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Application of Bedside Ultrasonography to Assess Axillary Veins and Predict Volume Responsiveness in Mechanically Ventilated Patients

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Abstract

Aim: This research aimed to explore the correlation between the axillary vein (AXV) and the inferior vena cava (IVC) for volume assessment following non-thoracic abdominal surgery in patients under mechanical ventilation. The primary objective was to determine whether the AXV could serve as a reliable indicator for evaluating volume responsiveness.

Study Design: This retrospective cohort study included 106 critically ill patients admitted to the intensive care unit (ICU) of Peking University People's Hospital after non-thoracic abdominal surgery between November 2023 and June 2024. All patients were on invasive mechanical ventilation (volume-controlled; tidal volume 8 mL/kg, positive end-expiratory pressure 5 cmH_2O) and had not yet recovered spontaneous respiration postoperatively. The relevant indices were monitored at postoperative admission to the ICU. The diameters of AXV and IVC were measured using ultrasonography, and the dilatation index (DI) was calculated. At admission, ultrasonography was performed on the left ventricle and the left ventricular outflow tract to determine the velocity time index (VTI). These indices were remeasured after a rapid infusion of 100 mL of sodium lactate Ringer's solution. The patients were categorized into volume-responsive and non-volume-responsive groups according to VTI measurements before and after the volume-loading test, and the correlation between the relevant parameters and hypovolemia was analyzed.

Results: The sensitivity and specificity of a critical AXV-DI value of 22.2% were 88.1% and 77.36%, respectively.

Conclusions: Axillary vein dilatation index is a valid indicator for volume assessment in postoperative patients in surgical ICUs.

Keywords: Axillary vein; Dilatation index; Inferior vena cava; Mechanical ventilation; Volumetric responsiveness.

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Introduction

Postoperative patients frequently experience volume insufficiency owing to factors such as preoperative water fasting and intraoperative anesthesia induction. Therefore, the evaluation of postoperative patient volume status and accurate indications for fluid resuscitation have become essential functions in the intensive care unit.[1] Conventional methods for postoperative volume assessment involve observing mucous membrane color, skin elasticity, urine volume, blood pressure, and heart rate (HR). While these methods are convenient, rapid, and do not require special operations, their accuracy cannot be precisely quantified. Invasive hemodynamic monitoring is clinically challenging and can be influenced by various factors, including the external environment, etiology, and other confounders that make it difficult to rapidly determine the effectiveness of volume resuscitation.[2-4] Ultrasonography is widely utilized to measure the respiratory variability of the inferior vena cava (IVC) for volume assessment owing to its simplicity, non-invasiveness, and reproducibility. However, factors such as gastrointestinal distension, abdominal subcutaneous emphysema, and high intra-abdominal pressure lead to poor visualization of the IVC, thereby compromising the accuracy of volume assessment.[5] The current study aimed to determine whether the axillary vein could serve as a vessel for volume assessment by measuring the respiratory variabilities of axillary vein dilatation index (AXV-DI) and inferior vena cava dilatation index (IVC-DI) in postoperative patients who underwent non-thoracic abdominal surgery.

Materials and Methods

Study Overview

This study was approved by the Ethics Review Committee of Peking University Peoples Hospital (Approval Number: 2020PHB118-01, Date: 02.06.2025). It was conducted in accordance with the ethical standards of the Institutional Research Committee and the 1964 Declaration of Helsinki, including its subsequent revisions. In this trial, data were collected from 106 postoperative patients who had undergone non-thoracic abdominal surgery and were admitted to the intensive care unit (ICU) between November 2023 and June 2024. Written informed consent was obtained from each participant.

Study Population

The inclusion criteria were as follows: patients who did not awaken from anesthesia, were on invasive mechanical ventilation, and had not recovered spontaneous respiration. The exclusion criteria were as follows: patients who had undergone thoracic or abdominal surgery; patients with atrial fibrillation, frequent ventricular premature beats, or other arrhythmias affecting velocity time integral (VTI) measurements identified by preoperative electrocardiogram (ECG) screening; patients diagnosed with valvular heart disease, tricuspid regurgitation, or pulmonary hypertension by echocardiography; patients with pneumothorax, massive pleural effusion, or superior vena cava syndrome; pregnant women; patients whose inferior vena cava examination by ultrasound was compromised by severe obesity, abdominal hypertension, large space-occupying lesions in the abdominal cavity, or severe intestinal distension; patients suspected of having pulmonary embolism; patients unable to undergo internal jugular vein puncture catheterization for monitoring central venous pressure (CVP); and patients who did not agree to participate in the trial.

