Merging Ultrasound in the Intensive Care Routine

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ABSTRACT: **Background:** Goal-oriented ultrasound examination is gaining a place in the intensive care unit. Some protocols have been proposed but the applicability of ultrasound as part of a routine has not been studied.

Objectives: To assess the influence of ultrasound performed by intensive care physicians.

Methods: This retrospective descriptive clinical study was performed in a medical-surgical intensive care unit of a university-affiliated general hospital. Data were collected from patients undergoing ultrasound examinations performed by a critical care physician during the period 2010 to June 2011.

Results: A total of 299 ultrasound exams were performed in 113 mechanically ventilated patients (70 males, mean age 65 years). Exams included trans-cranial Doppler (n=24), neck evaluation before tracheostomy (n=15), chest exam (n=83), focused cardiac echocardiography (n=60), abdominal exam (n=41), and comprehensive screening at patient admission (n=30). Ultrasound was used to guide invasive procedures for vascular catheter insertion (n=42), pleural fluid drainage (n=24), and peritoneal fluid drainage (n=7). One pneumothorax was seen during central venous line insertion but no complications were observed after pleural or abdominal drainage. The ultrasound study provided good quality visualization in 86% (258 of 299 exams) and was a diagnostic tool that induced a change in treatment in 58% (132 of 226 exams).

Conclusions: Bedside ultrasound examinations performed by critical care physicians provide an important adjunct to diagnostic and therapeutic performance, improving quality of care and patient safety.

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The accuracy of the physical examination in the intensive care unit is often questionable because of patient care requirements. Impediments to a comprehensive physical exam may occur in spinal injury patients, requiring up to four skilled caregivers to safely turn an adult patient; there is concern about vacuum loss in patients with open abdomen on vacuum systems, and fear of accidental extubation. Nonetheless, an accurate, methodological and skilled physical examination remains one of the cornerstones of successful patient care. Physicians have typically relied on their senses to obtain clues regarding the patient's ailment. Technology pushes those limits, allowing new insights into the pathophysiology of illness and its treatment. Ultrasound development has reached a level of portability and image definition that makes it possible to bring the device to the patient's bedside [1,2].

We retrieved data from ultrasound examinations performed in our medical-surgical ICU during the period January 2010 to July 2011. The current study is a retrospective analysis of the use and benefits observed. This study provides a qualitative and quantitative evaluation of the applicability of point-of-care ultrasonography in the intensive care setting and offers a view on the complex processes of merging a new routine into the medical round.

PATIENTS AND METHODS

The protocol was approved by the Ethics Committee of Barzilai Medical Center. Informed consent was waived. The medical records of patients hospitalized in our six-bed medical-surgical ICUs from 1 January 2010 to 30 June 2011 were reviewed regarding the use of ultrasound examination performed by intensivists. Examinations performed from 1 January 2010 to 31 December 2010 used an ATL HDI 3000 ultrasound machine provided with curvilinear and linear transducers, which was replaced with a Philips CX 50 with curvilinear, linear and facet transducers in January 2011.

A code was assigned to each patient for anonymity. Exams were classified according to body area and rationale. The examinations and invasive procedures were performed by experienced full-time ICU physicians.

The following data were extracted from routinely maintained medical charts: age and gender, diagnosis, type of exam and reason for performing it, and its influence on diagnosis and treatment. For invasive procedures performed under ultrasound guidance, success and complications were noted, as was the diagnostic value.

RESULTS

The study population comprised 113 patients (70 males, 43 females) with a mean age of 65 years (range 15–92 years). All

ICU = intensive care unit

patients were ventilated secondary to respiratory failure. Main ICU admission diagnoses are shown in Table 1. Altogether, 299 ultrasound exams were performed (average 2.6 examinations per patient). In 226 cases ultrasonography was performed in order to make diagnosis or treatment decisions (76%). In 73 cases it was used to guide an invasive procedure. Results are presented according to body area and examination rationale.

THORACIC ULTRASOUND

Chest ultrasound examinations were performed in 83 patients and pleural effusions were found in 48 of them. Fluid drainage was performed when the fluid amount was large enough to significantly impair ventilation or when empyema was suspected (24 thoracenteses). All thoracenteses were successful. Fluid showing compartmentalization compatible with empyema was seen in three cases, and the suspicion was confirmed after drainage by fluid assay. One empyema was found by fluid analysis but was not suspected on ultrasound exam (sensitivity 75%, specificity 54%). In three patients the exam showed pulmonary consolidation without effusion.

Atelectasis was found in 13 patients: 2 underwent flexible bronchoscopy toilette, in one patient positive end-expiratory pressure was increased, and 10 underwent physiotherapy and endotracheal suction. Ten patients were examined for pneumothorax and the examination was positive in 2 patients, negative in 5 and inconclusive in 3. Interstitial lung syndrome (extravascular lung water) was found in six patients [Table 2]. In one patient the examination was performed to assess a pulmonary infarct found by computed tomography angiography.

