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Accuracy of Rapid Ultrasound in Shock (RUSH) Exam for Diagnosis of Shock in Critically Ill Patients

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Background: Rapid ultrasound in shock (RUSH) is the most recent emergency ultrasound protocol, designed to help clinicians better recognize distinctive shock etiologies in a shorter time frame.
Objectives: In this study, we evaluated the accuracy of the RUSH protocol, performed by an emergency physician or radiologist, in predicting the type of shock in critical patients.
Patients and Methods: An emergency physician or radiologist performed the RUSH protocol for all patients with shock status at the emergency department. All patients were closely followed to determine their final clinical diagnosis. The agreement between the initial impression provided by RUSH and the final diagnosis was investigated by calculating the Kappa index. Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of RUSH for diagnosis of each case.
Results: We performed RUSH on 77 patients. Kappa index was 0.71 (P Value = 0.000), reflecting acceptable general agreement between initial impression and final diagnosis. For hypovolemic, cardiogenic and obstructive shock, the protocol had an NPV above 97% yet it had a lower PPV. For shock with distributive or mixed etiology, RUSH showed a PPV of 100% but it had low sensitivity. Subgroup analysis showed a similar Kappa index for the emergency physician and radiologist (0.70 and 0.73, respectively) in performing rush.
Conclusions: This study highlights the role of the RUSH exam performed by an emergency physician, to make a rapid and reliable diagnosis of shock etiology, especially in order to rule out obstructive, cardiogenic and hypovolemic shock types in initial exam of shock patients.

*Keywords:*Emergency; Ultrasound; Shock

1. Background

Undifferentiated hypotension is a fairly common condition in emergency departments (ED) and is fully recognized as an important predictor of overall mortality in hospitalized patients. Undoubtedly, earlier recognition of shock etiology can enable clinicians to perform faster diagnosis-directed therapies and subsequently better final outcomes in these patients. Thus, the potential use of target-directed ultrasonographic exams have grown recently (1-8). Use of rapid ultrasound in shock (RUSH) is one of these protocols, designed for early evaluation and continuous monitoring of critically ill patients in EDs (4, 9-11). However, this protocol has not been fully evaluated, practically in emergency departments.

2. Objectives

In this study, our purpose was to evaluate the reliability of this protocol to accurately diagnose the type of shock patients. In addition we tried to compare the agreement index between emergency physicians (EP) and radiologists when they used this protocol at EDs.

3. Patients and Methods

Based on the STARD guideline (Standards for the Reporting of Diagnostic accuracy studies), we designed and conduced a prospective study to evaluate the diagnostic accuracy for the RUSH protocol. The study was performed in accordance with the Declaration of Helsinki, and was approved by the ethics committee of our trauma research center.

3.1. Participants

From April 2013 to May 2014, we enrolled all patients with a shock at the ED of our hospital during the working shift of our EP or radiologist. Shock was defined as systolic blood pressure (SBP) below 100 mmHg or a shock index (heart rate divided by SBP) of more than one (4, 9).

Initial clinical evaluation and immediate resuscitative interventions were all accomplished without delay.

According to the time of the patients' arrival, the EP or radiologist performed the sonography exams based on the RUSH protocol concurrent with ongoing care of each patient. There was no overlap between procedures done by the EP and those accomplished by the radiologist. All necessary diagnostic and therapeutic interventions (for instance chest x-ray, CT scan, echocardiography or any other lab test) were fully undertaken without delay.

3.2. Shock Classification and Rapid Ultrasound in Shock Protocol

We considered four classic subtypes for the shock state: hypovolemic, cardiogenic, distributive (septic or neurogenic) and obstructive (due to pneumothorax, tamponade, pulmonary thromboembolic disease). In addition patients demonstrating combined features of different shock types were considered to have the "mixed type" and, the condition of those whose etiology could not be clarified was termed "not defined" (4, 9).

The RUSH exam has several major components summarized as heart evaluation inferior vena cava, thoracic and abdominal compartments and large arteries and veins (4, 9, 11). A one-page sheet was designed in order to obtain information regarding these components.

One board certified EP with five years of experience with more than 200 ultrasonographic exams per year performed this protocol based on the guidelines described by Perara et al. (4, 9). He had also passed a 20-hour workshop for emergency ultrasound including the RUSH protocol. Our radiologist was also board certified with four years of practical experience and was completely acquainted with this protocol. The emergency physician and the radiologist suggested possible shock types based on the RUSH exam findings at the end of the checklist.