Study Protocol/Data Collection

General patient information, including age, sex, height, weight, Body Mass Index (BMI), and Acute Physiology and Chronic Health Evaluation II scores (APACHE II), was collected. A central venous catheter was placed through the right internal jugular vein to monitor CVP, with the zero point set at the level of the fourth intercostal space in the right midaxillary line. Radial artery puncture was performed to monitor arterial blood pressure and record mean arterial pressure (MAP) and heart rate (HR). Meanwhile, bedside ultrasonography was performed to measure and calculate the IVC-DI and AXV-DI in all patients admitted to the department. The VTI of the left ventricular outflow tract (LVOT) was measured using ultrasonography with a low-frequency probe (3.5 MHz). Subsequently, a volume loading test was conducted: each patient was infused with 100 mL of sodium lactate Ringer's solution within one minute. After completion of the fluid infusion, heart rate (HR), CVP, and MAP were remeasured, and bedside ultrasonography was used to remeasure IVC-DI, AXV-DI, and VTI. Compared to pre-volume resuscitation, patients with a ≥10% increase in VTI after volume expansion were included in the volume-responsive (Responder, R) group, whereas patients with a <10% increase

in VTI after volume expansion were included in the non-volume-responsive (non-responder, NR) group.[6] A physician with five years of experience in critical care ultrasonography performed all examinations. Bedside ultrasonography was performed using the Mindray ME7 Doppler echocardiography system. Bedside transthoracic ultrasonography measurements were recorded as follows (Fig. 1): all patients were placed in the supine position, and the ventilator was set to volume-controlled ventilation mode with the following parameters: positive end-expiratory pressure (PEEP) of 5 cmH_2O, tidal volume of 8 mL/kg, respiratory rate of 15 breaths/min, and plateau pressure <30 cmH_2O.[8]

IVC measurements: The longitudinal image of the inferior vena cava was obtained using a 3.5-MHz low-frequency probe in B-mode in the subcostal region to measure the diameter of the IVC at a point 1 cm distal to the hepatic vein orifice.[7, 8] The maximum ($dIVC_{max}$) and minimum (dIVCmin) IVC diameters in one respiratory cycle were measured, and the IVC-DI was calculated as:

$IVC\text{-}DI=[(dIVC_{max}-dIVC_{min})/dIVC_{min}]*100\%$ (Fig. 1A).[8]

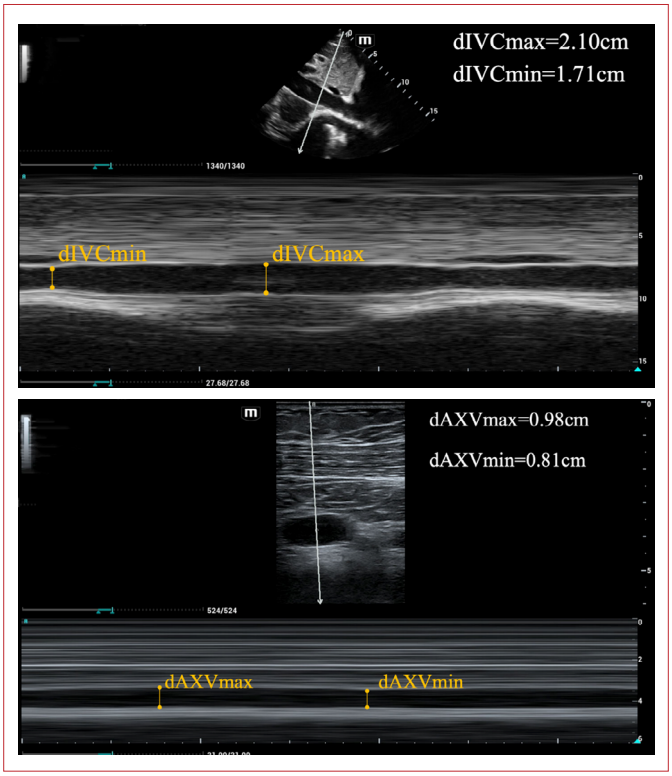

Figure 1. Bedside transthoracic ultrasonography measurements of the inferior vena cava and axillary vein. (A) IVC-DI=[($dIVC_{max}$-$dIVC_{min}$)/$dIVC_{min}$]*100%=(2.10-1.71)/1.71*100%=22.80%. (B) AXV-DI=($dAXV_{max}$-$dAXV_{min}$)/$dAXV_{min}$*100%=(0.98-0.81)/0.81*100%=20.99%.

