ORIGINAL ARTICLE

# Role of Ultrasound in Evaluation of Undifferentiated Shock in ICU Settings

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## Abstract

**Objective**: To classify shock, using ultrasonography as the modality of choice for imaging and to assess the diagnostic accuracy of ultrasound as a tool to classify shock.

**Design**: Prospective study

**Setting**: KEM Hospital, Pune in the ICU (Intensive care unit)

**Study Population**: 100 patients admitted to the ICU with undifferentiated shock.

**Methods**: Bedside ultrasound examination was performed within 1 hour of admission to the ICU. These patients were also evaluated clinically and biochemically to confirm the type of shock. All patients immediately received standard diagnostic emergent interventions including physical examination, intravenous access for whole blood assays, arterial gas analysis, electrocardiography, continuous cardiac monitoring, supplemental oxygen and chest radiograph. Clinical parameters, urine output, ECG and biochemical tests were performed within 12 hours of USG. Additional investigations were performed wherever required. The ultrasonographic diagnoses were compared with the respective final clinical diagnoses by employing the Cohen kappa inter-rater coefficient of agreement. In addition, various ultrasound parameters were also analyzed to assess the best predictors for each type of shock.

**Results**: The ultrasound diagnosis showed an overall good agreement (Cohen's kappa coefficient > or = 0.6) with the final clinical diagnosis, in identifying the type of shock, in the emergency setting, when ultrasound was done within 1 hour after admission to the ICU. In our study, ultrasound showed maximum sensitivity, specificity, negative and positive predictive values in the setting of obstructive shock. In addition, perfect agreement was seen between the ultrasound and clinical diagnosis, with a Cohen kappa coefficient of 1 in obstructive shock. The least sensitivity, specificity, negative and positive predictive values of ultrasound were seen in the setting of distributive shock. Least agreement between the ultrasound and clinical diagnosis was also seen in distributive shock, as most ultrasound findings were found to overlap with those in the other types of shock. (Cohen kappa coefficient of 0.6).

**Conclusions**: Ultrasonography carried out within 1 hour of admission to the ICU plays a major role in correct diagnosis of the type of shock and subsequent patient management. The best ultrasonographic predictors for diagnosis of each type of shock, can help the clinician to start timely specific interventions in critical care settings for each type of shock.


## Introduction

Shock is one of the leading causes of death worldwide. The fundamental approach to management, therefore, is to recognize overt and impending shock in a timely fashion and to intervene urgently to restore perfusion. Evaluation of a patient in shock can be challenging owing to its complex pathophysiology and the spectrum of overlapping clinical findings. It is essential for the intensivist to identify the type and etiology of shock so as to formulate an emergency plan of management to prevent disastrous outcomes. The aim of our study was to outline the role of emergency bedside ultrasound in the evaluation of the patient in shock. We, performed a prospective study in the ICU, using bedside ultrasound to evaluate patients admitted with undifferentiated shock so as to classify shock into 4 categories, ie. hypovolemic, distributive, cardiogenic and obstructive or any combination of the above; and to assess the diagnostic accuracy of ultrasound as a tool to classify shock, by comparing the diagnosis on ultrasound with the final diagnosis, based on clinical and biochemical evaluation.

## Methods

### Patient Selection

The prospective study was carried out at KEM Hospital, Pune in the ICU (Intensive care unit). A total of 100 patients of undifferentiated shock were included in the study. The duration of the study was 385 days ranging from 5th January 2014 to 25th January 2015.

Patients included in the study, had age >18 years, systolic blood pressure < 90 mmHg at presentation, and presence of at least one of the following signs or symptoms of hypoperfusion: unresponsiveness, altered mental status (including unexplained severe anxiety), syncope, respiratory distress, profound asthenia with fatigue and malaise, and severe chest or abdominal pain. Patients were excluded from the study if they had a clear cause of shock diagnosed before the ultrasonographic evaluation mandating prompt life-

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Received: 18.10.2016; Accepted: 07.05.2018

**Table 1: IVC size and collapsibility[7]**

| IVC size | IVC collapse with inspiration |
|---|---|
| Small < 1.5 cm | Normal >50% |
| Normal 1.5 to 2.5 cm. | Abnormal < 50% |
| Dilated >2.5 cm. | Dilated IVC: No change |

saving treatment, such as external bleeding, trauma, and pregnancy related complications.

### Equipment Used

Machines used for the study were Sonosite M-Turbo and Voluson ultrasound machines. The straight linear array probe- 5 – 12 MHz, Curvilinear probe- 2-5 MHz and Sector array ultrasound probe 1-5 MHz were used for the study. The R Statistical software was used for data analysis.