All examinations were done in a supine 30-degree upright position using a portable Sonoscape device. This device contains 2.5-5 curvilinear and 5-12 linear probes. The radiologist was unaware of the results of any paraclinical studies that had been performed for the patients.

3.3. Documenting Final Diagnosis

All patients were followed during their hospitalization in order to document their final diagnosis. Patients were transferred to other medical units (internal medicine, cardiology, or surgery) and the final clinical diagnosis was established by the second physician in charge. The second physicians were board certified specialists with acceptable expertise in their fields.

3.4. Statistical Analysis

Statistical analysis was done by the SPSS 18 software. We investigated the general agreement of defined shock types based on RUSH findings and final diagnosis of patients by calculating the Kappa index. We also performed subgroup analysis and measured the Kappa index for results of the RUSH exam obtained by the EP and the radiologist, individually. In addition, we assessed the Kappa agreement and reliability indices (sensitivity, specificity, positive (PPV) and negative predictive values (NPV) of this protocol for diagnosis of each type of shock, separately. For this analysis, we excluded patients with unknown final diagnoses.

4. Results

We enrolled 77 patients consisting of 38 men and 29 women with mean age of 61.5 years (range of 36 to 82 years) from April 2013 to May 2014. Mean duration time of the exam (from patient's arrival till sonography) was about 20 minutes (range of 10 to 25 minutes). Table 1 shows the prevalence of different types of shock based on the final diagnosis reached during hospitalization. The most frequent types of shock were cardiogenic shock (20 patients, 26% of the total). Eight cases (11%) died before we could clinically confirm the exact cause of shock state and were classified as "not defined". Based on the early RUSH exam findings for these patients, six were identified as mixed, and two as cardiogenic shock.

Table 1. Prevalence of Different Types of Shock Based on Final Clinical Diagnosis and RUSH Exam

Shock type based on RUSH	Shock Type Based on Final Clinical Diagnosis						Total
	Hypovolemic	Cardiogenic	Obstructive [a]	Distributive [b]	Mixed	Not Defined [c]	
Hypovolemic	16	0	0	1	1	0	18
Cardiogenic	0	18	0	0	1	2	21
Obstructive	0	0	10	0	1	0	11
Distributive	0	0	0	8	0	0	8
Mixed	0	0	0	1	7	6	14
Not defined	0	2	1	1	1	0	5
Total [d]	16 (20.8)	20 (26.0)	11 (14.3)	11 (14.3)	11 (14.3)	8 (10.3)	77

[a] Due to pneumothorax, pulmonary thromboemboli, tamponed.
[b] Including septic shock, neurogenic shock.
[c] Due to early death of patients, before definite clinical diagnosis.
[d] Data are presented as No. (%).

The Kappa index for general agreement between shock types was defined using the RUSH protocol and final diagnosis was 0.71 (P = 0.000) for all patients. This index was 0.70 (P = 0.000) when the protocol was performed by the EP and 0.73 (P = 0.000) when performed by the radiologist, reflecting acceptable agreement for this protocol.

Table 2 shows the sensitivity, specificity, PPV, NPV and Kappa index of the protocol for determining each individual type of shock, among all patients with known final diagnoses.

4.1. Hypovolemic Shock

Excellent sensitivity, good specificity and highest agreement with final diagnoses were seen in hypovolemic shock. We had 16 cases finally diagnosed as having hypovolemic shocks who were all found based on RUSH findings (100% sensitivity, and 100% NPV). Five were due to gastroenteritis, five due to traumatic solid organ injury, two due to diuretic overuse, two with gastrointestinal bleeding; one had a ruptured aortic aneurysm and one aortic dissection. We misdiagnosed two other patients as having hypovolemic shocks according to their sonography findings, yet the final diagnosis of one was determined as mixed and the other one as distributive shock secondary to urosepsis (96.2% specificity and 88.9% PPV). The criteria had the largest agreement with the final diagnosis (92%, P < 0.001) in this group of patients.