AXV measurements: With the patient in the supine position, a 7.5-MHz linear probe was applied to localize the right axillary vein. The third segment of the axillary vein was selected, and its position was scanned from below the midpoint of the clavicle, perpendicular to the clavicle, with gradual inward-outward adjustment. The probe was then shifted to the superior border of the pectoralis minor muscle and the lateral edge of the first rib to obtain the best cross-sectional view of the AXV. Color Doppler or spectral Doppler function was then applied to explore the short-axis view of the target vessel and to differentiate the axillary artery from the axillary vein.[9] The probe was rotated so that it was parallel to the clavicle, and the subclavicular long axis was applied to measure the maximal diameter of the AXV ($dAXV_{max}$) and the minimal diameter (dAXVmin) during a single respiratory cycle. The AXV-DI was calculated as follows:

$[(dAXV_{max}-dAXV_{min})/dAXV_{min}]*100\%$ (Figs. 1B).

Statistical Methods

Statistical analysis was performed using SPSS Statistics, version 27 (IBM Corporation, Armonk, New York, United States). Receiver operating characteristic (ROC) curve analysis and graphing were conducted using GraphPad Prism (GraphPad Software, Inc., San Diego, California, USA). For non-normally distributed measurements, the non-parametric Mann-Whitney test was used between the two independent samples. The non-parametric Wilcoxon test was used to compare paired values at T0 and T1. The diagnostic value, sensitivity, and specificity of AXV-DI and IVC-DI for measuring volume responsiveness were determined according to the ROC curve. Diagnostic efficiency was evaluated based on the area under the ROC curve (AUC), whereby an AUC>0.7 indicated good diagnostic accuracy of the index.

Results

Descriptive Statistics

A total of 106 patients were enrolled in this study, and their diagnoses are listed in Table 1. Four were excluded because the IVC or LVOT were not well visualized, and three patients were excluded because the axillary veins could not be identified. The remaining 95 patients included 51 females and 44 males. Among them, 42 patients were responders and 53 were non-responders. The age, height, weight, Body Mass Index, and APACHE II scores of the two groups were not statistically different (P>0.05) (Table 2). Table 3 shows the data

Table 1. Main diagnoses of patients in the study (total patients: 106)

Diagnoses	Number of patients
Cerebral Hemorrhage	19
Traumatic Brain Injury	10
Thyroid Carcinoma	10
Endometrial Cancer	10
Cervical Cancer	9
Oral Tumor	7
Benign Prostatic Hyperplasia	6
Cerebellar Hamartoma	6
Bladder Tumor	6
Meningitis	5
Uterine Polyps	5
Lumbar Disc Herniation	5
Lumbar Spinal Stenosis	2
Glioblastoma Multiforme (GBM)	1
Others	5

Table 2. General patient information

	Responders (n=42)	Non Responders (n=53)	Z	p
Age	48 (29–60.5)	55 (40.5–67.5)	-1.665	0.095
Height (m)	1.7 (1.61–1.74)	1.69 (1.59–1.72)	-1.310	0.190
Weight (kg)	73.35 (59.40–84.23)	69.14 (56.03–82.70)	-0.952	0.341
BMI (kg/m^2)	26.48 (22.59–28.27)	25.44 (19.21–28.90)	-0.307	0.758
APACHE II	18 (12–22)	15 (12–19.5)	-1.266	0.206

BMI: Body Mass Index; APACHE II: Acute Physiology and Chronic Health Evaluation II.

