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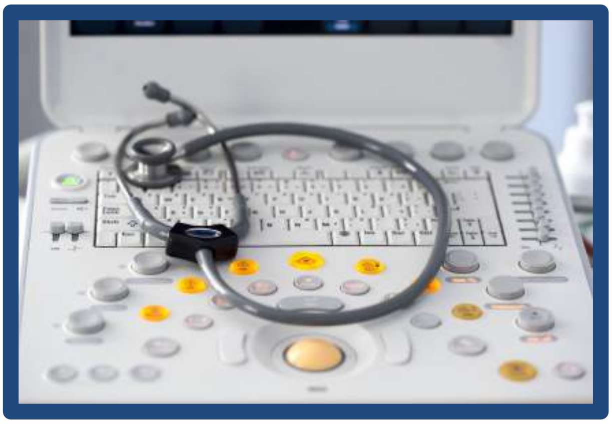
CACU

A Comprehensive Book on Critical and Acute Care Ultrasound

Manu Malbrain



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PREFACE

Critical and Acute Care Ultrasound

A Comprehensive Book on Critical and Acute Care Ultrasound

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This Comprehensive Book on Critical and Acute Care Ultrasound (CACU) summarizes the reviews published during the previous International Fluid Academy Days. The papers are published under the Open Access CC BY Licence 4.0.

Critical and Acute Care Ultrasound together with point of care ultrasound (POCUS) is becoming a holistic and translational discipline and is considered as the modern stethoscope for the critical care and emergency care physician.

Dr Roy Filly, Professor Emeritus of Radiology, and chief of the department of diagnostic sonography in Stanford predicted in 1988 that ultrasound would likely become the new stethoscope: "As we look at the proliferation of ultrasound instruments in the hands of untrained physicians, we can only come to the unfortunate realisation that diagnostic sonography truly is the next stethoscope: poorly utilized by many but understood by few"

This book is edited by Manu Malbrain, Internist-Intensivist, Director of the Intensive Care Department at the University Hospital in Brussels (UZB), Belgium, he is Professor at the Brussels Free University (VUB) and one of the chairmen of the iFAD meeting.

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CHAPTER 1

Executive summary on critical and acute care ultrasound use

Manu L. N. G. Malbrain, Brecht De Tavernier, Sandrine Haverals, Michel Slama, Antoine Vieillard-Baron, Adrian Wong, Jan Poelaert, Xavier Monnet, Willem Stockman, Paul Elbers, Daniel Lichtenstein

Over the past decades, ultrasound (US) has gained its place in the armamentarium of monitoring tools in the intensive care unit (ICU). Critical care ultrasonography (CCUS) is the combination of general CCUS (lung and pleural, abdominal, vascular) and CC echocardiography, allowing prompt assessment and diagnosis in combination with vascular access and therapeutic intervention. This review summarises the findings, challenges lessons from the 3rd Course on Acute Care Ultrasound (CACU) held in November 2015, Antwerp, Belgium. It covers the different modalities of CCUS; touching on the various aspects of training, clinical benefits and potential benefits. Despite the benefits of CCUS, numerous challenges remain, including the delivery of CCUS training to future Intensivists. Some of these are discussed along with potential solutions from a number of national European professional societies. There is a need for an international agreed consensus on what modalities and how best to (and deliver) training in CCUS.

Introduction

Over the past decades, ultrasound (US) has gained its place in the armamentarium of monitoring tools in the intensive care unit (ICU) [1]. A greater understanding of lung, heart, abdominal and vascular US and improved access to portable machines have revolutionised ICU care, with CCUS playing an important role in bedside examination, potentially becoming the stethoscope of the 21st century [1]. Critical care ultrasonography (CCUS) is the combination of general CCUS (lung and pleural, abdominal, vascular) and CC echocardiography, allowing prompt assessment and diagnosis in combination with vascular access and therapeutic intervention [2]. Although it has been practiced by enthusiasts for over 30 years, CCUS is a relatively young but increasingly widespread discipline. In this review, summarising the last Course on Acute Care Ultrasound (3rd CACU) held in Antwerp, Belgium on November 26th 2015, the usefulness and advantages of US in the critical care setting are discussed.

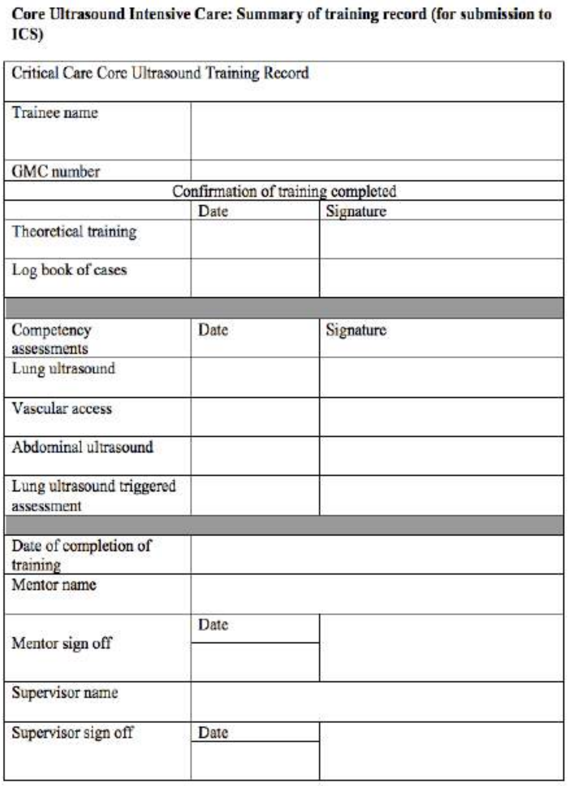
Delivering US training

Background

The use of ultrasound has expanded beyond the realms of radiologists and into many areas of healthcare. Although championed by enthusiasts, the use of ultrasound in intensive care unit (ICU) has lagged behind that of other specialties including emergency medicine. The lack of a uniform formal training structure and programme is a recurring issue across Europe and indeed worldwide. Even in countries with national programmes, there are significant variations within them. It thus poses the crucial questions of whether scans have been appropriately performed and reported, and whether there exists proper clinical governance to ensure a high standard of care.

Challenges

Two international expert statements acknowledged the challenges of obtaining appropriate training in CCUS and aimed to describe the components of competence so that clinicians may have specific goals of training while they develop their skills [2-4]. The framework defines the minimal requirements but is by no means rigid; each training organization can be adapted according to resources available. The statements acknowledge the various processes of certification, accreditation, or delivery of a diploma when validating the acquisition of competence. Currently, certification is only recommended for advanced CC echocardiography. For basic CC echocardiography, as well as for general ultrasonography, no formal certification/diploma is required although training has to be included in the curriculum of all intensivists.



Core Ultrasound Intensive Care: Summary of training record (for submission to ICS)

Critical Care Core Ultrasound Training Record		
Trainee name		
GMC number		
Confirmation of training completed		
	Date	Signature
Theoretical training		
Log book of cases		
Competency assessments	Date	Signature
Lung ultrasound		
Vascular access		
Abdominal ultrasound		
Lung ultrasound triggered assessment		
Date of completion of training		
Mentor name		
Mentor sign off	Date	
Supervisor name		
Supervisor sign off	Date	

Figure 1. Summary of training record for UK CUSIC programme*

*Intensive Care Society UK CUSIC Accreditation - http://www.ics.ac.uk/ics-homepage/accreditation-modules/cusic-accreditation/

Despite the lack of agreement regarding the minimum number of scans, duration of training and lack of appropriate trainers (accessibility), several key themes are consistent. Competency in ultrasound examination requires a combination of theoretical knowledge and practical skills. The delivery of theoretical knowledge can be in the form of online resources, via face-to-face lectures at courses or a hybrid of the two.

It is a practical skill and the initial learning requires direct, hands-on supervision by an expert usually at courses or the learner's own ICU. It is imperative that such mentored learning occurs using the appropriate patient mix and not just normal volunteers.

The UK Solution - CUSIC

The Intensive Care Society (UK) recently introduced the Core US Skills in Intensive Care (CUSIC) in order to provide a formal and robust training structure to attain these competencies. The programme ensures the highest level of competency-based training with clear learning objectives and outcomes defined from the onset for both the trainer and trainee.

The modules encompass the areas covered in the above international statements – focussed echocardiography, pleural/lung US, vascular and abdominal US, with a minimum number of scans defined for each module. The modular system allows for a degree of flexibility and ensures that a balance is achieved between service-provision and training/learning periods.

Each 3-month module comprises of 4 phases:

- PHASE 1: Initial **theoretical** and practical training
    - E-learning
    - Course
- PHASE 2: **Supervised** practice until competence demonstrated in acquiring and saving images
- PHASE 3: **Mentored** practice with completion of logbook demonstrating knowledge of an appropriate range of pathology
- PHASE 4: Completion of **competency assessments** within the range of practice

The various modules equip the intensivist with the skills to deal with the range of clinical situations he/she is likely to encounter. The trainee is expected to keep a logbook of the scans and procedures performed; a summary training record (figure 1) is reviewed by a board of experts before accreditation is awarded. Robust clinical governance policies are maintained through formalised working practice with all stakeholders including radiology and cardiology departments. This requires a considerable degree of preparation prior to commencement of the programme.

The Dutch solution – ICARUS consolidation

The Dutch Society for Intensive Care recently adopted the Intensive Care Ultrasound (ICARUS) consolidation program that was initially developed at VU University Medical Center Amsterdam (http://echografie.nvic.nl/). It is intended as a consolidation course for those intensivists that have already completed a basic level introductory course in CCUS. Similar to the UK solution, ICARUS relies heavily on mentorship.