4.2. Cardiogenic Shock

Good sensitivity, specificity and good agreement were seen in cardiogenic shock. We correctly distinguish 18 out of our 20 cardiogenic shock cases, indicating 90% sensitivity. Eleven were due to decompensated heart failure, three had myocardial infarction (MI), one had digital toxicity, and three had atrial fibrillation with a recent onset of rapid ventricular response. The cardiac etiology of the other two patients with heart failure could not be outlined by the initial RUSH exam (97% NPV). Their illness was due to diastolic dysfunction (in context of paroxysmal supraventricular tachycardia (PSVT)) and their ejection fraction was assumed good, and thus their shock was labeled as "not-defined" based on sonography findings. We also had two patients who were diagnosed as having cardiogenic shocks, one of them proved to have multiple causes and the other died before definite diagnosis could be made (98% specificity and 94.7% PPV). Agreement of sonography findings with final diagnosis was 89% (P < 0.001) for this shock type.

4.3. Obstructive Shock

Notable reliability indices and agreement were seen in obstructive shock. Among 11 patients with obstructive shocks, we only missed one case, which was due to traumatic rupture of the left hemidiaphragm (90.9% sensitivity and 98.3% NPV). By using the RUSH protocol, our examiners successfully diagnosed two patients with cardiac tamponade, two with extensive acute pulmonary thromboembolism, three with right heart failure related to secondary pulmonary hypertension (in the context of chronic pulmonary thromboembolic disease in two cases, and extensive pulmonary parenchymal disease in the other) two of three with pneumothorax. Pneumothorax in one patient could not be found with RUSH, however, the patient was correctly found to have an obstructive type of shock by sonography findings. One patient was labeled as having an obstructive shock but was found to have a mixed etiology (98.2% specificity and 90.9% PPV). Agreement of sonography findings with final diagnosis was 89% (P < 0.001) for this type of shock.

4.4. Distributive Shock

Good agreement, excellent specificity, but low sensitivity was seen in distributive shock. We found eight patients with distributive shocks with the early RUSH exam. Eleven patients had final diagnosis of distributive shocks; seven had sepsis (five with pneumonia, and one with cholangitis, iliopsoas abscess, tuberculosis and urinary tract infection) and two were due to neurogenic mechanisms. Two patients were miscategorized as hypovolemic and mixed etiology shock, and one could not be defined based on sonography findings (72.7% sensitivity and 95.1% NPV). The protocol demonstrated good agreement with final diagnosis in these patients (0.81, P < 0.001).

Table 2. Reliability Indices and Kappa Agreement of the Rapid Ultrasound in Shock Exam for Each Individual Shock Subtype [a,b]

	Shock Type Based on Final Diagnosis				
	Hypovolemic (n = 16)	**Cardiogenic (n = 20)**	**Obstructive (n = 11)**	**Distributive (n = 11)**	**Mixed (n = 11)**
Sensitivity	100%	90%	90.9%	72.7%	63.6%
Specificity	96.2%	98%	98.2%	100%%	98.2%
PPV [c]	88.9%	94.7%	90.9%	100%	87.5%
NPV	100%	97%	98.3%	95.1%	93.3%
Kappa (P Value)	0.92 (0.000)	0.89 (0.000)	0.89 (0.000)	0.81 (0.000)	0.70 (0.000)

[a] Data are presented as percentages.
[b] For these analysis eight patients with "not defined" final diagnoses were excluded.
[c] Abbreviation: PPV, positive predictive value of RUSH criteria to determine each type of shock; NPV, negative predictive value of RUSH criteria to determine each shock type; Kappa, index of agreement between diagnosis of shock type based on RUSH criteria and final diagnosis.

4.5. Mixed Etiology Shock:

Acceptable agreement, good specificity, while low sensitivity was seen in mixed types of shock.

Eleven patients were finally diagnosed as having multiple causes for their shock. Seven were correctly diagnosed using the RUSH criteria (sensitivity of 63.6%), while four were misdiagnosed as having hypovolemic, cardiogenic, obstructive and not defined etiologies. We also mislabeled one patient as shock due to mixed etiology, which appeared to have a distributive final diagnosis. Among our study participants we had six patients with RUSH findings suggestive of mixed type of shocks but their final diagnosis could not be established due to an early death. This protocol had the lowest agreement (0.70, $P < 0.001$) with the final diagnosis when patients had mixed etiologies as the cause for their shock status.