before volume expansion in the overall population. The HR, MAP, CVP, IVC-DI, and AXV-DI measured before resuscitation differed significantly between the two groups ($p<0.05$). During the operation, 26 patients (16 in the R group and 10 in the NR group) developed systolic blood pressure below 90 mmHg due to anesthesia and received phenylephrine (mean dose: 5 μg). Fifteen patients (10 in the R group and 5 in the NR group) exhibited signs of shock, requiring the use of vasopressors during surgery, and still needed norepinephrine (mean dose: 0.02 μg/kg/min) when they were transferred back to the intensive care unit. The volume of fluid infusion during the operation and the use of vasopressors were not significantly different between the two groups ($p>0.05$). The HR, MAP, CVP, LVOT-VTI, IVC-DI, and AXV-DI parameters were recorded for all patients before (T0) and after (T1) fluid resuscitation. In the R group, the IVC-DI and AXV-DI showed statistically significant differences before and after resuscitation ($p<0.05$) (Table 4).

The AUC values of IVC-DI and AXV-DI were 0.91 (95% confidence interval [CI]: 0.85–0.97) and 0.88 (95% CI: 0.81–0.95), respectively. The cutoff point of IVC-DI was 25.75%; the sensitivity and specificity of this cutoff were 78.57% and 94.34%, respectively. The cutoff point of AXV-DI was 22.2%; the sensitivity and specificity of this cutoff were 88.1% and 77.36%, respectively. Both IVC-DI and AXV-DI had high predictive values (Fig. 2).

Discussion

Volume status management is a first-line therapeutic option for increasing cardiac output (CO) and enhancing tissue oxygen perfusion in hemodynamically unstable patients. The assessment of intravascular volume and fluid responsiveness is crucial, as incorrect fluid management can have severe consequences in critically ill individuals.[10] Various methods of dynamic volume responsiveness evaluation, such as pulse pressure vari-

Table 3. Parameters before capacity loading

	Yes (n=42)	No (n=53)	Z	P
HR (beats/min)	101 (98.75–114)	72 (68–88)	-5.812	<0.05
MAP (mmHg)	62 (59.75–63.75)	71 (68–73.5)	-7.273	<0.05
CVP (cmH_2O)	4.5 (4.2–5.2)	7.4 (7–8.05)	-6.452	<0.05
Dose of norepinephrine (μg/kg/min)	0.03 (0.03–0.08)	0.03 (0.02–0.08)	-0.502	-0.616
Infusion volume (mL)	1727 (1427.5–2012.5)	1750 (1495.00–2030.00)	-0.409	0.683
IVC-DI (%)	32.30 (26.95–35.91)	10.56 (5.95–16.09)	-6.835	<0.05
AXV-DI (%)	37.32 (29.64–52.16)	16.33 (11.26–20.90)	-6.296	<0.05

HR: Heart rate; MAP: Mean arterial pressure; CVP: Central venous pressure; IVC-DI: Inferior vena cava dilatation index; AXV-DI: Axillary vein dilatation index.

Table 4. Parameters at T0 before rehydration and T1 after rehydration in responsive (R) and non-responsive (NR) patient groups

	Group	T0	T1	P
HR	R	101 (98.75–114)	89 (79–99)	<0.05
(beats/minute)	NR	72 (68–88)	72 (67.5–79)	0.063
MAP (mmHg)	R	62 (59.75–63.75)	66 (66–68)	<0.05
	NR	71 (68–73.5)	71 (69–76)	0.088
CVP (cmH_2O)	R	4.50 (4.20–5.20)	6.8 (5.65–7.23)	<0.05
	NR	7.4 (7–8.05)	7.5 (7.1–8.2)	<0.05
LVOT-VTI	R	16 (15–16)	18 (17–19)	<0.05
	NR	19 (18–22)	20 (19–22)	<0.05
IVC-DI (%)	R	32.30 (26.95–35.91)	21.56 (14.53–27.63)	<0.05
	NR	10.56 (5.95–16.09)	12.00 (6.76–18.31)	0.064
AXV-DI (%)	R	37.32 (29.64–52.17)	27.35 (17.33–37.30)	<0.05
	NR	16.33 (11.26–20.90)	14.27 (8.79–18.44)	0.088

HR: Heart rate; MAP: Mean arterial pressure; CVP: Central venous pressure; LVOT-VTI: Velocity time integral of the left ventricular outflow tract; IVC-DI, Inferior vena cava dilatation index; AXV-DI: Axillary vein dilatation index.