ICARUS starts with a one day course in a participating hospital. One of the instructors is then appointed as a mentor. A selection of 30 full ICARUS scans is then uploaded to the mentor who provides feedback. The course also includes a half day bedside session at a later date with the mentor and a formal exam that consists of theoretical questions, interpretation of archived US examinations and demonstration of US skills. Upon successful completion, intensivists receive ICARUS certification, issued by the society.

The UK and Dutch programmes described are by no means the only method and a comparison is shown in table 1.

	UK CUSIC accreditation	Dutch NVIC ICARUS consolidation accreditation	American College of Chest Physicians accreditation*
Duration (recommended)	1 year	3-9 months	3 years
Online course	Yes	No	Yes
Face-to-face course	Yes – 1	Yes - 2	Yes – 2
Online portfolio	No	No	Yes
Supervision/Mentor	Direct	Distant	Variable
Echocardiography	50 studies	30 studies	10 studies
Lung/Pleural	50 studies	30 studies	4 studies
Abdominal	20 studies	n/a	4 studies
Vascular	Vascular access	n/a	Doppler/DVT
Assessment	Yes – at end of each module	Yes – at completion of 30 exams	Yes – at completion of entire portfolio

Table 1. Comparisons of UK, Dutch and American accreditation programme

*American College of Chest Physicians Critical Care Ultrasonography accreditation - http://www.chestnet.org/Education/Advanced-Clinical-Training/Certificate-of-Completion-Program/Critical-Care-Ultrasonography

The French solution

France started to train intensivists and anesthesiologist more than 15 years ago [5]. In contrast with all other countries, France started to train the trainers and developing a 2-year specific diploma including basic practice with TTE and TEE. For years more than 100 intensivists and anesthesiologists every year were trained and acquired high competency on echocardiography in ICU. More than 5 years ago, France developed one year diploma for those who would like to reach advanced level including 100 hours of didactics, 100 TTE, 25-50 TEE and 20-25 ultrasound examinations for abdominal, transcranial and lung ultrasound. Today, a large majority of intensivists, anesthesiologists and emergency doctors are trained and are able to include ultrasounds in their daily practice. Also in France (Paris) exists the "Cercle des Echographistes d'Urgence et de Réanimation Francophones" (called CEURF), that organizes training courses on ultrasound devoted to critically ill, focusing on lung ultrasound and the BLUE-protocol. It is therefore a lung-centered training program which integrates the lung, deep veins combined with a simplified approach of the heart as a first line tool. CEURF teaches the users how to make use of more sophisticated when needed, following the rules of holistic ultrasound.

The European solution

Recently a consensus statement was published through the European Society of Intensive Care Medicine (ESICM) by a group of international experts on training standards for advanced CCUS [2]. The aim was to provide guidance to critical care physicians and students involved in advanced CCUS training and teaching. The consensus statement establishes specific requirements to guide instructors involved with the development of structured training programs defining different goals like image acquisition, image interpretation, and the cognitive base. This can be adapted in the future by national authorities or critical care medicine societies to establish their own certification process or when preparing for international exams (e.g., European Diploma in Echocardiography Care, EDEC)

Key messages

- Competency in CCUS requires a combination of theoretical and practical training
- Clearly defined syllabus and competencies are paramount to a successful training programme
- There is significant variation in CCUS training programmes across the world

How to consolidate US in your unit

Background

Distinct from the use of US in specialties outside the ICU, CCUS strongly focuses on cardiopulmonary interaction and bedside assessment with the aim to rapidly diagnosing, and treating patients with the ability to monitor response to treatment in real-time [6]. Image interpretation in the ICU setting is a holistic process, integrating all other available patient data, including those from haemodynamic monitoring and patient-ventilator interaction.

Challenges

A first challenge is the person of contact. Whilst the unique applications and nature of CCUS place it squarely within the ICU domain, most US trainers are in reality located in non-ICU specialties e.g. Cardiology and Radiology. Well-rounded training in CCUS is therefore likely to require collaboration with these specialties; specific contact persons in these departments provide a valuable source of support when interpreting complex or unusual images [1]. In an ideal world, regular CCUS multidisciplinary meetings discussing cases of interest will enhance the intensivist's ongoing learning and practice.

A second challenge lays in defining the limits. It also follows that practical boundaries must be clearly defined for an intensivist using CCUS. For example, in some institutions, it is agreed among specialties that CCUS focusses on point of care US of heart and lungs, including global assessment of left and right heart systolic function and chamber sizes, pericardial and pleural effusions, lung and pleural artifacts. This implies that intensivists will not draw conclusions on other visualised abnormalities e.g. valvular pathology. Clearly defining both possibilities and limitations of practicing CCUS in written protocols helps to avoid medicolegal and interprofessional conflict.

Finally, there is ongoing debate on the minimum training requirements. Given the non-uniformity of CCUS training nationally and internationally, a minimum training standard must be outlined before introducing CCUS in any ICU. Current consensus is that a minimum of 30 fully supervised CCUS examinations are needed for an acceptable safe level of practice. This is mainly based on expert opinion, with support from a few studies [6]. For governance and educational purposes, all images should be stored preferably using the hospital picture archiving and communication system (PACS) to ensure accessibility for all healthcare professionals involved in the patient's care, and to facilitate review and feedback.

Key messages

- The lack of sufficiently qualified trainers has been identified as a potential barrier to widespread dissemination of CCUS

- There is an urgent need for professional societies to develop a unified, competency-based training programme

Transcranial Doppler

Indications

Transcranial Doppler (TCD) can be very useful in a limited number of indications including the detection of vasospasm in the presence of a subarachnoid haemorrhage, cerebral perfusion pressure (CPP) and intracranial pressure (ICP) evaluation and the screening for brain death [7, 8].

Anatomy and windows

The most important vessels for TCD are the middle cerebral artery (MCA) and the anterior cerebral artery (ACA). At the level of the temporal bone, antegrade flow measures flow within the MCA; retrograde flow represents flow within the ACA.

Measurement	Calculation	Normal Values (ACM)
Peak Systolic Velocity (PSV)	-	85 cm/s
End Diastolic Velocity (EDV)	-	40 cm/s
Mean Velocity (Vm) = Time Averaged Peak Velocity (TAPV)	(PSV – EDV)/3 + EDV	55-60 cm/s
Pulsatility Index (PI)	(PSV – EDV)/Vm	0.6 – 1.0
Lindegaard Index (LI)	Vm ACM / Vm ACI	1.5

Table 2. Normal values of measurements and calculations that can be obtained with TCD.
Vm ACI = Mean Velocity in the Internal Carotid Artery

Probe, position and measurements

Table 2 lists the normal values of measurements and calculations that can be obtained with TCD. The Vm (mean velocity) is proportional to cerebral blood flow (high flow giving high velocities) and inversely proportional to vessel diameter, with vascular spasms resulting in high velocities (Figure 2). TCD is an early screening tool for the detection of vasospasm, a Vm greater than 120 cm/s indicates 'moderate vasospasm' while a Vm larger than 180 cm/s suggests 'severe vasospasm'. The Pulsatility Index (PI), used in conjunction with waveform morphology, is indicative of cerebrovascular resistance; the Lindegaard Index (LI) can further differentiate between vasospasm and hyperaemia. A LI < 3, indicates hyperaemia, where a LI > 6, indicates vasospasm.

Whilst TCD provides an inexpensive, non-invasive screening tool for vasospasm (sensitivity of 0.99 at the level of the MCA), it only has a specificity of 0.66. TCD is a screening tool for raised ICP and diminished CPP [9]. When the ICP increases, the Vm will decrease. A PI > 1.4 correlates with an ICP > 15 mmHg and a decreased CPP [10]. The formula 10.93 x PI) - 1.28 has been suggested for ICP measurement, but it remains that TCD is more useful in monitoring of ICP changes rather than providing an exact value [11, 12]. Likewise, while TCD can screen for brain death, it is not definitive due to the inability to scan the posterior circulation. Important limitations include inter-operator variability and inadequacy of acoustic windows in a proportion of adults.

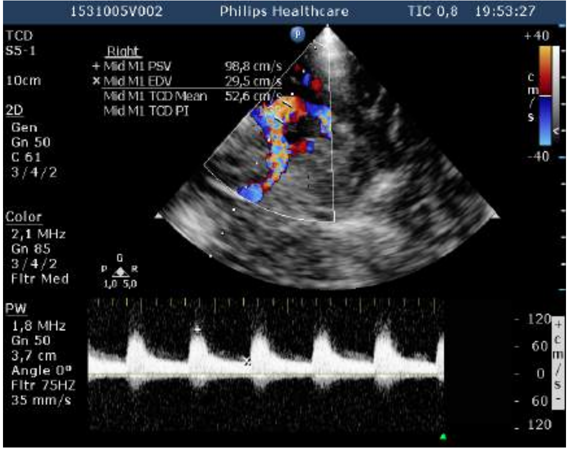


Figure 2. Transcranial Doppler image
The „+" indicates the Peak Systolic Velocity (PSV), while the „x" indicates the End Diastolic Velocity (EDV)

Key messages

- TCD is an inexpensive, non-invasive, bedside tool to assess the CNS but has limitations that the operator must be aware of
- TCD allows to assess not only the anatomy but also other parameters like the pulsatility index, the presence of vasospasm or an estimation of ICP

Measurement		
Peak Systolic Velocity (PSV)		Duration < 200 ms: poor prognosis
End Diastolic Velocity (EDV)	>20 cm/s: good prognosis	<20 cm/s: poor prognosis
Mean Velocity (Vm) = Time Averaged Peak Velocity (TAPV)	>120 cm/s: moderate vasospasm	> 180 cm/s: severe vasospasm
Pulsatility Index (PI)	>1.4: ICP > 15 mmHg	>2: ICP > 20 mmHg
Lindegaard Index (LI)	<3: hyperaemia	>6: vasospasm

Table 3. Overview of the pathological values obtained with TCD.

