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ORIGINAL ARTICLE

# Correlation Between Ultrasound-Measured Diameter and Blood Flow Velocity of the Internal Jugular Veins with the Preoperative Blood Volume in Elderly Patients

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**Abstract**
The study aimed to explore the correlation of the diameter and blood flow velocity of the internal jugular vein with the preoperative blood volume in elderly patients and to providence for rapid evaluation of preoperative blood volume with ultrasound in elderly patients. Thirty patients over 65 years old were recruited in the study. Patient's central venous pressure (CVP) was recorded before anesthesia. The maximum diameter (Dmax) and the minimum diameter (Dmin) of the left internal jugular vein were measured by M type ultrasound and the respiratory variation index (RVI), defined as (Dmax – Dmin) / Dmax × 100%, was calculated. The maximum blood flow velocity (BVmax) and the minimum blood flow velocity (BVmin) were measured by Doppler ultrasound, and the blood flow variation index (BVI), defined as (BVmax – BVmin) / BVmax × 100%, was calculated. Then, each of the patients was given with 5 ml/kg crystalloid solution, and the relevant data were measured again and compared to that before infusion. The correlation between each measurement index and CVP, and their efficiency in predicting CVP > 6 mmHg were statistically evaluated. No matter before or after infusion, Dmax, Dmin, BVmax, and BVmin were positively correlated with CVP (Correlation is significant at the 0.01 level (2-tailed)); and RVI was negatively correlated with CVP (Correlation is significant at the 0.01 level (2-tailed)); however, BVI is negatively correlated with the CVP with no statistically significant difference. Through the analysis of ROC curve, Dmax, Dmin, RVI, BVmax, and BVmin could be used to predict the CVP > 6 mmHg in these patients, and the best index was BVmax; BVI diagnosis was not effective. Ultrasonic measurements of internal jugular vein diameter, respiratory variability, and blood flow velocity were correlated with preoperative CVP in elderly patients, indicating that these indexes could potentially be used to evaluate the preoperative blood volume in elderly patients.

**Keywords** Diameter of the internal jugular vein · Respiratory variation index · Blood flow velocity · Preoperative blood volume

## Introduction

Surgery in the elderly patients could potentially result in a rapid depletion of sodium and water levels in the body. To minimize the risk, fluid therapy is provided via the infusion of crystalloids [1]. However, excessive infusion of fluids may increase the tissue perfusion, eventually leading to gastrointestinal edema, impaired respiratory function, and poor wound healing [2–4]. Several studies have shown that goal-directed fluid therapy (GDFT) can promote the recovery of gastrointestinal function and reduce the incidence of postoperative complications [5, 6].

To provide adequate GDFT, there is a need to develop a simple non-invasive method to determine the blood volume accurately. Static and dynamic monitoring techniques can be used. Common dynamic techniques used clinically include FloTrac/Vigileo system and transesophageal echocardiography (TEE) [7]. However, these techniques are invasive and require complex technology, which limits their clinical application, especially in the evaluation of blood volume before anesthesia [8]. Therefore, vascular

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ultrasound (US) has been proposed as an alternative for the monitoring of perioperative blood volume. Conventionally, this technique involves using a US probe to assess the blood flow in the inferior vena cava (IVC). However, the accuracy of this measurement is limited by the deep position of this vein and by the interference in the US signal caused by the abdominal organs [9]. To overcome this problem, the internal jugular vein (IJV) has been proposed as an alternative route to measure blood volume.

In this study, we explored the feasibility of using vascular US to measure the diameter and blood flow velocity of the IJV as a tool to monitor the perioperative blood volume in elderly patients.

## Patients and Methods

### Patient Characteristics

Patients above 65 years who were scheduled to have surgery under general anesthesia from June 2018 to June 2019 in Affiliated Jinhua Hospital, Zhejiang University School of Medicine, Zhejiang, China, were included in the study. Patients with impaired heart function, pulmonary hypertension, and chronic lung disease were excluded from the study. Patients suffering from vascular disorders such as severe vascular sclerosis, peripheral vascular disease, and stenosis or obstruction of the superior vena cava and/or IJVs were also excluded.

The sample required for the study was calculated using the GPOWER 3.1 software [10]. We did 5 patients according to this experimental method, we found the indicator with the largest sample size was the maximum blood flow velocity of the IJV, and its mean was 7.12 SD 1.41 cm/s before infusion and 8.03 SD 1.52 cm/s after infusion. Using an alpha level of 0.05 and a statistical inspection force of 0.9, the bilateral inspection sample required for this study was estimated to be 30 cases.