HEMODYNAMIC MANAGEMENT

Examinations were begun by measuring the inferior vena cava diameter and respiratory variation. Later on, a focused cardiac ultrasound exam was added to the protocol. Sixty cardiac examinations were performed, 47 of them for hemodynamic evaluation in shock patients. As a result of the exam, fluid management was changed in 45% of patients: 16 received fluid resuscitation for hypovolemia (34%) and 5 received diuretic treatment for hypervolemia (11%). Twenty-six patients (55%) had a normal volemic state [Table 2]. Echocardiography was performed in three patients to rule out tamponade or pulmonary embolism. In 10 patients (21%) ultrasound was also used to calculate cardiac output. In one patient no cardiac or inferior vena cava image could be obtained. In 3 patients (5%) expert consultation was requested because of a doubtful echocardiography image.

Table 1. Main admission diagnosis (patients may have more than one diagnosis)

Diagnosis	n
Sepsis	61
Pulmonary origin: acute lung injury	48
Extra-pulmonary origin: acute lung injury	6
Surgical	42
Trauma	7
Pancreatitis	6
Intoxication	3
Neurology	16
Others	3

ABDOMINAL ULTRASOUND

Abdominal exams were performed in 41 patients. Ascites was suspected in 26 patients and confirmed in 17 (65%). Peritoneal fluid drainage was performed in seven patients. Two of these seven were referred for urgent laparotomy after drainage of grossly infected fluid [Table 2]. An ultrasound sensitivity of 100% and specificity of 67% for infected ascites was found. Complication or failure to drain did not occur.

Seven patients underwent bladder ultrasonography because of an abrupt decrease in urinary output, 4 of whom (57%) presented a distended bladder secondary to catheter obstruction. In 7 patients (17%) biliary tract, pancreatic or

Table 2. Number of ultrasound examinations done: area and main ultrasound diagnosis

Type of ultrasound	No. of exams done	Ultrasound diagnoses	n (%)
Thoracic	83	Pleural effusion	48 (58%)
		Empyema	4 (5%)
		Atelectasis	13 (16%)
		Consolidation	3 (5%)
		Pneumothorax	10 (12%)
		Interstitial lung	6 (7%)
		Pulmonary infarct	1 (1%)
Hemodynamic evaluation	47	Hypovolemia	16 (34%)
		Hypervolemia	5 (11%)
		Normovolemia	26 (55%)
Abdomen	41	Ascites	17 (41%)
		Infected ascites	2 (5%)
		Urinary retention	7 (17%)
Transcranial Doppler	24	Elevated pressure	8 (33%)
		Normal pressure	12 (50%)
		Brain death	1 (4%)
		No window	2/17 (12%)
Vascular not for access	4	Deep vein thrombosis	3 (75%)
		Catheter misplacement	1 (25%)
Pre-tracheostomy evaluation	15	Percutaneous approach	4 (27%)
		Open surgery	11 (73%)

kidney disease was suspected and a radiologist was requested to redo the ultrasonography

TRACHEOSTOMY EVALUATION

Neck ultrasonography before percutaneous dilatational tracheostomy was performed in 15 patients. Eleven patients (73%) were referred for surgical tracheostomy and 4 (27%) were found suitable for PDT. Reasons for referral to open surgery were enlarged thyroid isthmus or a blood vessel crossing the midline at the planned puncture site [Table 2].

TRANS-CRANIAL DOPPLER (TCD)

Middle cerebral artery flow velocity measured through the temporal window was performed as an intracranial pressure surrogate on 24 occasions in 17 patients. Seven TCD were performed during follow-up, in one case up until declaration of brain death. No temporal window was found in 2 of the 17 patients (12%). In 8 cases a high pulsatility index suggested high ICP. Pulsatility index was normal in 12 exams (50%) [Table 2]. In one patient TCD was performed after tissue plasminogen activator treatment for ischemic cerebrovascular accident.

ULTRASONOGRAPHY AS AN ADMISSION SCREENING TOOL

Admission ultrasound comprises the use of a multisystemic approach including sequential examinations at a single session within 12 hours of patient admission. This methodology was used in 30 patients and included hemodynamic assessment of cardiac function and IVC diameter, extravascular lung water assessment, presence or absence of cavitary fluids in pleural and/or peritoneal spaces, and TCD when the patient was comatose. We started to perform admission ultrasound after replacement of the ultrasound device in January 2011. Since then 129 patients were admitted to the ICU and admission ultrasonography was performed in 23% of them, representing 15% of the total examinations. The obtained information guided hemodynamic intervention in 22 patients, in 18 of whom (82%) the treatment was changed. Empyema was ruled out in three patients admitted with pleural effusion. Infected ascites was excluded in two patients with free abdominal fluid. Increase in ICP was excluded in two unconscious patients. In two cases the examination was not informative due to poor image quality.