Lung ultrasound

BLUE-protocol

The clinical data are usually sufficient for diagnosis of respiratory failure in most patients, although the BLUE-(Bedside Lung ultrasound in Emergency) protocol will help in difficult cases [1, 13]. The BLUE-protocol sequentially screens strategic areas (BLUE-points) and generates a profile based on the presence and characteristics of specific patterns / artefacts with accuracies >90%. The BLUE-protocol is one application among many other, describing the clinical relevance of lung ultrasound in the critically ill, namely in the differential diagnosis of an acute respiratory failure with the identification of different signs: the bat sign (pleural line), lung sliding (seashore sign), the A-lines (horizontal artefact), the quad sign and sinusoid sign indicating pleural effusion, the fractal and lung sign indicating lung consolidation, the B-lines and lung rockets indicating interstitial syndromes, abolished lung sliding with the stratosphere sign suggesting pneumothorax, and the lung point indicating pneumothorax. Two more signs, the lung pulse and the dynamic air bronchogram are used to distinguish atelectasis from pneumonia.

With the BLUE-protocol one can identify 8 profiles by which it becomes possible to differentiate between 6 acute syndromes (Figure 3): pulmonary edema, pulmonary embolism, pneumonia, chronic obstructive pulmonary disease, asthma, and pneumothorax, each showing specific US patterns and profiles.

Key messages

- Lung ultrasound has higher diagnostic sensitivity and specificity compared to plain chest radiographs
- The use of the BLUE protocol allows to differentiate between distinct causes of respiratory failure: pulmonary edema, pneumonia, pneumothorax, pulmonary embolism, chronic obstructive lung disease and asthma

CCUS during circulatory failure

FALLS-protocol

The FALLS-protocol (Fluid Administration Limited by Lung Sonography) adapts the BLUE-protocol in acute circulatory failure, by combining basic CC echocardiography and lung US, with the appearance of B-lines considered the endpoint for fluid therapy [14, 15]. It is a decision tree used to sequentially search for obstructive, cardiogenic, hypovolemic and distributive shock in the absence of an obvious clinical cause.

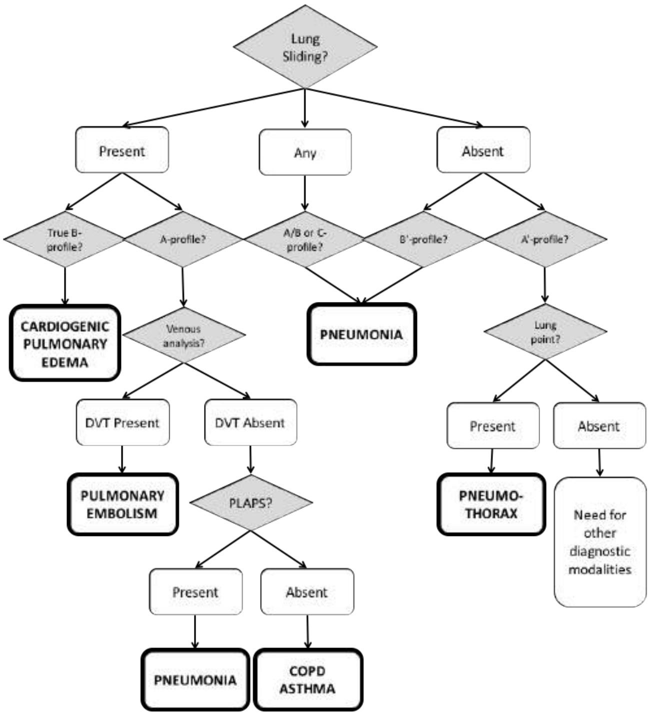


Figure 3. The modified BLUE-protocol starting at the upper and lower BLUE-points looking for lung sliding, and moving to the PLAPS-point, allows immediate differential diagnosis of the main causes of acute respiratory failure using lung and venous ultrasound. Adapted from Lichtenstein et al. with permission. PLAPS = Postero Lateral Alveolar and/or Pleural Syndrome. See text for explanation.

By firstly ruling out obstructive and cardiogenic causes, the remaining causes (hypovolemic and distributive e.g. septic shock) usually require fluid therapy, which should lead to clinical improvement in hypovolemic shock. Conversely in distributive shock, the fluid will accumulate without clinical improvement, saturating the lung interstitial compartment, revealing a transformation from A-lines to B-lines (the FALLS-endpoint indicating clinically occult hypervolemia) (Figure 4). The FALLS-protocol aims to decrease the mortality of shock, mainly septic, by a prompt diagnosis. The main limitation here is that no study has been designed to prove the ability of such an approach to improve prognosis.

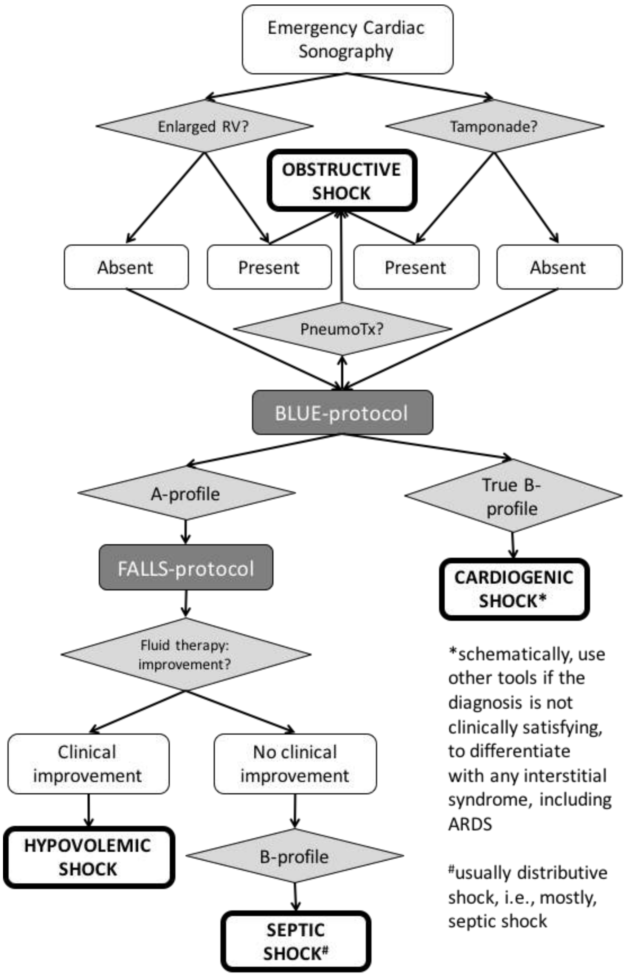
SESAME-protocol, ultrasound in cardiac arrest

The SESAME-protocol or "Sequential Echographic Scanning Assessing Mechanism Or Origin of Severe Shock of Indistinct Cause" involves a rapid, sequential assessment for shockable causes followed by assessment of the presence or absence of pneumothorax, pulmonary embolism, hypovolemia/hemorrhage finally followed by exclusion of pericardial tamponade, all highly reversible causes of shock [14]. The final step of the assessment, performed in the absence of the previous causes, focuses on the heart.

The main practical consideration in all these protocols is time-criticality. A compact US machine with a rapid start-up time allows for swift navigation around the bedspace. A universal long-range microconvex probe makes it possible to image the lungs, veins, abdomen and heart with a single probe. The absence of any software filter enables the user has to start up the machine and scan with minimal delay.

Key messages

- The systematic (and holistic) use of CCUS in various protocols provides a comprehensive assessment of the patients cardiovascular and respiratory system
- The SESAME protocol allows to differentiate between reversible causes during cardiac arrest in the following sequence: first exclude pneumothorax, followed by pulmonary embolism, hypovolemia (e.g. abdominal bleeding), cardiac tamponade, and finally cardiac disorders
- The FALLS protocol allows to establish a sequential diagnosis in patients with shock: first exclusion of obstructive (pericardial tamponade, pulmonary embolism, pneumothorax), followed by cardiogenic, hypovolemic and finally distributive (sepsis) causes of shock



*schematically, use other tools if the diagnosis is not clinically satisfying, to differentiate with any interstitial syndrome, including ARDS

#usually distributive shock, i.e., mostly, septic shock

Figure 4. The FALLS protocol.
A decision tree facilitating the understanding of the FALLS-protocol. According to Weil classification, cardiac and lung ultrasound sequentially rule out obstructive, cardiogenic (from left heart), hypovolemic and finally distributive shock, i.e. septic shock in current practice. Adapted from Lichtenstein et al. with permission. Legend: FALLS-protocol = Fluid Administration Limited by Lung Sonography; BLUE-protocol = Bedside Lung Ultrasound in Emergency; RV = right ventricle; PneumoTx = pneumothorax

The role for transoesophageal echocardiography

Investigating thromboembolism
TOE is an elegant tool providing both detailed diagnostic and monitoring information in critically ill patients and also intraoperatively [16-18]. TOE is useful in the bedside investigation of thromboembolic events through visualisation of thrombi involving the proximal pulmonary arteries, atheroma plaques (≥ 5 mm) in the thoracic aorta, patent foramen ovale and atrial septal aneurysm [19]. TOE may also visualize thrombi into the main or the right pulmonary artery, then allowing diagnosis of proximal pulmonary embolism at the bedside in a mechanically ventilated patient. However, apical thrombi can be better visualised with transthoracic imaging because of the location of the ventricular apex [20].