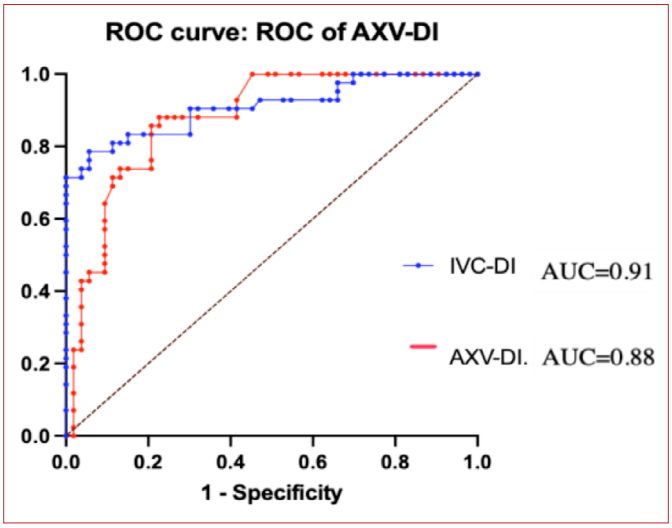

Figure 2. Receiver operating characteristic curves for IVC-DI and AXV-DI.
***Wilcoxon test. IVC-DI: Inferior vena cava dilatation index; AXV-DI: Axillary vein dilatation index.**

ability, stroke volume (SV) variability, respiratory variability of the IVC diameter, end-expiratory occlusion test, passive leg raising test, and fluid challenge test, have been widely studied and extensively applied in clinical settings.[11] The mini-fluid challenge has been validated in numerous studies for its ability to rapidly assess fluid responsiveness.[6,12] The CO is determined by multiplying SV by HR; SV is calculated by multiplying the VTI of the left ventricular outflow tract, measured via Doppler ultrasonography at the five-chamber cardiac interface, by the cross-sectional area (CSA), which is computed from the diameter (d) of the LV outflow tract (formula: $CSA=\pi(d/2)^2$, and SV=VTI*CSA). Therefore, the measurement of VTI is related to the CO. With the widespread use of bedside ultrasonography devices in ICUs, the respiratory variability of the IVC, measured by ultrasonography, has become a prevalent tool for volume assessment. The physiological behavior of the IVC varies between spontaneous breathing and mechanical ventilation conditions.[13] During spontaneous respiration, the intrathoracic cavity is negatively pressurized during inspiration, and the IVC volume decreases because of the increase in venous return; therefore, the IVC diameter decreases. During expiration, intrathoracic pressure increases, and venous return decreases; therefore, the diameter of the IVC at the end of expiration increases. In the presence of positive-pressure mechanical ventilation, the respiratory variability of the IVC shows the opposite physiological pattern; that is, the IVC diameter increases during inspiration and decreases during expiration. During autonomic breathing, the collapse index (CI) is applied to assess the variability of the IVC.[14] Individuals with a high IVC-CI are more prone to experiencing hypovolemia (>50%–70%). When the IVC-CI is low, patients may be more likely to be hypervolemic (<20%).[15] Mechanical ventilation can be used to evaluate the variability of the IVC through the IVC-DI: $DI=(D_{max}-D_{min})/D_{min}*100\%$.[16] The significant variation in respiratory measurements, driven by respiratory modulation in patients with spontaneous breathing, hampers the standardization of IVC measurements on ultrasonography. A study published in 2004 reported that, when predicting volume responsiveness in mechanically ventilated patients, an IVC-DI of 18% achieved a sensitivity and specificity of 90% in distinguishing between volume-responsive and non-volume-responsive groups.[17] To eliminate interference from spontaneous breathing in assessing respiratory variability, we included only patients who were mechanically ventilated and did not engage in spontaneous breathing. However, changes in the diameter of the IVC depend on several factors such as vascular compliance, CVP, right atrial pressure, and abdominal pressure.[18] Consequently, conditions such as elevated intra-abdominal pressure and obesity might compromise the reliability of IVC volume assessments.[19, 20] Another important objective of this trial was to explore whether alternative vessels could serve as substitutes when the IVC cannot be monitored. The AXV, as a central vein, is easily visualized using ultra-