### Data Collection

The patient's blood pressure, heart rate, and oxygen saturation ($SpO_2$) were monitored in the operating room. All patients were measured under spontaneous breathing in order to reduce the error caused by mechanical ventilation, and all patients were anesthetized and completed surgery after measurement. Catheterization of the right IJV jugular vein was performed under US guidance with the M-Turbo (Sonosite Company) system, and the patient's CVP was continuously monitored through the use of a pressure transducer.

The diameter and blood flow velocity measurements of the IJV were obtained with the patient in the supine position and the head in a neutral position. The maximum (Dmax) and minimum diameter (Dmin) of the left IJV were measured using M-type US at the level of the cricoid cartilage. The respiratory variation index (RVI) was then calculated using the following formula:

$$\mathrm{RVI} = (\mathrm{Dmax} - \mathrm{Dmin})/\mathrm{Dmax} \times 100\%.$$

The maximum blood flow velocity (BVmax) and the minimum blood flow velocity (BVmin) of the left IJV were measured using a Doppler US. The blood flow variability index (BVI) was then calculated using the following formula:

$$\mathrm{BVI} = (\mathrm{BVmax} - \mathrm{BVmin})/\mathrm{BVmax} \times 100\%$$

All the measurements were performed three times, and an average reading was obtained.

The patient's CVP was recorded at the same time.

After acquiring these measurements, each patient was then given a 5 ml/kg crystalloid infusion over 20 min for capacity loading. At the end of the infusion, the relevant data were measured again as indicated by the consensus guidelines on liquid treatment during anesthesia issued by anesthesia branch of the Chinese medical association in 2014 [11]. These guidelines state that the circulation capacity, cardiovascular function, tissue perfusion, and organ function are best maintained up to CVP between 6 and 8 mmHg. In this study, we choose to use 6 mmHg as the cutoff value to predict CVP. The accuracy of Dmax, Dmin, RVI, BVmax, Bvmin, and BVI indices in predicting CVP were compared before and after the infusion.

### Statistical Analysis

The measured data were expressed as an average standard deviation. The intra-group comparison was performed using the two-way analysis of variance test (ANOVA), while intra-group comparison was performed the one-way ANOVA test. The Pearson's correlation test was used to identify the correlation between all the indices and CVP. The accuracy of all US indices in predicting CVP was calculated using a receiver operating characteristic curve (ROC), and AUC of 1 indicates perfect prediction and 0.7 suggests no prediction. The Youden index (J), was used to identify the optimal cutoff points for all US indices to predict an elevated CVP. A $p$-value below 0.05 was deemed to be statistically significant. All statistical calculations were performed using the statistical package for

**Table 1** Comparison of Dmax, Dmin, RVI, CVP, BVmax, BVmin, and BVI before and after infusion ($n=30$)

| Index | Before infusion | After infusion | *P*-value |
|---|---|---|---|
| Dmax (cm) | 1.02 SD 0.18 | 1.13 SD 0.16 | 0.016 |
| Dmin (cm) | 0.67 SD 0.18 | 0.80 SD 0.15 | 0.003 |
| RVI (%) | 35.05 SD 9.05 | 29.40 SD 5.64 | 0.005 |
| BVmax (cm/s) | 7.82 SD 1.60 | 8.07 SD 1.60 | 0.533 |
| BVmin (cm/s) | 6.27 SD 1.68 | 6.54 SD 1.61 | 0.526 |
| BVI (%) | 20.78 SD 10.20 | 19.81 SD 9.12 | 0.700 |
| CVP (mmHg) | 5.67 SD 1.45 | 6.30 SD 1.47 | 0.097 |

the social sciences (SPSS) software version 19 (IBM® SPSS® Statistics).

### Ethical Considerations

This study was approved by the ethics committee of the Jinhua Municipal Central Hospital, ethical review No. (87), and written informed consent was obtained from all patients participating in the study.

## Result

### Patient Characteristics

A total of 18 male and 12 female patients were included in this study with an average age of 73.3 SD 4.2 years, average height of 1.65 SD 0.67 m, average weight of 60.40 SD 6.47 kg and average BMI of 22.10 SD 1.67 kg/m$^2$.