### Ultrasonographic Technique

A comprehensive ultrasonography exam was carried out with the following parameters being studied. It was based on the RUSH protocol.[1]

### Cardiac Parameters

The parasternal long axis(PLAX) and the apical four-chamber (A4C) views were used to evaluate :

1. Left ventricular ejection fraction (EF) using Teicholz formula.[2] EF < 50% was considered as hypodynamic (Figure 1) while EF> 75% was considered as hyperdynamic.
2. Cardiac tamponade characterized by massive pericardial effusion with diastolic right atrial and ventricular collapse.[1]
3. Right heart strain[1] indicated by dilatation of the right atrium and ventricle.

### Lung Parameters

A curvilinear probe (2 to 5 MHz) was used to visualize the lungs. A straight linear array probe 5 – 12 MHZ frequency, was used for the assessment of pneumothorax. Lungs were assessed for the presence of 'A' lines, 'B' lines, and presence of consolidation. The ultrasonography profiles which were commonly seen were [3,4] 'A' profile - A lines with sliding movements suggestive of normal lung, 'B' profile with multiple B lines suggestive of pulmonary edema and 'C' profile suggestive of consolidation (Figure 2). 'A' profile with absence of lung sliding and identification of lung point were considered diagnostic of pneumothorax. Pleural effusion was looked for in the dependent lung areas delineated by the chest wall and the diaphragm.

### Abdominal Parameters

*Fast Examination[1,5]*

The standard curvilinear ultrasound probe was used. Specific areas to assess include the space between the liver and kidney (Morison pouch), perisplenic space, and the area around and behind the bladder (pouch of Douglas). A dark or anechoic area in any of these 3 potential spaces represents free intra-peritoneal fluid.[1]

*IVC Evaluation*

An estimate of the intravascular volume can be determined noninvasively by looking initially at the IVC.[6] Measurement of the IVC size and collapsibility was performed at the point just inferior to the confluence with the hepatic veins, at a point approximately 2 cm from the junction of right atrium and IVC.[1] The maximum and minimum diameters of the IVC tracing were measured to determine IVC collapsibility.[6] The IVC collapsibility is given by the formula:[6] (Maximum expiratory diameter – Minimum inspiratory diameter)/ Maximum expiratory diameter.

Table 1 shows the relationship between IVC size and collapsibility[7] and outlines the parameters for IVC measurement, A normal IVC measures between 1.5 to 2.5 cm in diameter and shows >50% collapsibility with inspiration.

A smaller caliber IVC with an inspiratory collapse greater than 50% roughly correlates to a CVP of less than 10 cm of water. This phenomenon is observed in hypovolemic and distributive shock states. A larger sized IVC that collapses less than 50% with inspiration correlates to a CVP of more than 10 cm of water.[1] This may be seen with cardiogenic and obstructive shock (Figure 3).

### Evaluation of the Vasculature

*Aortic Aneurysm and Dissection*

Using a curvilinear probe, the abdominal aorta was evaluated from epigastrium to iliac bifurcation. The diameter of the abdominal aorta was measured in short axis view, a measurement >30 mm was considered a sign of dilation.[1] The presence of aortic dissection was evaluated by colour flow imaging which delineated 2 lumens (Figure 4).

*Deep Vein Thrombosis*

The deep veins of the leg were examined for collapsibility in the short axis using a linear 5—12-MHz probe. Absence of collapsibility, presence of an echogenic thrombus within the lumen, and absent or decreased flow on colour doppler imaging were considered diagnostic for intra luminal thrombosis.[1]

Our study protocol was based on the RUSH[1] protocol to classify shock into the following categories

Classification of Shock Based on Ultrasound Findings:[1,8]

Based on our ultrasonography findings, we classified shock into 5 types as follows:

1. Hypovolemic:

   Heart: Hyperkinetic left ventricle *

   Inferior vena cava: Collapsed IVC or IVC diameter < 1.5 cm with >50% collapse *

   Lungs: 'A' Profile

   Abdomen: Aortic aneurysm/Aortic dissection

   *- necessarily present.
2. Distributive:

   Heart: Raised/decreased/normal EF.

   Inferior vena cava: Diameter < 2.5 cm. with > 50% collapse.

   Lungs: 'A' profile or 'C' profile.

   At least 2 of these signs must be present.
3. Cardiogenic:

   Heart: Hypokinetic left ventricle*

   Inferior vena cava: 1.5-2.5 cm. or > 2.5 cm. with <50% collapse

   Lungs: 'B' profile*

   Peripheral veins: normal.

