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Role of echocardiography in guiding fluid therapy in shocked patients with impaired cardiac contractility

Role of echocardiography in guiding fluid therapy in shocked patients

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Abstract

Aim: Excessive fluid delivery has harmful effects, such as volume overload and pulmonary and systemic edema, which restrict oxygen transport to different tissues, increasing tissue hypoxia. Therefore, gathering accurate data on the fluid status and intra-cardiac filling pressures in patients with circulatory failure is crucial, particularly in patients who have compromised cardiac function. This study was designed to evaluate the role of echocardiography in guiding fluid therapy in shocked patients with impaired cardiac contractility in the Emergency Department of Alexandria Main University Hospital.

Material and Methods: We enrolled 100 patients who presented with shock and impaired cardiac contractility (ejection fraction < 52%) from August 2021 to July 2022. The baseline left ventricular outflow tract (LVOT) velocity time integral (VTI) and inferior vena cava (IVC) collapsibility index were measured using echocardiography; then, the passive leg raising (PLR) test was performed; and the second LVOT VTI was measured. Fluid challenge using 250-mL normal saline was administered to patients who tolerated the PLR test and did not show signs of volume overload during the PLR test. After fluid challenge, the third LVOT VTI was obtained.

Results: Twenty-one patients were excluded from the fluid challenge step as they did not tolerate the PLR test or they experienced signs of fluid overload (lung congestion) during the PLR test. Using the cutoff value of the IVC collapsibility index >51.85%, the sensitivity, specificity, positive predictive value, and negative predictive value were 75.0%, 80.0%, 82.5%, and 71.8%, respectively. The area under the receiver operating characteristic curve for the IVC collapsibility index for predicting fluid responsiveness was 0.774.

Discussion: The IVC showed major respiratory variations in the responder group compared with that in the other two groups, indicating that the intra-cardiac filling pressures (preload) in the responder group were low and their hearts were working on the steep portion of the Frank–Starling curve.

Keywords

Echocardiography, Contractility, Shock, Fluids

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Introduction

Fluid therapy represents a major challenge in managing shocked patients, particularly those who have cardiac dysfunction. When the heart is working on the steep region of the Frank–Starling curve, preload will increase with intravenous (IV) fluids, thus significantly increasing the stroke volume, implying that fluid administration improves cardiac output and oxygen delivery to different tissues [1].

Clinicians cannot depend solely on clinical examination to evaluate the fluid status or responsiveness to fluid therapy [2]. Many studies have illustrated the role of imaging in assessing fluid responsiveness in patients with sepsis, those with septic shock and surgical patients [3, 4]; however, in our study, we only discussed the role of echocardiography in guiding fluid therapy in patients who have impaired cardiac contractility.

This study was designed to evaluate the role of echocardiography in guiding fluid therapy in shocked patients with impaired cardiac contractility in the ED of AMUH.

Material and Methods

Study design and setting

This prospective interventional non-randomized study was conducted in the ED of Alexandria Main University Hospital (AMUH) from August 2021 to July 2022. This study was reviewed and approved by the Ethics Committee of Alexandria University (reference number 0201517). Informed consent was obtained from all patients or next of kin.

Characteristics of participants

We enrolled 100 patients who presented with shock and had impaired cardiac ejection fraction (<52%) (available at: https://www.ncbi.nlm.nih.gov/books/NBK459131/) before receiving any IV fluids, vasopressor, or inotropes. Patients with trauma, unstable arrhythmias, lower limb amputation, prosthetic aortic valves, or pregnant, those on mechanical ventilation, and those aged <18 years were excluded from this study.

Sample Size: Using the Power Analysis and Sample Size (PASS 2020) software (NCSS, LIC, Kaysville, Utah, USA, ness.com/software/pass), the Department of Medical Statistics, Medical Research Institute, Alexandria University calculated the sample size considering 5% significance level and 3% precision using the Z-test [5].

Interventions

This study was conducted by the corresponding author who completed 5 years of training in the use of echocardiography in the ED and attended 100-h dedicated online echocardiography training. Moreover, the author has performed more than 500 reviewed echocardiography examinations before conducting this study.

We performed echocardiographic examination using the Sonoscape S6 portable color Doppler system (Yizhe Building, Yuquan Road. Nanshan, Shenzhen, 518051, Guangdong, China) using a phased array probe (1.9–6 MHZ).

After history taking and ABCDE assessment, performed by the emergency physician in charge of the case, shock was defined as systolic blood pressure of <90 mmHg for >30 min or a shock index (heart rate/systolic blood pressure) of >1 [6], with signs of tissue hypoperfusion, as follows: disturbed level of consciousness, cold clammy skin, oliguria, or serum lactate levels of >2.0 mmol/L [7].

Shocked patients were subjected to echocardiographic examination and were included in the study if they had an EF <52% (by the Simpson method or M-mode). The baseline LVOT VTI (before receiving any IV fluids, vasopressor, or inotropes) was obtained using the apical five-chamber view using pulsed wave Doppler signal from the left ventricular outflow tract, while the patient was supine or in the left lateral position. By tracing the LVOT VTI curve, we obtained the velocity time interval (VTI) [3].