### Comparison of Dmax, Dmin, RVI, CVP, BVmax, BVmin, and BVI Before and After the Infusion

Following infusion, there was a statistically significant increase in the Dmax and Dmin from 1.02 (SD 0.18) to 1.13 (SD 0.16) ($P=0.016$) and 0.67 (SD 0.18) to 0.80 (SD 0.15) ($P=0.003$), respectively, while a statistically significant decrease in the RVI from 35.05% (SD 9.04%) to 29.40% (SD 5.64%) was noted ($P=0.005$) (Table 1).

### Correlation Between Dmax, Dmin, RVI, BVmax, BVmin, and BVI with CVP Before and After the Infusion

For both pre- and post-infusion measurements, there was a statistically significant positive correlation between Dmax, Dmin, BVmax, and BVmin with CVP (Correlation is significant at the 0.01 level (2-tailed)). A negative correlation between BVI and RVI with CVP was noted, but this relationship was not statistically significant (Table 2).

**Table 2** Correlation between Dmax, Dmin, BVmax, BVmin, RVI, BVI before and after infusion, and CVP before and after infusion ($n=30$)

| | Before infusion | | | | | | After infusion | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dmax | Dmin | BVmax | BVmin | RVI | BVI | Dmax | Dmin | BVmax | BVmin | RVI | BVI |
| *r* value | 0.685* | 0.802* | 0.771* | 0.664* | −0.679* | −0.161 | 0.603* | 0.729* | 0.738* | 0.714* | −0.588* | −0.302 |
| Correlation | Positive correlation | Positive correlation | Positive correlation | Positive correlation | Negative correlation | Negative correlation | Positive correlation | Positive correlation | Positive correlation | Positive correlation | Negative correlation | Negative correlation |

*Correlation is significant at the 0.01 level (2-tailed)

### Accuracy of Dmax, Dmin, RVI, BVmax, BVmin, and BVI in Predicting a CVP Above 6 mmHg

Through the area under the ROC, for both pre- and post-infusion measurements, Dmax, Dmin, Bvmax, Bvmin, RVI, and BVI, respectively, indicating that all parameters except BVI could be used to predict a CVP greater than 6 mmHg accurately (Table 3, Fig. 1, Fig. 2). Before the infusion, the diagnostic specificity was the highest for BVmin and BVmax (90%). The sensitivity was highest for Dmin (100%). After the infusion, the diagnostic specificity was the highest for BVmin (94.4%), while the diagnostic sensitivity was the highest for Dmax and BVmax (100%).

**Table 3** The efficiency of Dmax, Dmin, RVI, BVmax, BVmin, and BVI before and after infusion in predicting CVP > 6 mmHg by the ROC curve ($n = 30$)

| | Before infusion | | | | | | After infusion | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dmax | Dmin | BVmax | BVmin | RVI | BVI | Dmax | Dmin | BVmax | BVmin | RVI | BVI |
| Diagnostic critical value | 1.10 cm | 0.71 cm | 8.72 cm/s | 6.67 cm/s | 30.50% | 22.11% | 1.12 cm | 0.83 cm | 7.97 cm/s | 7.03 cm/s | 30.93% | 14.24% |
| Sensitivity (%) | 90.0 | 100.0 | 90.0 | 90.0 | 90.0 | 55.0 | 100.0 | 91.7 | 100.0 | 83.3 | 91.7 | 83.3 |
| Specificity (%) | 80.0 | 85.0 | 90.0 | 90.0 | 85.0 | 80.0 | 61.1 | 83.3 | 88.9 | 94.4 | 77.8 | 50.0 |
| Youden index | 0.700 | 0.850 | 0.800 | 0.800 | 0.750 | 0.350 | 0.611 | 0.750 | 0.889 | 0.778 | 0.695 | 0.333 |
| Area under curve | 0.880 | 0.908 | 0.955 | 0.940 | 0.875 | 0.690 | 0.824 | 0.912 | 0.949 | 0.935 | 0.866 | 0.653 |

## Discussion

The maintenance of adequate preoperative blood volume in elderly patients is necessary to protect the function of tissues and organs, to reduce the occurrence of surgical complications, and to promote patient recovery after surgery [12]. Various methods can be used to monitor blood volume during surgery to guide fluid administration. The RVI of the inferior vena cava is one of the most commonly used methods [13, 14]. However, this vein is difficult to image via US due to its deep location. Various studies have explored the accuracy of using the IJV to measure the blood volume. However, to our knowledge, few studies have been conducted assessing the adequacy of this technique in elderly patients.

