuscript preparation and editing & manuscript review processes; FG helped conceive the study and contributed to the study design, definition of intellectual content, experimental studies, data acquisition, statistical analysis, and preparation and editing of the manuscript; XZ helped conceive the study and contributed to the literature search, manuscript editing and manuscript review processes. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Fujian Provincial Hospital Institutional Review Board (IRB No. K2019-05-001) and was registered before patient enrollment (ChiCTR2100048376 (http://www.chictr.org.cn/showprojen.aspx?proj=128501); principal investigator: Fayang Lian; date of registration: July 6, 2021). Written informed consent was obtained from all patients before participation in the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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