Monitoring ventricular function
TOE is particularly useful in ventricular function monitoring in the ICU and during major surgery or interventional procedures. An initial TOE investigation after admission to ICU should highlight regional wall motion abnormalities. Any changes can be detected on periodic assessment and related with perfusion alterations or alteration in the patient's clinical state. Volumetric assessment of the left ventricle is facilitated by 3-D TOE because of improved spatial resolution, and more accurate and reproducible measurements [21], although a simple measurement of LV areas on a short axis view is usually adequate in the critically-ill patient. LV systolic function is very easily and accurately assessed by eyeballing evaluation and simple graduation of systolic function in 4 categories, as supranormal, normal, moderately and severely depressed allows treatment adaptation and shock classification. Furthermore, right ventricular dilation, associated or not with a paradoxical septal motion, must be regarded in view of potential causes of right ventricular failure when a perfusion deficit is present (cardiogenic shock, ventilation-perfusion mismatch, ARDS etc.).

Valvular assessment
Another advantage of TOE is the assessment of native or prosthetic valve dysfunction. Mitral and tricuspid valve issues can be captured by TOE

with a combination of transverse and longitudinal planes in the multiplane facility. Assessment of aortic valve function is more difficult but possible using a deep transgastric view in transverse plane (0°) in the stomach or a LAX view (120°) at the gastro-oesophageal transition[22]. This view in fact allows dynamic imaging of all four valves. The different views are summarized in table 4.

view	To visualize	Indication
Transgastric		
SAX	LV, RV	Global function, RWMA, pericardial fluid, static evaluation of filling, LVH
MV	MV, LV	MV disease
ME		
4-chamber	4 chambers, MV, TV	Global function, RWMA
MV commissural	MV leaflets, scallops	MV disease
2-chamber	LV, MV scallops	MV disease
LVOT	LV, RV, AV, LVOT	Valve function, SAM, AI, AS
Upper mediastinal	AA, pulmonary arteries, AV	AS, AI, aneurysm, dissection, PA flow
Deep transgastric 0°	AV, LVOT, AA, MV	AV function, AS, AI
Clockwise rotation 0°	RV, TV	TI, RV function
120°	RV inflow, RA, RV outflow, PV	TI, PI, PS
Descending aorta	DA	Dissection, aneurysm, low flow state, pleural fluid, posterior pulmonary complications

Table 4. Summary of different TOE views. AA, ascending aorta; AI, aortic valve insufficiency; AS, aortic stenosis; AV, aortic valve; DA, descending aorta; LV, left ventricle; LVH, left ventricular hypertrophy; LVOT, left ventricular outflow tract; MV, mitral valve; PI, pulmonary valve regurgitation; PS, pulmonary valve stenosis; PV, pulmonary valve; RV, right ventricle; RWMA, regional wall motion abnormalities; SAM, systolic anterior motion of the anterior MV leaflet; TI, tricuspid valve insufficiency; TV, tricuspid valve.

Additionally, TOE is useful in early follow-up after mitral valve repair, in 2-D or 3-D [23]. Function of the repaired valvular apparatus, presence of paravalvular leaks, systolic motion of the anterior mitral leaflet can all be examined, however, the effects of anaesthetic / sedatives and the altered preload and afterload conditions must be taken into account.

Monitoring fluid status

A smaller TOE probe left in situ enables real-time examination of ventricular function and fluid responsiveness, particularly in patients with precarious haemodynamics. An extensive review of assessment of loading conditions through echocardiography can be found elsewhere. Fluid responsiveness evaluation could be assessed by flow variation of aortic flow (transaortic valvular Doppler variation with mechanical ventilation) or cyclic changes of superior caval vein diameter, as assessed with M mode of the superior caval vein in a bicaval view. A large observational and prospective study performed in patients with shock has reported that SVC collapsibility index has the best specificity, whereas respiratory variations of aortic blood flow the best sensitivity [24].

Tissue Doppler adds important information both on systolic and diastolic function of the LV; all myocardial Doppler signals are load dependent Care should be taken that ventilator settings, such as PEEP, can influence diastolic function parameters [25, 26].

Key messages

- TEE has become a gold standard for hemodynamic monitoring in the ICU
- TEE allows assessment of presence or not of thromboembolism, pericardial fluid, fluid status, valvular and ventricular function
- The advantage is that image quality is superior, however compared to other hemodynamic monitoring techniques it is user dependent and semi-continuous (as the probe may heat with prolonged use)

The role for transthoracic echocardiography

Transthoracic echocardiography (TTE) is non-invasive and easy to perform at the bedside, and can diagnose the cause of shock or respiratory failure in more than 80% of cases even in the presence of mechanical ventilation and pre-existing lung disease [27]. TTE can also guide the pericardiocentesis in the case of pericardial tamponade.

Assessment of the inferior vena cava can demonstrate fluid-responsiveness [28, 29]. However a recent study reported limited accuracy [24]. Respiratory variations of aortic blood flow recorded using pulsed Doppler also reflect fluid-responsiveness [30]. Cardiac output can be estimated from the left ventricular outflow tract area, the aortic velocity time integral and the heart rate.

Pulmonary arterial pressures are easy to assess in ICU patients. Tricuspid regurgitation can be identified on apical 4-chamber view using continuous wave Doppler [31], with the maximal velocity of the tricuspid regurgitation corresponding to the maximal systolic pressure gradient between the right ventricle and the right atrium. The sum of this measured pressure gradient with the right atrial pressure (central venous catheter reading) calculates the right ventricular systolic pressure, and subsequently the pulmonary systolic arterial pressure, with good correlation between pulmonary Doppler and invasive systolic arterial pressure [32]. Pulmonary artery occlusive pressure (PAOP) is a useful index in pulmonary oedema, with good correlation between invasively-measured PAOP and Doppler evaluation [33]. In patients with respiratory failure and cardiac failure, TTE can be used to assess the left ventricular ejection fraction, differentiating between systolic or diastolic left ventricular dysfunction or severe valvular regurgitation.

Key messages

- TTE has evolved as the modern stethoscope for the intensivist
- Similarly to TEE, TTE also allows assessment of presence or not of thromboembolism, pericardial fluid, fluid status, valvular and ventricular function
- Compared to TEE it is readily available but image quality in ICU patients is sometimes poor (e.g. in presence of subcutaneous emphysema, COPD,...)

Assessment of the left ventricle

The assessment of the left ventricle includes the measurements of the ejection fraction (EF), the cardiac output (CO) and the left ventricle filling pressure [34, 35].

Ejection Fraction

Ejection fraction doesn’t equal contractility since it also takes afterload and preload into account (Table 5). If you increase the afterload, you will decrease the ejection fraction without a change in contractility.

Measurement	View	Calculation	Limitations
Shortening Fraction	PLAX	(LVEDD – LVESD) / LVEDD	Not reliable when RWA at septal or posterior wall. Measurement needs to be perpendicular on the posterior wall.
Shortening Fraction of the LV Area	PSAX	(LVEDD – LVESD) / LVEDD	Not reliable when RWA.
True Ejection Fraction	A4C	Simpson Biplane Method	Most reliable method.
E Point Septal Separation (EPSS) = Mitral Valve Opening	PLAX	M mode. Normal < 7 – 10 mm	
Eyeballing	PLAX / PSAX / A4C		Operator dependent. Reliable when experienced provider.

Table 5. Evaluation of left ventricular ejection fraction. PLAX = Parasternal Long Axis View, PSAX = Parasternal Short Axis View, A4C = Apical 4 Chamber View. RWA = Regional Wall Abnormalities. LVEDD = Left Ventricular End Diastolic Diameter. LVESD = Left Ventricular End Systolic Diameter.

Cardiac Output

You measure the diameter (in cm) at the Left Ventricular Outflow Tract (LVOT) 0.5 cm before the aortic valve at the ventricular side in the PLAX. In a next step you can calculate the surface of the LVOT Area (in cm^2). In the A5C or A3C view you measure the Aortic Blood Flow (ABF) with Pulse Wave (PW) Doppler. You subsequently trace the edge of the ABF curve to calculate the Velocity Time Interval (VTI) which is the Area Under the Curve (AUC). A normal LVOT VTI is > 18 cm. If you multiple this VTI with the LVOT Area, you will get the stroke volume (in cm^3 or mL). Finally, when you multiply the stroke volume with the frequency you will get the cardiac output. If you divide the cardiac output by the Body Surface Area (BSA) you get the Cardiac Index (CI). This method is very accurate and can be considered as gold standard function [36].

Diastolic Function

Diastolic Dysfunction shifts the LV End Diastolic Pressure (LVEDP)/ LV End Diastolic Volume (LVEDV) curve to the left and narrows the therapeutic range for safe intravenous fluid administration. The LV Pressure Gradient will decrease and the flow over the mitral valve will decrease. It will cause A (Late Filling over the Mitral Valve) to be larger than E (Early Filling over the Mitral Valve) in a Pulse Wave (PW) Measurement just behind the mitral valve. It has to be noted that mitral flow largely depends on age, heart rate, preload and afterload and as such, this flow cannot be used to assess diastolic function of the LV. The measurement of the movement of the mitral valve annulus at the lateral wall in Tissue Doppler Imaging (TDI) is not dependent on preload and we call this E′ and A′. E′ velocity can be used to assess diastolic dysfunction, where an E′ lower than 8-10 usually corresponds to a diastolic dysfunction. The third part of the assessment is the measurement of the size of the left atrium (LA). If the LA has a normal size, there is no diastolic dysfunction (Table 6). But we have to keep in mind that the size of the LA may change during preload changes.

PAOP

The E/E′ ratio correlates very well with Pulmonary Artery Occlusion Pressure (PAOP or wedge pressure) since the E′ is independent of the preload (and only dependent on the LV relaxation) while the mitral flow (E) is dependent on the PAOP and on the LV relaxation. The cut-off for a raised PAOP is 18 mmHg. An E/E′ ratio below 8 is usually associated with low or normal PAOP and above 12 corresponds to PAOP>18 mmHg with a grey zone between 8 and 12. But the accuracy of this parameter to assess PAOP was recently discussed and only extreme values corresponds to a low or to an high PAOP.