ULTRASOUND-GUIDED VASCULAR ACCESS

Ultrasound was used to guide central venous or arterial line insertion in 42 patients. The internal jugular vein (17 catheterizations) and femoral vein (2 catheterizations) were accessed without failure or complication, as were the axillary and femoral arteries (5 catheterizations). Subclavian vein catheterization was successfully performed 10 times although failure occurred four times in extremely obese patients (10%), leading to iatrogenic pneumothorax in one (2%). In three patients unknown deep venous thrombosis of the right internal jugular vein was identified immediately before ultrasound-guided catheterization. An alternate site for catheter insertion was found with ultrasound. The number and type of ultrasound-guided procedures are shown in Table 3.

PDT = percutaneous dilatational tracheostomy
TCD = trans-cranial Dopper
ICP = intracranial pressure

Table 3. Number of procedures done with ultrasound dynamic guidance

Procedure	n	Failure
Subclavian vein access	14	4
Jugular vein access	17	0
Femoral vein access	2	0
Axillary arterial access	3	0
Femoral arterial access	2	0
Pleural fluid drainage	24	0
Peritoneal fluid drainage	7	0

Table 4. Influence of the ultrasound examination on patient's care

Result	n/total (%)
Requested image obtained	258/299 (86%)
Ultrasound as a diagnostic tool	226/299 (76%)
Ultrasound-guided change in treatment	132/226 (58%)
Unexpected findings	4/299 (1.4%)

VISUALIZATION AND INFLUENCE ON TREATMENT

Successful ultrasound visualization of the organ or system occurred in 258 of the 299 exams (86%). In 226 cases the ultrasonography was a diagnostic tool (76%) and in 132 cases a treatment was given or modified according to the ultrasound findings (58%). In four cases (1.4%) imaging revealed a clinically unexpected finding [Table 4]. Help from a specialized team was requested to clarify a doubtful image in 10 of the 299 exams (3.3%).

DISCUSSION

This is the first retrospective analyses of the impact of bedside ultrasound in the ICU. We assessed the influence of the ultrasonographic examination on multiple organs and systems with goal-oriented exams aiming to improve diagnosis and patient care and to achieve rapid evaluation at patient admission. The results of the ultrasonography performed by the intensivist at the patient bedside were important for answering a clinical question or guiding an invasive procedure. Accurate diagnostic information was achieved and the

information obtained induced a treatment change in more than half the cases. Remarkably, the ultrasound exam also picked up a few but significant unexpected findings, some of them requiring specific treatment.

Ultrasound training is not mandatory for intensivists in Israel and is not standardized or accredited. Strictly limiting its use to answer specific questions appears to be safe and accurate after a short training [3]. The use of this "visual stethoscope" should not be more dangerous than the traditional one [4].

Patients were selected for ultrasonography by the attending physician according to diagnostic or interventional necessities without a specific protocol. For quality assurance and patient safety, if there was any question about the obtained image a consultant with expertise in the relevant area was immediately requested on the same day, or the next day if the ultrasound was performed at night. Invasive procedures were withheld in cases of unclear image.

The ultrasound machine available in our ICU in 2010 included a curvilinear transducer appropriate for abdominal examination and a linear transducer for vascular view. Later on, a new device with three transducers – linear, curvilinear and facet – replaced the older one. With this new-generation instrument, focused cardiac ultrasonography and TCD became possible. As shown in our study, ICU patients underwent an average of 2.6 ultrasound examinations during their ICU stay.

Experience with ultrasound was gained progressively, starting with vascular central catheter insertion and chest exams for pleural effusion. The safety and benefits of ultrasound for central line insertion are well documented. Anatomic landmark insertion is not without risk. Many studies have assessed the use of ultrasound to prevent complications of venous puncture such as a pneumothorax or arterial puncture. The literature notes the risk of pneumothorax using the landmark approach as ranging from 1.5% to 35% [5-8]. During our study, the failure rate was about 10%. Failure was limited to unsuccessful subclavian vein access probably for anatomic reasons [9]. Only one pneumothorax occurred (2%).

Unexpected deep vein thrombosis was disclosed in three patients, two of whom had a previous central venous catheter insertion. Although symptomatic pulmonary emboli appear to be rare in those cases, blind manipulation of a clotted vein could potentially dislodge the thrombus [10].