While the patient is in the supine position, IVC scanning was performed through subcostal Window with M-mode. The minimum and maximum diameters were measured using the M-mode, as illustrated in Figure 1.

The collapsibility index was calculated using the following equation: IVC collapsibility index = (IVCmax–IVCmin / IVCmax)-100% [8].

Then, the passive leg raising (PLR) test was performed using the following technique [9]:

- Place the patient in the semi-recumbent position with the head up at 45°.
- Lower the patient's upper body to the horizontal level and passively raise both legs at 45°.
- The second LVOT VTI was obtained 90 seconds later.

Patients who tolerated the PLR test and did not develop clinical or lung ultrasound signs of fluid overload (lung congestion) were given IV fluid bolus (250-mL normal saline) over 10 min, followed by the measurement of the third LVOT VTI.

Patients who did not tolerate the PLR test or those who developed clinical or lung ultrasound signs of fluid overload (lung congestion) during the PLR test were excluded from the fluid challenge.

The differentiating factor used to allocate patients to groups (non-responders or responders) was the percentage of LVOT VTI variability between the third and baseline VTI values (our gold standard to assess fluid responsiveness).

Patients who showed LVOT VTI variability < 10% were considered non-responders. In contrast, those who showed LVOT VTI variability > 10% were considered fluid responders [10, 11].

Therefore, in this study, we included three groups of patients: non-responders, responders, and those who were excluded from the fluid challenge (third group).

Outcome measures

The outcome measured was the variability in the LVOT VTI to determine fluid responsiveness and how the IVC collapsibility index is correlated with the LVOT VTI variability.

Statistical analysis

Data were fed to the computer and analyzed using Statistical Package for the Social Sciences, version 20.0. (Armonk, NY: IBM Corp). Categorical data were represented as numbers and percentages. Quantitative data were expressed as ranges (minimum and maximum), means with standard deviations, or medians and interquartile ranges (IQRs), as appropriate. The chi-square test was used to compare the three groups. Continuous data were tested for normality of distribution using the Shapiro–Wilk test. For non-normally distributed quantitative variables, the Kruskal–Wallis test was used to compare three groups, followed by a post hoc test (Dunn's multiple comparisons test) for pairwise comparison between each two groups. Receiver operating characteristic (ROC) curve analysis was performed to predict the performance of the IVC collapsibility index in predicting fluid responsiveness. [12].

Ethical Approval

Ethics Committee approval for the study was obtained.

Results

According to the demographic characteristics of the three studied groups, a male predominance was observed in all groups. In the non-responder group, males accounted for 74.3%, whereas females accounted for 25.7%. In the responder group, males accounted for 52.3%, whereas females accounted for 47.7%. Finally, in the third group, males accounted for 52.4 %, whereas females accounted for 47.6%. The median age of the patients in the non-responder group was 62 years; however, that of those in the responder group and the third group was 64 years. No significant statistical difference in sex or age was observed between the three study groups (Table 1).

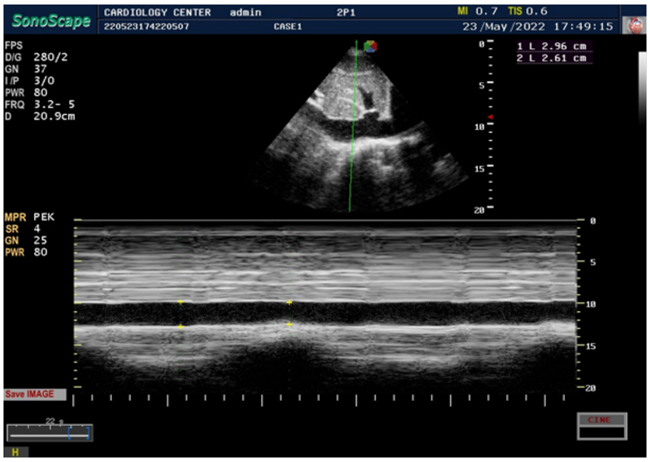

Figure 1. M-mode shows the maximum and minimum inferior VC diameters obtained through the subcostal window, while the patient was supine (collapsibility index = 11.8%).

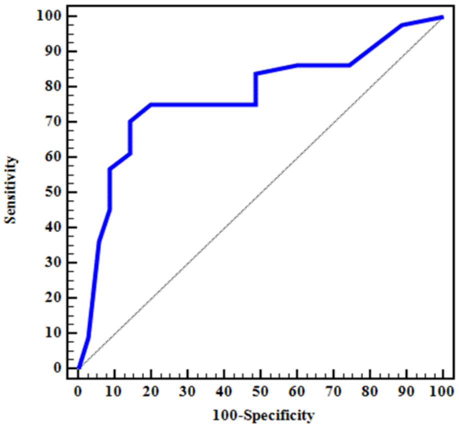

Figure 2. The ROC curve illustrating the diagnostic performance of the IVC collapsibility index

Regarding the comparison between the three studied groups according to ejection fraction, the median ejection fraction in the non-responder, responder, and third groups was 37.0%, 34.0%, and 35%, respectively. No significant statistical difference in the ejection fraction was observed between the three study groups.