Key messages

- Assessment of the left ventricle provides important information for the ICU physician
- LV assessment includes cardiac outpur, LV ejection fraction, diastolic function and estimation of PAOP

Assessment of the right heart

In the statement of the American College of Chest Physicians and of the French Society of Intensive Care, which defined for the first time critical care echocardiography (CCE), it is recommended to intensivists to be competent in evaluating RV function [3]. At the advanced level of CCE, intensivists have to accurately detect RV dilatation and paradoxical septal movement, to diagnose acute cor pulmonale (ACP), to evaluate the impact of mechanical ventilation and respiratory settings on RV function. For such goals, different echo parameters have been proposed.

Evaluation of RV size
Moderate RV dilatation is defined as a ratio between RV end-diastolic area (RVEDA) and left ventricular end-diastolic area (LVEDA) greater than 0.6, whereas a severe dilatation is defined when this ratio is greater than 1, the RV is bigger than the LV [37]. This can be evaluated by transthoracic echocardiography (TTE) on an apical 4-chamber view or by a transoesophageal echocardiography (TOE) on a transverse mid-esophageal view. We have suggested that this can be qualitatively done just by visualizing the view on the screen of the echo machine [37]. Very frequently, in case of RV dilatation, the inferior vena cava also appears on a subcostal view as dilated and congestive without any respiratory movement. This reflects a high right atrial pressure [38].

Interventricular septal movement
In some very abnormal situations, when the pressure into the RV becomes higher than the pressure into the LV, a paradoxical septal movement can be diagnosed. When occurring at end-diastole, this reflects a huge RV diastolic overload. When occurring at end-systole early diastole, this reflects RV systolic overload. Usually, this pattern is qualitatively evaluated (it is present or not) but it can also be quantified using the eccentricity index of the LV [39]. This index is the ratio between the antero-posterior diameter of the LV and the septo-lateral one. In a normal situation, because the LV is purely spherical, the eccentricity index in diastole and in systole is 1, whereas in case of RV overload, the LV is compressed and then the eccentricity index is greater than 1. The movement of the interventricular septum may be evaluated either using TTE on a parasternal short axis view or using TOE on a transgastric short axis view. The association of RV dilatation and paradoxical septal motion at end-systole defines cor pulmonale.

Doppler evaluation of RV ejection flow
The use of the pulsed-wave Doppler (PWD) in the RV outflow track allows analyzing whether there are respiratory variations of RV ejection during tidal ventilation. When occurring, it always reflects a significant impact of tidal ventilation on RV function, either due to a preload effect (usually corrected by fluid expansion) or due to an afterload effect (fluid expansion is useless and even deleterious and changes in respiratory settings have to be considered).
From the RV ejection flow recorded by the PWD at end-expiration, some information on the status of the pulmonary circulation may be obtained. When the acceleration time, which is the time between the beginning and the peak of the ejection, is below 100 ms, it reflects some degree of pulmonary artery pressure elevation. When the flow is biphasic, this is very suggestive that a significant obstruction of the pulmonary circulation is present, either due to a massive pulmonary embolism (proximal obstruction) or to a severe acute respiratory distress syndrome (ARDS) (distal obstruction).

More "advanced" echo parameters of RV function
Study of the lateral part of the tricuspid annulus during systole has been proposed to evaluate RV systolic function. Tricuspid annular plane systolic excursion (TAPSE) with the time motion mode evaluates the amount of movement; S wave using the tissue Doppler imaging (TDI) evaluated the maximal velocity. Larger is the movement or higher is the velocity better is the RV systolic function. Different cut-off values have been proposed to define RV systolic dysfunction but usual-

ly an S wave below 11.5 cm/s [40] and a TAPSE below 12 mm [41] are considered as significantly abnormal.

It has also been proposed to use the mean acceleration of the RV ejection flow in mechanically ventilated patients for an ARDS [42]. The mean acceleration is the ratio between the maximal velocity of the RV ejection flow and the acceleration time. This is correlated to RV systolic function and inversely correlated to RV afterload. Then, a decrease in the mean acceleration time is suggestive of a decrease in RV systolic function and an increase in RV afterload as observed during tidal volume in some patients. New ultrasound techniques (speckle tracking) may analyse much more accurately the systolic function of the RV but this technique is still under evaluation [42].

Interest of TOE-Focus in specific situations

TOE may be very useful and is safe in mechanically ventilated patients. In case of clinical suspicion of pulmonary embolism, in a patient who had a cardiac arrest following by circulatory failure, it may give the diagnosis in a few minutes at the bedside by visualizing clot into the pulmonary arteries [43]. In severe ARDS patients, this is the gold standard approach to diagnose ACP [44] and open formaen ovale which occurs in 20-22% of the patients [45].

Key messages

- Assessment of the right ventricle provides important information for the ICU physician
- RV assessment includes RV anatomy and function, RV dimensions, presence of pulmonary hypertension

Assessment of fluid responsiveness

Concept of fluid responsiveness

When making the decision to infuse fluids in a patient with acute circulatory failure, the clinician has to face a therapeutic dilemma. On the one hand, the fluid-induced increase in cardiac preload might increase cardiac output and, eventually, oxygen delivery to the tissues. On the other hand, volume expansion may contribute to fluid overload, a condition that has been clearly demonstrated to be associated with poor outcome, especially in patients with sepsis and acute respiratory distress syndrome (ARDS). Moreover, due to the shape of the Frank-Starling relationship, the fluid-induced increase in preload leads to a significant increase in cardiac output only in case of fluid responsiveness. This corresponds to around 50% of cases in patients with acute circulatory failure who are hospitalised in the intensive care unit [46].

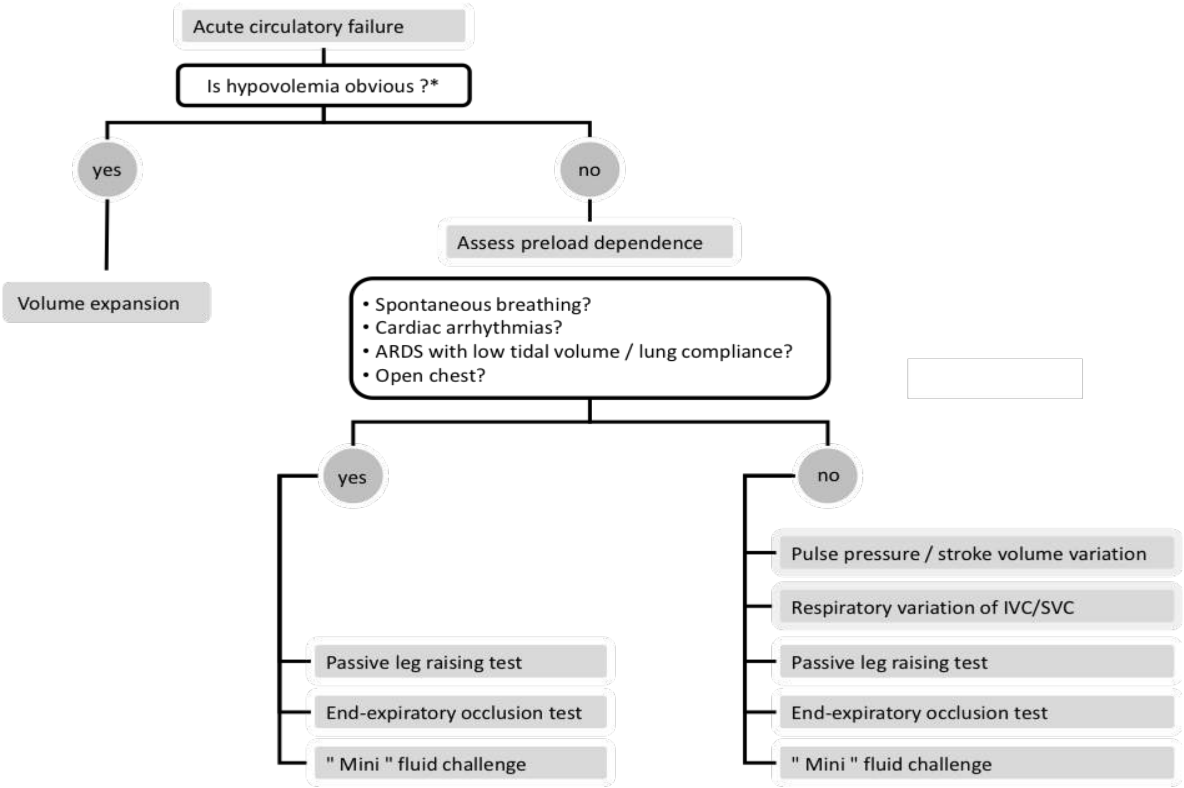
This is the reason why some methods have been investigated in order to assess fluid responsiveness at the bedside. All these methods can be used with echocardiography, what may be especially useful when no other measurement of cardiac output is available.

Before describing these indices, one must emphasise two major points. First, the question to assess fluid responsiveness only arises in case of acute circulatory failure, i. e. when one has decided to increase cardiac output because of inadequacy between oxygen demand and supply. Second, the indices described below are useless when fluid responsiveness is extremely likely, as for example in a patient with unresuscitated haemorrhagic shock or during the initial, unresuscitated phase of septic shock (Figure 5).

Static indices of cardiac preload

It has been clearly demonstrated that no static measure of cardiac preload reliably predicts fluid responsiveness in most situations. The main reason is physiologic. Because the slope of the Frank-Starling relationship depends on ventricular systolic function, a given value of preload could correspond either to the steep or the flat part of the curve [46].

Echocardiographic static measures of preload include the left end-diastolic volume and area and all indices derived from the mitral flow and mitral annulus motion Doppler analysis. Although these indices estimate left ventricular preload, but they do not indicate preload dependence of stroke volume except for very low values [46]. For basic CCUS, a few echo parameters are very likely associated with fluid-responsiveness, as a small IVC and a small hyperkinetic left ventricle, eventually associated with a dynamic obstruction, whereas it is very unlikely to have a fluid responsiveness status when the mitral inflow is restrictive.