5. Discussion

It has been suggested that a goal-directed ultrasonographic study could be an excellent rapid diagnostic method to evaluate possible etiology of the shock status at bed-side (4, 9, 11, 12). Our study demonstrated acceptable general agreement between the results of this early ultrasonographic study and final clinical diagnosis of patients in shock (Kappa = 0.71). Volpicelli et al. reported similar agreement in their study, which was focused on a similar multi-organ sonography evaluation of critical patients (12). Another important finding was that we did not find any significant difference between agreement indices of the RUSH exam performed by the EP compared to those done by the radiologist (0.70 vs. 0.73). In practice, however, time required to access a radiologist at the emergency department is considerably longer, thus causing delay in etiologic diagnosis using the RUSH. Thus, we feel that emergency physicians with expertise of emergency ultrasound are the best candidates to perform this protocol and subsequently administer earlier, more goal-directed therapies for these critical patients at the ED. In addition they would be able to actively monitor the effects of the therapeutic interventions and if necessary make appropriate adjustments by using RUSH (9-12).

5.1. Hypovolemic, Cardiogenic and Obstructive Shock States

This protocol is sufficiently reliable to rule out hypovolemic, cardiogenic or obstructive subtypes of the shock (NPV above 97% for all of them). The highest agreements were seen in these shock types (Kappa 0.92, 0.89 and 0.89, respectively).

The point is that there exist certain life-saving critical therapeutic approaches for these three subtypes, considerably effective on their final outcome. Results regarding obstructive shock possibly delineate that the operators can accurately outline signs of right ventricular strain and then further extend their investigations to find important underlying etiologies (2, 13-15). The only case with obstructive shock which we could not accurately diagnose the underlying etiology was a hypotensive man in the comatose state, who showed rupture of the left hemidiaphragm and entry of bowel loops in the associated hemi thorax indicated by the CT scan as the cause of obstructive shock. In fact, extensive rupture of the diaphragm is a rare yet an important traumatic injury, which can be easily missed in sonographic studies (16).

5.2. Distributive and Mixed Etiology Subtypes of Shock

We found low sensitivity for this protocol to outline the distributive shock mechanism (72.7%). Most cases of distributive shocks are due to sepsis. Inflammatory response to a systemic infection proceeds through systemic inflammatory response syndrome (SIRS), severe sepsis and septic shock stages. Consequently indices of circulation also dynamically change in the process of systemic infection (17, 18). These dynamic alterations can easily mislead the operators in a single session of evaluation. However, if the operators execute serial studies in patients suspected of underlying septic etiology, they can monitor the response of the cardiovascular system to resuscitative interventions and provide more efficient applications of this protocol (19-21).

When there were multiple etiologies for unstable hemodynamic conditions of the patient, the protocol had the least sensitivity and agreement. Thus, we strongly suggest that physicians interpret results of this exam with more caution, when they have high clinical suspicion for one of these two categories. We should note that the main goal of early multi-organ sonography exam of a patient in a shock state is to clarify underlying clinical conditions in shorter time frame or at least to exclude certain life-threatening conditions. The significance of findings in these protocols must be further evaluated in the process of treatment. These considerations again denote that emergency physicians (and not radiologists) are the best candidates for using the RUSH protocol, since they are actively involved in the process of treatment at the ED from the start (10, 17, 21).

The overall role of an early RUSH exam should be in the hands of clinicians to make a rapid and acceptably accurate diagnosis of the shock type in a hypotensive patient, especially to rule out obstructive, cardiogenic or hypovolemic shock types. In addition agreement indices were not significantly different between the emergency physician and radiologist as operators of this protocol.

5.3. Limitations

In our study a single emergency physician and a single radiologist performed the exams. This means that our results are influenced by their extent of personal experience and skills at emergency ultrasound. We also had a limited number of patients in each distinctive subgroup of shock; this prompts us to interpret subgroup results with more caution.

Authors' Contributions

Study concept and design: Mohammad Hadi Gharib and Kaveh Samimi. Acquisition of data: Mohammad Reza Ghane, Mohammad Hadi Gharib, Hossein Mohammad Kazemi and Kaveh Samimi. Analysis and interpretation of data: Mohammad Hadi Gharib and Kaveh Samimi. Drafting of the manuscript: Mohammad Hadi Gharib, Hossein Mohammad Kazemi and Kaveh Samimi. Critical revision of the manuscript for important intellectual content: Mohammad Reza Ghane, Mohammad Hadi Gharib, Ali Ebrahimi, Kaveh Samimi, Maryam Rezaee and Hamidreza Rasouli. Statistical analysis: Mohammad Hadi Gharib. Administrative, technical, and material support: Mohammad Hadi Gharib, Ali Ebrahimi, Maryam Rezaee and Hamid Reza Rasouli. Study supervision: Mohammad Reza Ghane, Mohammad Hadi Gharib and Ali Ebrahimi.

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