The findings of our study indicate that the diameter of the IJV before and after the infusion decreased during inhalation as the intrathoracic pressure decreased, and increased during expiration as the intrathoracic pressure increased. After the infusion, a statistically significant increase in both diameter and blood velocity and a statistically significant decrease in the RVI was noted. These variations correlated with the amount of fluid administered, indicating that the diameter of the IJV is sensitive to an increase in blood volume and can therefore be used to detect an insufficient blood volume. Our results validated the results of a previous study [15] which investigated the value of RVI of IJV in patients with sepsis. They concluded RVI of IJV was a precise, easily acquired, non-invasive parameter of fluid responsiveness in patients with sepsis who were not mechanically ventilated. But their study only measured the RVI of IJV; we differed from theirs as we also measured the diameter and blood flow velocity of IJV.

Several other studies in the past had also suggested that RVI provided excellent correlations with CVP [16–19], but they only compared the correlation between RVI and CVP. In our study, we found that the Dmax, Dmin, BVmax, BVmin, and RVI of the IJV in elderly patients before

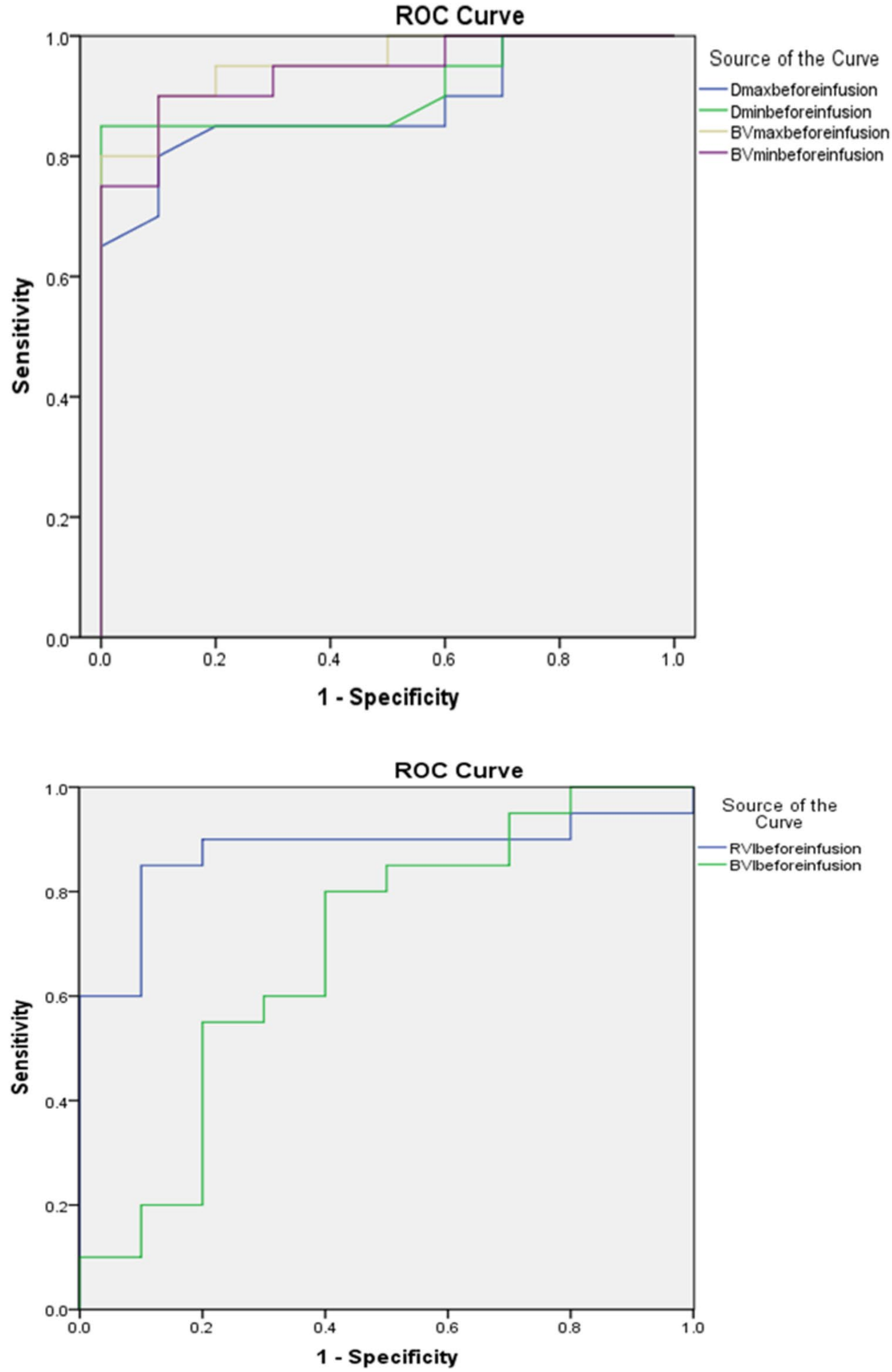


**Fig. 1** The ROC curve of Dmax, Dmin, BVmax, BVmin, RVI, and BVI before infusion in predicting CVP > 6 mmHg

infusion had a good correlation with CVP. Although BVI was negatively correlated with CVP, the correlation was not statistically significant. This result could be related due to differences in blood flow velocity with respiratory changes, but also due to the small infusion volume provided in our study. Among these indicators, the Dmax, Dmin, BVmax, BVmin, and CVP were positively correlated, while RVI and CVP were negatively correlated before and after the infusion. BVI was also negatively correlated with CVP and also increased after infusion, but the difference was not statistically significant.