*Very initial phase of septic shock, when no fluid has been already administered, in case of haemorrhagic shock or in case of hypovolaemic shock due to diarrhoea, vomiting or ketoacidosis for instance.

Figure 5. Decisional algorithm for the prediction of fluid responsiveness.

Respiratory variation of stroke volume

The relationship between respiratory cycle and cardiac preload is a complex one. Under positive pressure ventilation, each respiratory cycle induces changes in cardiac preload. This results in greater variation of stroke volume if both ventricles are operating on the steep portion rather than on the plateau of the Frank-Starling relationship.

Echocardiography estimates the left ventricular stroke volume through the velocity-time integral (VTI) of the systolic Doppler signal when the sampling window of pulsed Doppler is placed in the outflow tract of the left ventricle. Variability in stroke volume can be assessed simply by measuring changes in aortic peak velocity (rather than VTI itself). It has been shown that when the respiratory variation of the aortic peak velocity is greater than 12% or VTI variations of more than 20%, fluid responsiveness is likely [46].

The primary limitation to the use of respiratory variation of LVOT velocity is that it is sometimes difficult to keep the Doppler sample window in the left ventricular outflow tract during breathing movements. In this regard, if an arterial catheter is in place, the respiratory variation of pulse pressure is much easier to assess. Moreover, this method cannot be used in cases of cardiac arrhythmias or spontaneous breathing (even in patients receiving intubation) (Figure 5). Indeed, in such cases, changes in stroke volume primarily reflect the irregularities of the cardiac or respiratory cycles rather than preload dependence (false positives). Right ventricular dysfunction and or dilation may also induce a false positive due to an afterload effect of the mechanical ventilation rather than a preload effect. Also, when tidal volume is low and/or when lung compliance is low, as during ARDS, changes in right ventricular preload induced by mechanical ventilation might be too low to generate significant variations of stroke volume, even if the patient is preload dependent (false negatives) (Figure 5). Finally, when the thorax and/or the pericardium are open, respiratory variability indices may be unreliable [46].

Respiratory variation in the diameter of the vena cava

The diameter of the vena cava depends on the intramural pressure (which itself depends on the circulating blood volume) and the extramural pressure (intra-abdominal pressure for the inferior vena cava, intrathoracic pressure for the superior vena cava). Significant respiratory changes in the diameter of the vena cava indicate that positive pressure ventilation affects systemic venous return, suggesting preload dependence.
Fluid responsiveness was found to be predicted by a respiratory variation of the inferior vena cava ([maximum diameter – minimum diameter] / minimum diameter or [maximum diameter – minimum diameter] / mean of maximum and minimum diameters) higher than 18% or 13%, respectively, and a superior vena cava collapsibility index ([maximum diameter – minimum diameter] / maximum diameter) greater than 36% in mechanically ventilated patients.
In some critically ill patients with poor subcostal windows, the inferior vena cava may be difficult to image. Superior vena cava collapsibility can only be measured with transesophageal echocardiography, which requires special expertise. Unlike the respiratory variability of aortic velocity, respiratory variability of diameter of the vena cava can be used in patients with cardiac arrhythmias but is invalid in the case of spontaneous breathing and, likely, in case of low tidal volume and low lung compliance (Figure 5). Finally, intra-abdominal hypertension might invalidate inferior vena cava variability measurements. The accuracy of IVC and SVC variations to assess fluid-responsiveness were recently discussed in a large prospective study and I was demonstrated that IVC is a poor predictor and the cut-off values are different that previously published [24].

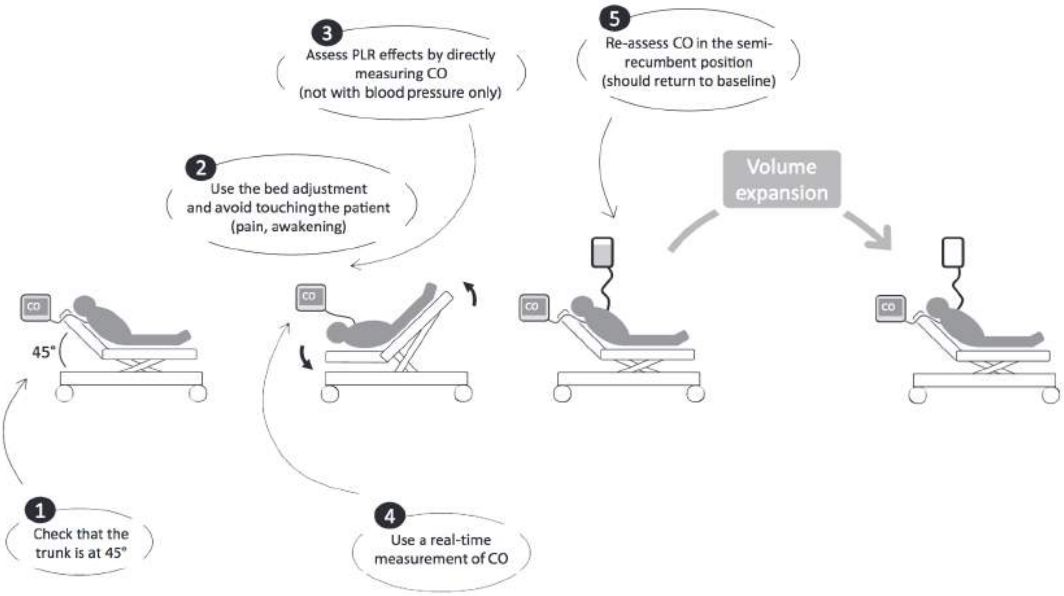


Figure 6. The best method for passive leg raising, indicating the five rules to be followed. Adapted from Monnet et al. with permission [47]. CO, cardiac output; PLR, passive leg raising.

The passive leg raising test

The elevation of the lower extremities relative to the horizontal position provokes the transfer of a volume of venous blood into the thorax. The resultant increase in right and left ventricular preload can be used to evaluate preload dependence. The PLR-induced increase in cardiac preload does not depend on cardiac rhythm or intrathoracic pressure variations, so PLR is an alternative to indices based on respiratory variability where they are not valid [47](Figure 6).

Measurements	Diagnosis
E' Lateral > 10 cm/s, E' Septal > 8 cm/s **LA Volume < 34 mL/m²**	Normal Left Ventricular Relaxation
E' Lateral > 10 cm/s, E' Septal > 8 cm/s **LA Volume > 34 mL/m²**	Athlete's heart
E' Lateral < 10 cm/s, E' Septal < 8 cm/s **LA Volume > 34 mL/m²**	Left Ventricular Dysfunction

Table 6. Diastolic function

Several studies have demonstrated that an increase in stroke volume by more than 10% during PLR predicts fluid responsiveness with good diagnostic accuracy, even in patients with cardiac arrhythmias, spontaneous ventilation, or ARDS. With echocardiography, an increase in the VTI of the left ventricular outflow tract of more than 10% during PLR predicts the response to volume expansion with good [48]. The test is more sensitive when the manoeuvre is started from the semi-recumbent position because it allows the mobilization of the large abdominal venous volume in addition to the volume of blood contained in the lower extremities [47].

A first limitation of the method is that it is sometimes difficult to maintain the probe stationary relative to the thorax during postural change. The test is much easier to perform in case of continuous monitoring of cardiac output with a specific device. A second limitation is that the PLR test often cannot be used during active surgery and is contraindicated in intracranial hypertension and unstable pelvic fractures. Finally, whether intra-abdominal hypertension is a condition where PLR may be unreliable has been suggested but is not certain [47].

The end-expiratory and end-inspiratory occlusion tests

During mechanical ventilation, inspiration cyclically increases the backward pressure of venous return, thus reducing the cardiac preload. Stopping mechanical ventilation at end-expiration for a few seconds interrupts this cyclic reduction: end-expiratory occlusion (EEO) induces a transient increase in cardiac preload. Observing the resulting effects on stroke volume allows one to assess preload dependence. If cardiac output increases by more than 5% during a 15-second EEO, the presence of fluid responsiveness is likely [47]. The test is very easy to perform with a continuous measurement of cardiac output, such as pulse contour analysis. Furthermore, adding the effects on the LVOT blood flow of a 15-sec end-*inspiratory* occlusion, which decreases cardiac output in case of preload responsiveness, increases the test sensitivity. If the addition (in absolute values) of the changes in VTI during a 15-sec EEO and during a 15-sec end-inspiratory occlusion is more than 13%, fluid responsiveness is very likely.

The EEO test can be used in patients with cardiac arrhythmias and with ARDS, regardless of the level of positive end-expiratory pressure. Although it can be used in patients with mild spontaneous breathing activity, it cannot be performed if the spontaneous breathing interrupts the inspiratory hold. When US is used to perform the test, another limitation is that it requires a very precise measurement of VTI, which is difficult for non-experts.

Fluid Challenge

When no other index is available, it may be best to test fluid responsiveness by administering a small quantity of fluid, observe its effects on cardiac output, and expect that a larger volume of fluid will exert similar effects. This can be performed serially, stopping volume expansion when fluid no longer increases cardiac output. Nevertheless, since that fluid challenge usually consists in infusing 300-500 mL of fluid, the method inherently would induce fluid overload.
A new method called "mini fluid challenge" has been proposed. The effects of 100 mL of colloid (given in a speedy manner) on stroke volume were shown to predict the response of cardiac output to a subsequent 500 mL volume expansion [49]. These changes in stroke volume were estimated with echocardiography [49]. Nevertheless, small amounts of fluid only induce small changes in stroke volume and cardiac output. Whether echocardiography is precise enough in non-expert hands to detect these changes is far from certain.