Chest ultrasound allows better analysis of chest X-ray exam since it enables an accurate distinction to be made between pleural effusions and atelectasis [11,12]. Integrated information can then reduce the use of radiography. In our study, chest ultrasound was used to differentiate lung infiltration, atelectasis, interstitial syndrome or pleural effusion, and to obtain a diagnostic fluid sample or drain an effusion. The decision to drain an effusion was based on an interpleural distance of more than 2 cm, the sonographic presence of undulating fibrin bounds, or increased fluid echogenicity [11-13]. We found a high sensitivity and specificity of ultrasound exam for empyema. No failure or complication occurred as a result of the intervention. In case a small anterior pneumothorax was suspected on chest X-ray, ultrasonography provided additional confirmation of the diagnosis.

Ultrasound B-lines are a surrogate of lung interstitial congestion [11,14]. We used ultrasound for assessing fluid status, extravascular lung water and cardio-hemodynamic examination, focusing on cardiac function and inferior vena cava variation as previously reported [3,15,16]. Fluid management was changed according to the image in 45% of cases. The remaining 55% of unstable patients were found to be normovolemic, requiring pharmacological treatment.

Ultrasound measurement of cardiac output was performed in 21% of patients requiring hemodynamic assessment or shock classification. It was previously found to approximate thermodilution measurement by 17% [17]. Integrated information of cardiac and lung ultrasound was used in our ICU to reach decisions on fluid management, as was recently validated [18].

Goal-oriented abdominal ultrasound is also gaining a place in the ICU [19]. With peritoneal fluid drainage, we found two patients who were immediately referred to laparotomy because the fluid showed fecal contamination. The ultrasonography clearly hastened their diagnosis and treatment. Although the specificity of abdominal fluid drainage for detection of infected peritoneal fluid was low, sensitivity was high and neither failure nor complications were seen. In postoperative patients, adhesions can fix the bowel to the abdominal wall which could lead to a blind abdominal puncture. Our study showed that ultrasound-guided paracentesis performed by intensivists is safe, reliable and feasible and facilitates specific treatment.

Abdominal ultrasound is also used to exclude bladder distension in patients with sudden decrease of urinary output. Ultrasound examination obviated the common practice of back-flushing the urinary catheter in 57% of cases. A radiologist was invited to perform the abdominal examination when a more comprehensive study was required.

We performed ultrasonographic assessment of the anterior neck before tracheostomy to appraise the best surgical approach. Neck ultrasonography before PDT increases safety as patients found to be unsuitable for PDT can be referred for open tracheostomy [20]. In patients found suitable, PDT was performed without complications. The high percentage of our patients referred for an open approach (73%) may be related to their advanced age and high incidence of neck kyphosis.

By using trans-cranial Doppler in the middle cerebral artery it was possible to calculate pulsatility. As previously published, the pulsatility index is a surrogate for ICP measurement [21]; we were thus able to forestall neurosurgical intervention to directly measure ICP. Treatment aiming to reduce ICP was given to five patients with a high pulsatility index. Elevated

ICP was excluded in 50% of our patients. Sequential TCD showed deterioration up until brain death. Progressive narrowing of the flow wave, reverse flow direction, or flow disappearance reduces uncertainty about this diagnosis [22]. Once flow reversal occurs neurological recovery does not occur [23]. The absence of a sonographic temporal window for TCD in our study was 12%.

We used sonographic examination as part of the physical examination at ICU admission in patients with multiple organ failure. Ultrasound guided the hemodynamic intervention in 82% of shock patients and was complementary to the diagnostic work for source of infection in septic patients. A similar ultrasound approach was found useful in the emergency department for evaluation of shock [24]. Manno et al. [25] proposed a similar protocol for ultrasound use in the ICU. Our study was different in that we also performed TCD in unconscious patients, examined the neck before tracheostomy, and performed bladder examinations in anuric patients.

Since our study was retrospective, predefined criteria for ultrasonography were not applicable; therefore, there is a potential for bias as the type and timing of ultrasonography was decided according to the situation and physician expertise, without randomization. Neither the operator nor the care team was blinded to the patient situation or the unmistakable presence of an ultrasound machine. The true prevalence of organ abnormalities may have been underestimated as the ultrasonography was goal oriented to solve an immediate question. Circumstances that hampered the examination were not appropriately noted and data are lacking.

CONCLUSIONS

Examinations performed by the ICU attending physician shorten the time to accurate diagnosis, improve patient safety, and reduce the need for more invasive examinations. Rapid, accurate and non-invasive diagnostic information should help decrease patient morbidity and mortality. Continuous education and training is mandatory. If the obtained image is unclear or controversial, obtaining other imaging (X-ray or computed tomography) is crucial. We strongly recommend our practice of inviting the site expert to evaluate the study. Merging the ultrasound examination as part of the physical examination will have a profound impact on the safety and quality of health care.

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