   *- necessarily present.
4. Hypovolemic / Distributive shock:

   Features of distributive shock

   Presence of free fluid*

   *- necessarily present.
5. Obstructive shock:

   Heart: Cardiac tamponade / Right heart strain#

   IVC: <50% respiratory collapse and IVC diameter >2.5 cms.*

   Lungs: 'A' Profile / Pneumothorax#.

   Peripheral veins: Deep vein

**Table 2: Sensitivity, specificity and positive predictive value of ultrasound in diagnosing different types of shock**

| | Hypovolemic shock | Distributive shock | Cardiogenic shock | Hypovolemic/ distributive shock | Obstructive shock |
|---|---|---|---|---|---|
| Sensitivity | 60% | 71.78% | 81.11% | 75% | 100% |
| Specificity | 100% | 86.8% | 96.11% | 100% | 100% |
| Positive predictive value | 100% | 77.77% | 85.12% | 100% | 100% |

**Table 3: Correlation between final diagnosis and ultrasound diagnosis for shock and the Cohen's kappa inter-rater coefficient of agreement between them**

| Types of shock | Final diagnosis clinical and biochemical | Ultrasound diagnosis | Cohen's kappa coefficient | Strength of agreement |
|---|---|---|---|---|
| Hypovolemic (n=10) | 10 | 6 | 0.73 | Good |
| Distributive (n=39) | 39 | 28 | 0.6 | Good |
| Cardiogenic (n=22) | 22 | 18 | 0.79 | Good |
| Hypovolemic/Distributive (n=24) | 24 | 32 | 0.8 | Good |
| Obstructive (n=5) | 5 | 5 | 1.0 | Very good |

thrombosis.

*- necessarily present.

#- Either of these must be present.

Accordingly, the type of shock was classified into 5 categories namely: hypovolemic, distributive, cardiogenic, hypovolemic/distributive and obstructive types. These patients were also evaluated clinically and biochemically to confirm the type of shock. Additional investigations were performed wherever required. The biochemical and clinical parameters were evaluated by the intensive care physician and the final diagnosis was established based on these and also depending on the response to treatment. The diagnostic accuracy of ultrasound to classify shock was then assessed by statistical analysis.

### Statistical Evaluation

The ultrasonographic diagnoses were compared with the respective final clinical diagnoses by employing the Cohen kappa inter-rater coefficient of agreement. Values assumed by the coefficient in the analysis performed, were reported with the 95 % confidence intervals. For our statistical hypothesis test, $p \leq 0.05$ was considered significant. The sensitivity, specificity, positive and negative predictive values of ultrasound to diagnose each type of shock were calculated. In addition, we also analyzed the various ultrasound parameters to assess the best predictors for each type of shock. The R Statistical software and Microsoft Excel were used for statistical calculation.

## Results

The total number of patients in our study was 100. The average age of patients was 51.5 years (range=30-80 years). The predominant type of shock in our study was distributive shock (39 %), followed by hypovolemic/ distributive type, (24 %), cardiogenic shock (22%), hypovolemic shock (10%). The least common type of shock was obstructive shock (5%) cases.

The ultrasonographic findings in hypovolemic shock in our study were: increased ejection fraction of >70% in 60% cases (n= 6 of 10), 'A' profile in 90% patients (n=9 of10), IVC diameter <1.5 cm. in 80% patients (n=8 of 10), IVC collapsibility >50%, in 100% (n=10 of 10) patients.

The ultrasonographic findings in distributive shock in were: Normal ejection fraction in 71.8% (n= 28 of 39), 'A' profile in 79.5% cases (n=31 of 39), normal caliber IVC with >50% collapsibility in 79.5% cases (n=31 of 39).

The ultrasonographic findings in cardiogenic shock in our study were reduced ejection fraction of <55% in 100% cases (n=22 out of 22), 'B' profile on lung ultrasound in 81.8% cases (18 of 22), IVC collapsibility <50% in 66.67% patients (n= 14 of 22 cases).

The ultrasonographic findings in hypovolemic/distributive shock in our study were: free fluid seen in 100% cases, (n=24 of 24), normal ejection fraction in 75% patients (n=18 of 24),'A' profile on lung ultrasound in 95.8% patients (n=23 of 24), pleural effusion in 46% cases (n=11 of 24), normal caliber IVC with >50% collapsibility in 83.3% patients (n=20 of 24).