Conclusion
Several tests have been developed to detect preload responsiveness and to guide decision making about volume expansion. This avoids unnecessary fluid administration and harmful volume overload. Many of these tests can be performed with the help of echocardiography. This may be particularly useful when cardiac output monitoring is absent, either because it is not indicated or because it has not been installed yet. In particular, US can be used for measuring the respiratory variations of the velocity of the aortic flow and of the diameter of the vena cava and for assessing the effects of a PLR test or, in ventilated patients, of 15-sec end-inspiratory and end-expiratory occlusions.

Key messages

- Dynamic measures outperform static measures in the determination of fluid responsiveness in patients
- Various bedside test such as the PLR and the end-inspiratory/expiratory occlusion hold have been advocated as a test of fluid responsiveness without actual fluid administration
- All tests need to be interpreted in the context of the individual patient especially with regards to respiratory parameters

Abdominal ultrasound

Abdominal US on ICU can be performed for diagnostic and therapeutic purposes. Several free open access medical educational (FOAM) resources are available on the internet (Table 7). Bedside abdominal US, in experienced hands is focused, with the aim of answering a specific clinical question e.g. presence of free intraabdominal fluid, urinary tract obstruction (hydronephrosis), hydrops of the gall bladder, bladder or stomach distension, increased renal resistive index, portal vein thrombosis etc.

Abdominal US		
	FAST scan in trauma	http://www.sonoguide.com/FAST.html
	RUSH protocol and discussion	http://emcrit.org/rush-exam/
	Indications for FAST	http://www.trauma.org/archive/radiology/FASTindications.html
Miscellaneous Resources and links		
	Sonosite Education	http://www.sonositeeducation.com
	Ultrasound training solutions	http://www.UStraining.com.au/information/medical-education-links
	Bedside US iBook by @USpod	https://itunes.apple.com/us/book/introduction-to-bedside-US/id554196012?mt=13

Table 7. FOAM resources on ultrasound

FAST Scan

The most established focused abdominal US examination is the FAST (Focused Assessment with Sonography for Trauma). The goal is the identification of free intraabdominal fluid/blood using 4 standard views: subcostal, right and left upper quadrant and suprapubic.

eFAST Scan

This combines a FAST scan with lung US to identify pneumothoraces.

RUSH Scan

The RUSH scan (Rapid US for Shock and Hypotension) is an examination designed to be rapid and easy to perform in the emergency department. In addition to abdominal and lung US, it also includes views of the heart (parasternal long axis and apical 4-chamber), inferior vena cava and aorta.

Other diagnoses that are amenable to the point-of-care US include liver / gallbladder abnormalities e.g. acute cholecystitis, abscess, biliary obstruction and renal abnormalities e.g. atrophy, abscess, cysts.

Key messages

- The detection of free fluid in the abdomen is a simple skill to acquire
- In experienced hands, abdominal ultrasound can provide other useful information like gastric distension, hydrops of the gall bladder, bladder distension, hydronephrosis, renal resistive index and much more

Vascular access

Using the traditional 'landmark approach', placement of vascular catheters such as central venous catheters (CVC), peripherally inserted central catheters (PICC) and arterial catheters carries risks e.g. arterial puncture, pneumothorax. Direct visualisation using real-time US guidance allows identification of the target vessel and optimal insertion site, thereby reducing the incidence of complications. Furthermore, by avoiding the Trendelenburg position, patient comfort is improved. Guidelines and recommendations advocate the introduction of US for vascular access in clinical practice [50].

General principles

In most patients, the target vessels can be visualised using a linear high-frequency probe. US can be performed either in static (considered the absolute minimum for vascular access) or dynamic mode. Dynamic, or real-time US guidance is performed under sterile conditions. The choice of in-plane or out-of-plane approach is usually based on operator preference, with no general recommendations made even though a recent randomized study between both approaches seems to favor the short axis for the sub-clavian access.

Central venous access

Internal jugular vein (IJV): The IJV is the most straightforward to approach by US and the easiest for novices to access. The IJV can be easily identified in the neck, usually lateral or superior to the carotid artery (Figure 7) and demonstrates good compressibility.

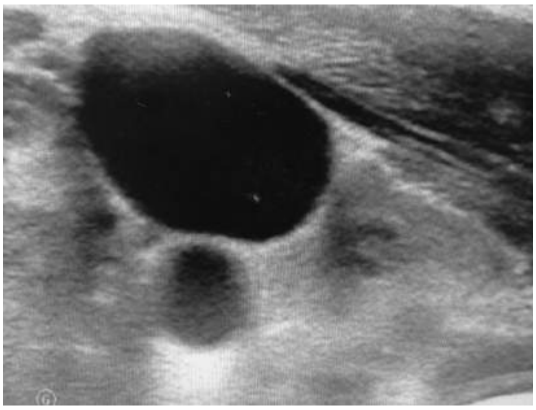


Figure 7. Vascular access
Internal jugular vein (IJV) lying on top of carotid artery (CA)

Subclavian vein (SV): The SV is traditionally shunned by clinicians using the landmark approach due to the higher risk of complications. In a recent publication, SV catheterization was associated with a lower risk of bloodstream infection and symptomatic thrombosis but a higher risk of pneumothorax than jugular or femoral vein catheterisation [51]. Whilst US guided SV catheterisation largely avoids the risks of pneumothorax and arterial puncture, it requires more skill and training than the jugular approach by virtue of its anatomical location. The preferred approach is a longitudinal visualisation of the vessel with an in-plane approach, with "tenting" of the vessel "roof" must be seen just prior to vascular puncture (Figure 8).

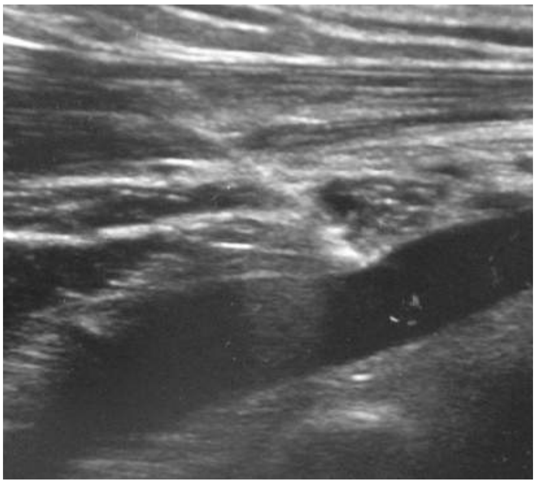


Figure 8. Vascular access
Longitudinal visualization in an in-plane approach of the subclavian vein with typical "tenting" of the vein, confirming correct entry.

Femoral vein (FV): The femoral vein, though not a preferred vessel, can be easily identified and cannulated. Cannulation of the superficial femoral vein in the mid-thigh is an alternative approach when one wants to avoid the groin area. PICC and Midline catheters (ML): PICC and ML catheters avoid central structures and are ideal for patients receiving ambulatory care. The target vein (basilic vein for PICC and ML or cephalic vein for ML) should be screened for patency and size (diameter up to 3 times that of the catheter), which is essential to avoid vein thrombosis. This technique requires a lot of experience and practice, but once mastered will be very valuable for many patients.

Arterial cannulation
Arterial cannulation is commonly performed in critically ill patients. US guidance allows alternative approaches, such as cannulation of the radial artery in the mid fore-arm, thereby avoiding the problem of catheter kinking when inserted over joints.

Training and education
Several training methods for US guided catheter placement have been described. Approaches can be trained on training gels and other devices but this is not a substitute for supervised bedside training. It usually takes 10 one-to-one supervised procedures before a trainee can work more independently.

Key messages

- The use of real-time, US guidance for vascular access is rapidly becoming normal practice
- Various professional bodies, although advocating the use of US, differ with regards to whether the in- or out-of plane approach should be the default position

Discussion

Ultrasound has evolved beyond just being the remit of radiologists and has become an important tool in the armament of the Intensivists.

This review has highlighted the various aspects of CCUS and its place in modern intensive care unit. It summarises key learning points as well as challenges for the practicing clinician. CCUS is not meant to replace traditional clinical examination but rather enhances it – improving diagnostic acumen. By no means ultrasound can replace clinical examination but classic physical examination in combination with holistic ultrasound will provide the clinician with a full physiological examination. Hence, the ultrasound may become the modern stethoscope for the ICU physician. CCUS scans do not represent comprehensive imaging studies and should never replace studies performed by specialist colleagues, such as radiologists, radiographers or cardiologists.

Of the various modalities of CCUS, echocardiography is the most established – both in terms of clinical practice but also training delivery. The European Diploma in Echocardiography (EDEC) established by the European Society of Intensive Care Medicine is testament of this. Whilst this Advanced qualification has been clearly defined, what constitutes basic competencies is lacking across Europe. Programmes such as CUSIC and ICARUS mentioned above form the framework of future work.

Despite the landmark expert consensus statement published in 2011, there remains a void in what competencies and hence how best to train future colleagues in this field. The lack of qualified trainers is often highlighted as the biggest stumbling block in the introduction of a standardised training programme. There is an urgent need for professional organisations to first address the lack of guidance in training before the issue of trainers can be addressed.

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Notes

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CHAPTER 2

The Role of Point-of-Care Ultrasound in Intra-Abdominal Hypertension management

Bruno M Pereira, Renato G Pereira, Robert Wise, Gavin Sugrue, Tanya L Zachrison, Alcir E Dorigatti, Rossano K Fiorelli, Manu L.N.G. Malbrain

Introduction: Intra-abdominal hypertension is a common complication in critically ill patients. Recently the Abdominal Compartment Society (WSACS) developed a medical management algorithm with a stepwise approach according to the evolution of the intra-abdominal pressure and aiming to keep IAP ≤15mmHg. With the increased use of ultrasound as a bedside modality in both emergency and critical care patients, we hypothesized that ultrasound could be used as an adjuvant point-of-care tool during IAH management. This may be particularly relevant to the first and second basic stages of the algorithm. The objective of this paper is to test the use of POCUS as an adjuvant tool in the management of patients with IAH/ACS.