sonography. Meanwhile, the AXV is not obstructed by the clavicle and is not influenced by intra-abdominal pressure or positive-pressure ventilation.[21] A study by Zhu et al.[22] showed that the diameter of the AXV in the supine position was positively correlated with CVP and fluid volume responsiveness. In addition, the internal jugular vein tends to collapse, and the femoral vein is less susceptible to compression, whereas the AXV differs from both, and the right axillary vein is close to the right side of the heart. Therefore, the right axillary vein is the most viable alternative to the central vein in the IVC.[23] Molokoane-Mokgoro et al.[24] examined non-invasive ventilator-assisted ventilation in volunteers and found that positive pressures delivered via non-invasive ventilation in the IVC and AXV produced a similar degree of diameter change, and the dilatation indices were similar at PEEP parameters of 5 and 10 cmH_2O. Similarly, in our study, the right AXV was used, and the ventilator was set to volume control mode with a tidal volume of 8 mL/kg and a PEEP level of 5 cmH_2O. The results showed that the difference in AXV-DI before fluid resuscitation was statistically significant between the two groups. Meanwhile, the ROC curve showed that the AUC values of IVC-DI and AXV-DI were 0.91 and 0.88, respectively, both being >0.7, suggesting that AXV-DI and IVC-DI were equally predictive of volume assessment under mechanical ventilation. Among the spontaneously breathing population, Chen et al.[9] demonstrated that the axillary vein collapsibility index (AXV-CI) is a practical predictive indicator, similar to the inferior vena cava collapsibility index (IVC-CI), in spontaneously breathing patients, and can effectively predict whether older patients undergoing gastrointestinal surgery will experience hypotension after anesthesia induction. This study provides a research basis for exploring the relationship between preoperative patient volume assessment and AXV-CI. Currently, research on point-of-care volume assessment is mainly focused on operating rooms and intensive care units, which may be related to the limited availability of ultrasonography equipment and techniques. In addition to the aforementioned methods, Pulse Indicator Continuous Cardiac Output (PICCO) is an invasive approach to hemodynamic monitoring that can provide specific parameters such as blood volume, systemic vascular resistance, and cardiac function, thereby guiding the selection of fluid resuscitation, antidiuretic agents, and inotropic agents.[25] The Global End-Diastolic Index (GEDI) can directly reflect the cardiac volume status and is more precise than CVP in indicating cardiac preload.[26] In a recent study, Jia et al.[27] found that in patients with non-valvular heart disease, the GEDI was significantly correlated with the maximum diameter of the inferior vena cava (IVC_{max}) (r=0.311, p=0.007), as well as with the minimum diameter of the inferior vena cava (IVC_{min}) (r=0.308, p=0.007). This information also provides another perspective for follow-up research related to our study.

Feasibility of This Trial

The study sample comprised postoperative non-thoracic and abdominal surgery patients with no spontaneous respiration, minimizing the influence of interfering factors and facilitating timely volumetric assessment of postoperative patients when spontaneous respiration had not yet been restored. The AXV is a highly compliant vessel whose volume and hemodynamics change with respiration; it has the advantage of being less affected by positive-pressure ventilation than the IVC, thereby yielding more stable measurements.

Study Limitations

In a previous study, an IVC-DI of 18% showed 90% sensitivity and 90% specificity in differentiating between volume-responsive and non-volume-responsive groups. The reasons behind the differences in results mainly include the small sample size and the restriction of the trial population to patients who had undergone non-thoracic abdominal surgeries.

Conclusion

For patients under mechanical ventilation in the surgical ICU, determining the AXV-DI using bedside ultrasonography can be a feasible method for postoperative volume assessment; moreover, the AXV can be used as an alternative vessel for fluid volume assessment in patients whose IVC diameter cannot be measured. Given the limitations of this study, further research is needed to confirm whether AXV-DI can be applied to other clinical situations.

Ethics Committee Approval: Ethics committee approval was obtained from Ethics Review Committee of Peking University Peoples Hospital (Approval Number: 2020PHB118-01, Date: 02.06.2025).

Informed Consent: Written informed consent was obtained from each participant.

Conflict of Interest: The authors have no conflicts of interest to declare.

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