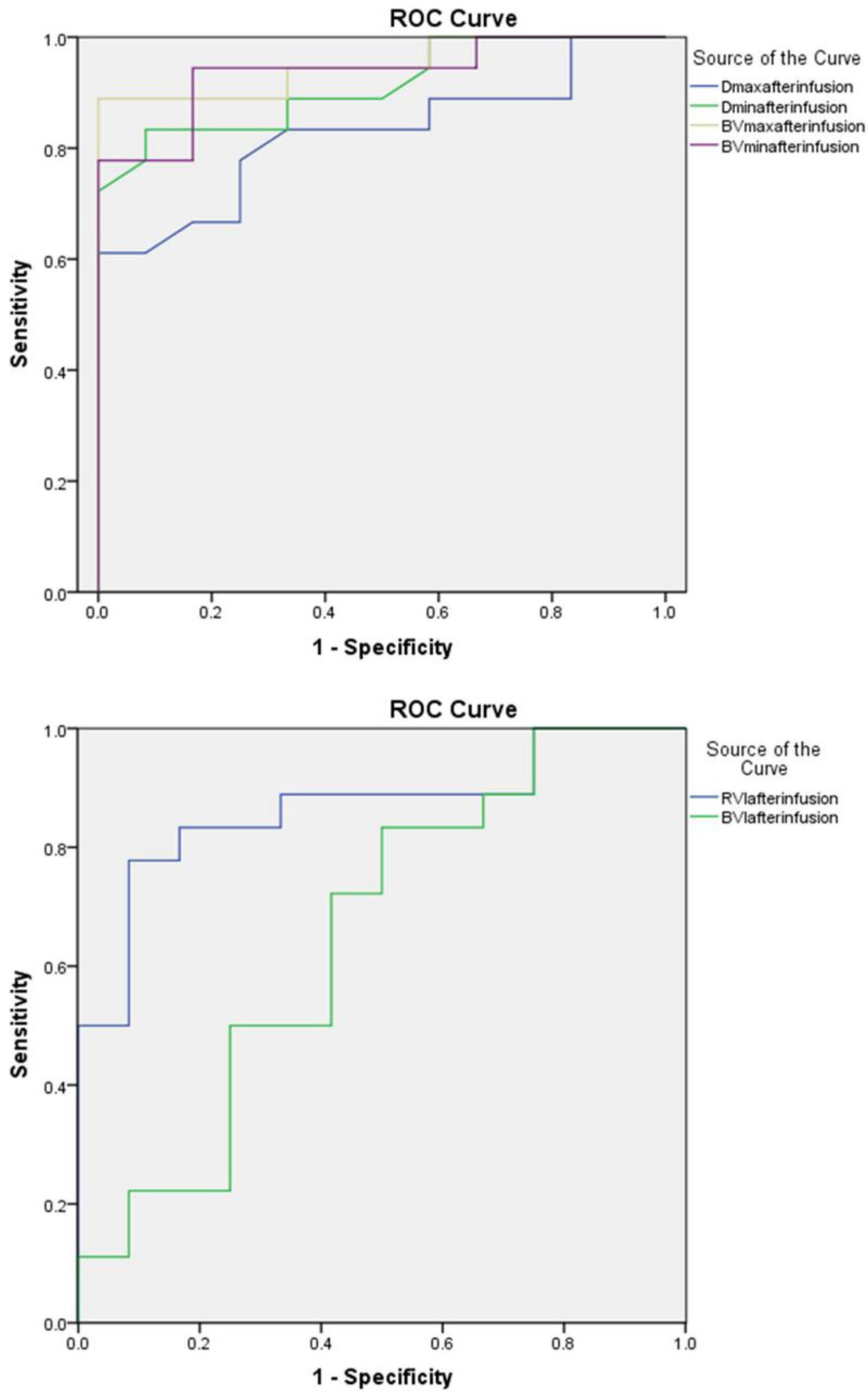


**Fig. 2** The ROC curve of Dmax, Dmin, BVmax, BVmin, RVI, and BVI after infusion in predicting CVP > 6 mmHg

The velocity of venous blood reflux is mainly determined by the pressure difference between the two ends of the blood vessel. When the pressure difference is large, the blood flow velocity will be fast and vice versa [17]. As a result, the blood in the IJV will flow back to the superior vena cava, and its velocity will depend on the pressure difference between the IJV and the superior vena cava. The pressure of the superior vena cava varies with the periodic pressure changes of the right atrium and respiration and eventually influence the blood flow velocity in the IJV accordingly. When blood volume is relatively insufficient, the thoracic pressure on the right atrium and superior vena cava pressure will increase and vice versa. Based on Poiseuille's law, this change will lead to an increased blood flow velocity of the IJV.

In this study, after the infusion, the BVmax increased, while the BVI decreased. However, for both parameters, the difference was small and not statistically significant. A potential reason for this could be the relatively small infusion volume provided to the patients in our study. Further research should therefore look into the impact of increasing the volume of the infusion on these indicators.

CVP is an indirect measure of cardiac preload and can reflect the state of patients' blood volume. Although recent studies have shown that CVP has some limitations [20, 21], it is still recommended by some mainstream clinical guidelines as an important reference index for fluid resuscitation [22]. According to the consensus guidelines issued by the anesthesia branch of the Chinese medical association in 2014, a CVP between 6 and 8 mmHg can provide enough circulatory capacity to match with the cardiovascular function while providing optimal tissue perfusion, cardiac output without compromising organ function. A CVP of 6 mmHg was also found to be a good indicator for circulatory capacity in a meta-analysis and was therefore selected as the cutoff point in our study [23].