According to the baseline IVC diameter and respiratory variation, the median minimum IVC diameters in the non-responder, responder, and third groups were 1.7 cm, 1.0 cm, and 1.8 cm, respectively. The median maximum IVC diameter in the non-responder, responder, and third groups was 2.7 cm, 2.1 cm, and 2.5 cm, respectively. The median IVC diameter collapsibility index in the non-responder, responder, and third groups was 26.1%, 55.6%, and 18.2%, respectively. Significant statistical differences in the IVC diameter and its respiratory variation ($p < 0.001$) were observed between the non-responder and responder groups and between the responder and third groups. Using the cutoff value of the IVC collapsibility index > 51.85%, the sensitivity, specificity, PPV, and NPV were 75.0%, 80.0%, 82.5%, and 71.8%, respectively, in predicting fluid responsiveness.

In Figure 2, the ROC curve illustrating the diagnostic performance of the IVC collapsibility index in predicting fluid responsiveness, the AUC was 0.774.

Discussion

In this study, 44% of the study cases were fluid responders, and this result was consistent with those reported by Memon AU et al., who found in their observational study that nearly half of the individuals with cardiogenic shock responded to fluid challenge [13].

No significant statistical difference in the recorded clinical parameters was observed between the three study groups, and this result was consistent with the results reported by Hiemstra B et al., who found that the clinical indicators of shock were critical for detecting the presence of shock; however, they did not identify the kind of shock or whether cardiac output was elevated, normal, or decreased [14].

The IVC showed major respiratory variations in the responder

Table 1. Comparison between the three groups according to demographic characteristics

	Total (n=100)	Non-responder (n=35)	Responders (n=44)	Third Group (n=21)	Test of Sig.	P
Sex						
Male	60 (60%)	26 (74.3%)	23 (52.3%)	11 (52.4%)	x^2 = 4.579	0.101
Female	40 (40%)	9 (25.7%)	21 (47.7%)	10 (47.6%)		
Age (years)						
Range	53–74	53–71	53–74	55–74	H=5.965	0.051
Mean±SD	63.9±6.6	61.9±5.7	64.8±6.6	65.2±7.5		
Median (IQR)	63 (60–70)	62 (60–66)	64 (60–70)	64 (55–70)		

IQR, interquartile range; SD, standard deviation; H, Kruskal-Wallis test; c^2, chi-square test; p, p-value for comparison between the three studied groups group compared with that in the other two groups, indicating that the intra-cardiac filling pressures (preload) in the responder group were low and their hearts were working on the steep portion of the Frank–Starling curve. No significant statistical difference in the ejection fraction was observed between the three study groups, as the responsiveness to fluid therapy depends primarily on intra-cardiac filling pressure (degree of myocardial stretch).

Compared with previous studies, Elsaeed AMR et al. found that the IVC collapsibility index >35% has a sensitivity of 95.8% and specificity of 93.7% for predicting fluid responsiveness in patients with sepsis (available at: https://doi.org/10.1186/s42077-022-00226-1). Nagi AI et al. reported that cutoff value >32% had a sensitivity of 72.41% and specificity of 82.76% for predicting responsiveness to fluid therapy (available at: https://doi.org/10.1186/s42077-021-00194-y). Pereira RM et al. showed that the AUC for the IVC collapsibility index was 0.981 in predicting responsiveness to fluid therapy [4]. Ismail MT et al. discovered that at the cutoff value of 40%, the IVC collapsibility index had a sensitivity and specificity of 93.3% and 70.7%, respectively, with an AUC of 0.908 (95% confidence interval [CI], 0.84–0.975), for predicting fluid responsiveness [15]. Suehiro K reported that respiratory variations of the IVC could reliably predict fluid responsiveness during spontaneous breathing with a pooled sensitivity and pooled specificity of 80% and 79%, respectively, with an AUC of 0.857 [16]. The differences between this study and the aforementioned studies may be because we only examined patients with impaired cardiac contractility who may already have elevated intra-cardiac filling pressures; however, others have examined different types of shock, including septic and hypovolemic shock, which usually respond to the initial fluid bolus.

The use of the IVC collapsibility index in predicting fluid responsiveness may be limited due to diseases in the right side of the heart, such as right-sided heart failure, tricuspid regurgitation, and pulmonary hypertension [17]. Moreover, in patients on mechanical ventilation, the IVC collapsibility is affected by the positive end-expiratory pressure level [18] and intra-abdominal hypertension [19].

Study strength: This study only included patients with shock who had impaired cardiac contractility before providing any fluids or supportive medications, which might have improved the accuracy of the obtained results.

Study limitations: This study was conducted on spontaneously breathing patients only.

Conclusion

The IVC collapsibility index can help clinicians solve the dilemma of fluid therapy in shocked patients with impaired cardiac contractility, thus protecting them from the hazards of unnecessary fluid administration. It is a simple and repeatable test.

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Scientific Responsibility Statement
The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement
All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Conflict of interest
The authors declare that they have no conflicts of interest.

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