The ultrasonographic findings in obstructive shock in our study were reduced ejection fraction of <55% in 100% cases (n=5 out of 5), cardiac tamponade in 40% cases (n= 2 out of 5 cases), right heart strain in 60% cases (n=3 out of 5), 'A' profile on lung ultrasound in 100% cases (n=5 out of 5), distended IVC with < 50% collapsibility in 100% patients (n= 5 of 5).

The sensitivity, specificity and positive predictive value of ultrasound in diagnosing different types of shock were also statistically evaluated and is depicted in table 2. Table 3 depicts Correlation between Clinical Diagnosis and Ultrasound Diagnosis for Shock and the Cohen kappa Inter-Rater Coefficient of Agreement between them.

Table 2 depicts that ultrasound showed the highest Sensitivity, Specificity and Positive predictive value in diagnosing obstructive shock. The lowest specificity and Positive predictive value was seen in diagnosing distributive shock, and the lowest sensitivity was seen in diagnosing hypovolemic shock.

Table 3 shows that ultrasound showed an overall good correlation with the final diagnosis in the evaluation of shock. The highest degree of agreement was seen in obstructive shock and the least was seen in distributive shock.

In addition, we statistically evaluated each ultrasound parameter to ascertain the best predictors of each type of shock, shown in Table 4. This evaluation was not performed by other investigators in the setting of shock. Hence our study differed from other similar studies.

Table 4 outlines the collective parameters which predict the diagnosis of each type of shock on ultrasound evaluation.

## Discussion

Bedside ultrasonography is an excellent diagnostic methodology to evaluate the etiology of undifferentiated hypotension at bedside. A rapid, yet comprehensive multi-organ protocol improves the diagnostic accuracy in cases of challenging clinical situations in the intensive care unit. The ultrasound diagnosis showed an overall good agreement (Cohen's kappa coefficient > or = 0.6) with the final clinical diagnosis, in identifying the type of shock, in the emergency setting, when ultrasound was done within 1 hour after admission to the

**Table 4: Collective parameters which predict the diagnosis of each type of shock**

| Parameters | Types of shock | | | | |
|---|---|---|---|---|---|
| | Hypovolemic (n=10) | Distributive (n=39) | Cardiogenic (n=22) | Hypovolemic/ Distributive (n=24) | Obstructive (n=5) |
| Ejection fraction | >70% (n=6) | 55-70% (n=28) | < 55% (n=22) | 55-70% (n=18) | < 55% (n=5) |
| Right heart strain | - | - | - | - | Present (n=3) |
| Cardiac tamponade | - | - | - | - | Present (n=2) |
| Lung profile | - | 'C' profile (n=8) | 'B' profile (n=18) | 'A 'profile (n=23) | - |
| Pleural effusion | - | - | - | Present (n=11) | - |
| IVC size | < 1.5 cm (n=10) | 1.5 to 2.5 cm. (n=31) | 1.5 to 2.5 cm. (n=17) | 1.5 to 2.5 cm. (n=20) | >2.5 cm. (n=5) |
| IVC collapsibility | >50%, (n=10) | >50%, (n=39) | <50%, (n=14) | >50%, (n=24) | <50% (n=5) |
| Free fluid | - | - | - | Present (n=24) | - |
| Aortic aneurysm | Present (n=2) | - | - | - | - |
| Aortic Dissection | Present (n=1) | - | - | - | - |
| Deep vein thrombosis | - | - | - | - | Present (n=3) |

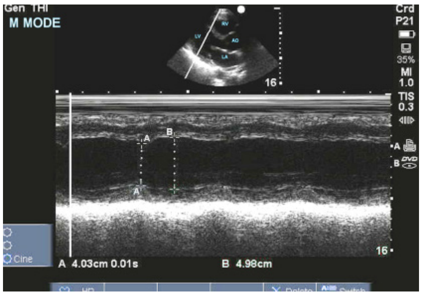


**Fig. 1: Evaluation of ejection fraction using M mode echocardiography. Distance A represents the end systolic diameter and distance B represents the end diastolic diameter. Ejection fraction by Teicholz method was 39.1% in this case (hypodynamic), seen in a case of cardiogenic shock in our study**