When analyzing the ROC curve, all indexes except for BVI before infusion had high sensitivity and specificity and can therefore be used to predict an elevated CVP. BVmax had the best diagnostic efficacy with a diagnostic threshold of 8.72 cm/s and a sensitivity and specificity of 90% before infusion. The diagnostic threshold after the infusion was 7.97 cm/s with a sensitivity of 100% and a specificity of 88.9%. However, only the differences in Dmax, Dmin, and RVI before and after the infusion were statistically significant. Although the other indicators varied following infusion, the difference was not statistically significant. This may be related to the small infusion volume provided to the patients in this study, limited infusion time and small sample size. Therefore, further research using a larger sample and a larger infusion volume is needed. The main reference index of this study is central venous pressure, and more reference indexes may be added to obtain more results.

An increase in the threshold cutoff points following infusion was noted for all other indices. Compared with all other indices, the specificity of Dmax and RVI decreased after the infusion, and therefore, the indices have limited use as diagnostic indicators for CVP.

## Conclusion

This study showed that US measurements of Dmax, Dmin, BVmax, BVmin, and RVI of the IJV could be used to measure perioperative blood volume and provide a simple, reliable method to guide preoperative infusion in elderly patients. In future studies, we can add more reference indicators, study more target population, and compare with the current study of inferior vena cava.

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**Authors Contribution** Wei Wang was the major writer and designer of the experiment. Qingqing Liu and Zhijian Lan were the participants of the experiment. They participated in the specific measurement and data recording of some experiments. Xiaohong Wen was the master tutor of Wei Wang and Qingqing Liu, and she participated in the design and guidance of the experiment.

## Declarations

**Ethics Approval and Consent to Participate** This study was approved by the ethics committee of the Jinhua Municipal Central Hospital, ethical review No. (87), and written informed consent was obtained from all patients participating in the study.

**Conflict of Interest** The authors declare no competing interests.



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