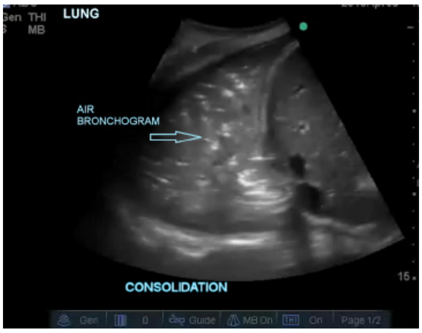


**Fig. 2: 'C' profile in a case of distributive shock in our study**

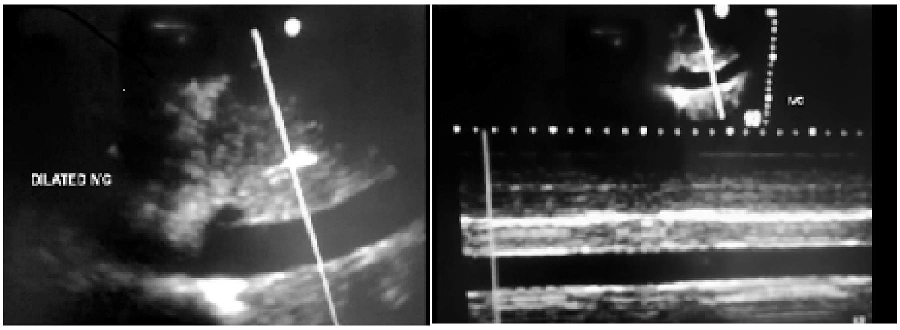


**Fig. 3: Absent collapsibility of the IVC on M Mode in a case of obstructive shock in our study**

ICU. Thus, our protocol was effective in providing an initial diagnosis in cases of undifferentiated hypotension in the emergency department.

In our study, ultrasound showed maximum sensitivity, specificity, NPV (negative predictive value) and PPV (positive predictive value) in obstructive shock. In addition, perfect agreement was seen between the ultrasound and clinical diagnosis, with a Cohen kappa coefficient of 1 in obstructive shock. The least sensitivity, specificity, NPV and PPV of ultrasound was seen in distributive shock. Least agreement between the ultrasound and clinical diagnosis was also seen in distributive shock, as most ultrasound findings were found to overlap with those in the other types of shock. (Cohen kappa coefficient of 0.6).

Our study also revealed how a combination of ultrasonographic findings can reliably predict the diagnosis of each type of shock in the emergency setting. Identification of the best predictors of each type of shock, can help the radiologist and the intensivist to predict the type of shock and plan emergent interventions accordingly. This would significantly influence clinical decision making and have an invaluable role in the management of critically ill patients.

Our study had a few limitations. One of these is that the differentiation of hypovolemic from distributive shock is often difficult, as the ultrasonographic findings may overlap in many cases. However clinical differentiation is also not always possible. This limitation was also encountered in the study by ***Volpicelli et al***[8] Hence our study was similar to their study.

In our study, the 'C' pattern of consolidation was encountered in a case of hypovolemic shock thereby indicating that consolidation need not always serve as a septic focus. It may co-exist independently with some other pathology. This limitation was also encountered in the study by *Volpicelli et al.*[8] In the study by *Postma, Wood D.R., Wallis L.A,*[9] there was no "gold standard" investigation to compare the ultrasound findings with, hence they were not able to objectively asses the diagnostic accuracy of ultrasound. This limitation was not encountered in our study and the studies by *Volpicelli et al*[8] *and Ghane et al,*[10] as the gold standard was a diagnosis based on a combination of clinical and biochemical investigations.

## Conclusion

Bedside ultrasonography in patients with undifferentiated shock is useful for rapid evaluation of various causes of shock and offers accurate diagnosis for subsequent treatment. Bedside ultrasonography, within 1 hour of admission is an excellent diagnostic

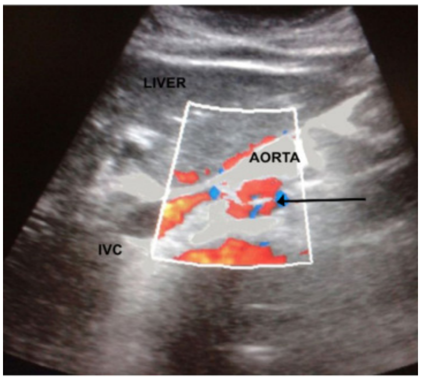


**Fig. 4: Colour Doppler image (axial section) showing aortic dissection in a case of hypovolemic shock in our study. The arrow shows the dissected intimal flap**

tool to differentiate between 5 types of shock ie. hypovolemic, distributive, cardiogenic, hypovolemic/distributive and obstructive types. Our study shows that there is good agreement between ultrasound diagnosis and clinical diagnosis of shock. Therefore we recommend that this simple, less expensive and non-invasive tool should be used as the investigation of first choice in patient management in ICU settings for the management of shock.

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