Methods: Seventy-three consecutive adult critically ill patients admitted to the surgical intensive care unit (ICU) of a single urban institution with risk factor for IAH/ACS were enrolled. Those who met inclusion criteria were allocated to undergo POCUS as an adjuvant tool in their IAH/ACS management.

Results: A total of 50 patients met inclusion criteria and were included in the study. The mean age of study participants was 55 (±22.6) years, 58% were men, and the most frequent admission diagnosis was post-operative care following abdominal intervention. All admitted patients presented with a degree of IAH during their ICU stay. Following step 1 of the WSACS IAH medical management algorithm, ultrasound was used for NGT placement, confirmation of correct positioning, and evaluation of stomach contents. Ultrasound was comparable to abdominal x-ray, but shown to be superior in determining the gastric content (fluid vs solid). Furthermore, POCUS allowed faster determination of correct NGT positioning in the stomach (antrum), avoiding bedside radiation exposure. Ultrasound also proved useful in: 1) Evaluation of bowel activity; 2) Identification of large bowel contents; 3) Identification of patients that would benefit from bowel evacuation (enema) as an adjuvant to lower IAP; 4) And in the diagnosis of moderate to large amounts of free intra-abdominal fluid.

Conclusion: POCUS is a powerful systematic ultrasound technique that can be used as an adjuvant in intra-abdominal hypertension management. It has the potential to be used in both diagnosis and treatment during the course of IAH.

Introduction

The abdominal compartment is susceptible to wide ranging pressure variations. According to the Abdominal Compartment Society (WSACS, www.wsacs.org) 2013 consensus guidelines (1), normal intra-abdominal pressure in critically ill adults is regarded as 5-7mmHg. Intra-abdominal hypertension (IAH) is defined by a sustained or repeatedly elevated pressure (>12mmHg) and has four grades: Grade I 12-15mmHg; Grade II 16-20mmHg; Grade III 21-25mmHg; Grade IV > 25mmHg. Recently the Abdominal Compartment Society (WSACS) developed a medical management algorithm with a stepwise approach based on the evolution of intra-abdominal pressure with the goal of keeping IAP ≤15mmHg (level of evidence grade 1C)(Figure 1). This algorithm is based on five basic principles, namely: 1) Evacuation of intraluminal contents (e.g. stool, gastric residual volume); 2), Evacuation of intra-abdominal contents (e.g. abscess, blood collection, ascites); 3) Improvement of abdominal wall compliance; 4) Optimization of fluid administration (neutral fluid balance); 5) Optimization of systemic and regional perfusion.

With the increased use of ultrasound (2) as a bedside modality in both emergency and critical care patients (3), we hypothesized that ultrasound could be used as an adjuvant point-of-care tool during IAH management. This may be particularly relevant to the first and second basic stages of the algorithm. The WSACS divides these two stages of IAH/ACS into 4 steps, as shown in Figure 1. The objective of this study was to test the use of POCUS as an adjuvant tool in the management of patients with IAH/ACS.

Methods

Ethical considerations
This IRB approved study (17031113.0.0000.5404) enrolled all adult critically ill patients admitted to the surgical intensive care unit (ICU) of a single urban institution from December 19th 2016 to February 28th 2017 with risk factors for IAH/ACS. Informed consent was waived, as there was no deviation from standard care and the WSACS medical management algorithm that was already adopted in the ICU.

Study population
All patients admitted with risk factors for IAH/ACS were included and treated according to the 2013 WSACS guidelines (1). The inclusion criteria are shown in Table 1. Seventy-three consecutive patients were included in the study. A trained intensivist or surgeon performed POCUS for three consecutive days after admission:

1. When evacuation of intraluminal contents was indicated;
    1.1 Ultrasound was used to confirm NGT position and compared to x-ray imaging for patients requiring nasogastric tube (NGT) for intra-abdominal decompression (WSACS algorithm step 1);
    1.2 Stomach and bowel US was performed daily to evaluate hollow viscous content and/or enema effectiveness (WSACS algorithm step 2) and/or colonoscopy decompression (WSACS algorithm step 3);
2. When evacuation of intra-abdominal content was indicated;
    2.1 Abdominal POCUS was performed daily, either to evaluate the presence of abdominal free fluid, or to help percutaneous drainage (WSACS algorithm step 2).

Inclusion criteria	
A	*ICU patients/ minimum ICU stay of 3 days*
B	*18 years of age or older*
C	*Intubated and mechanically ventilated*
D	*Adequately sedated (RASS -4 or -5)*
E	*Able to lie in a supine position for all measurements*
F	*Undergoing treatment for IAH/ ACS*
G	*Not exhibiting abdominal respiratory muscle activity*
H	*Not having a temporary open abdomen*
I	*Not exhibiting abdominal respiratory muscle activity*

***Table 1**. Inclusion criteria adopted for the study*

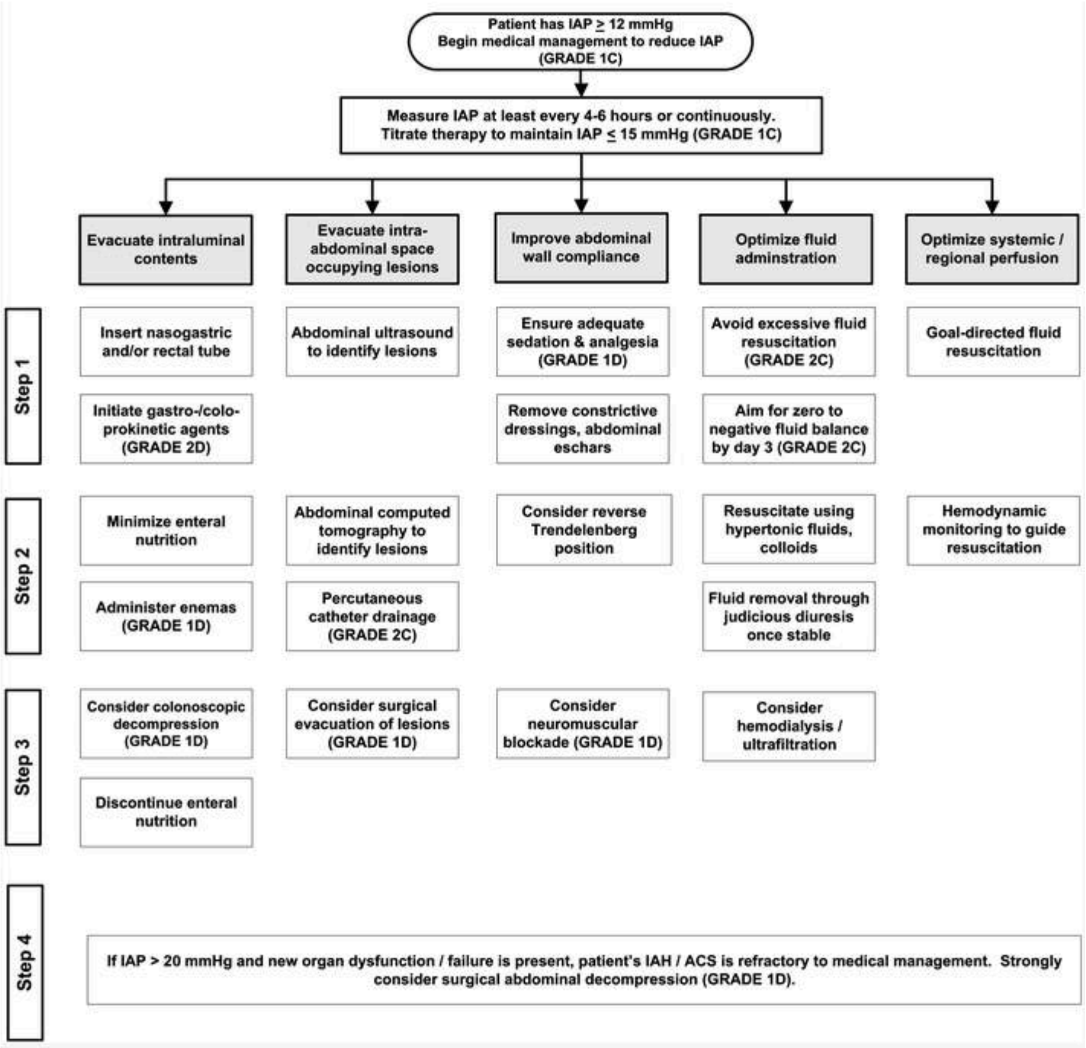

Figure 1. WSACS IAH/ ACS Medical Management Algorithm

IAP measurement

The IAP was measured according to the WSACS guidelines at end-expiration, with the patient in the supine position and the zero reference set at the level where the midaxillary line crosses the iliac crest. The IAP was either measured via the height of the urine column (Foley Manometer) or via a bedside monitor with a pressure transducer (AbViser®, ConvaTec – São Paulo, Brazil).

POCUS method

POCUS images were obtained in a systematic fashion with the patient in supine position, immediately after each 6-hour intra-abdominal pressure measurement , at end-expiration with adequate sedation, with or without the use of neuromuscular blocking drugs. A 64 elements *Mobissom* (mobissom.com.br) M1 convex wireless ultrasound was used for all examinations (3.5 Mhz, 90-200 mm, phased array).

For patients requiring NGT, images were obtained in B-mode with the transducer positioned at the level of the epigastrium. First, ultrasound gel was liberally applied over the epigastrium. The convex transducer was placed in a transverse plane resulting in visualization of the antrum and body of the stomach. At this moment, insertion of the NGT was commenced and the stomach content was observed. Once the NGT was visible in the hollow viscous, a 20ml flush of air was delivered to confirm correct positioning (Figure 2).

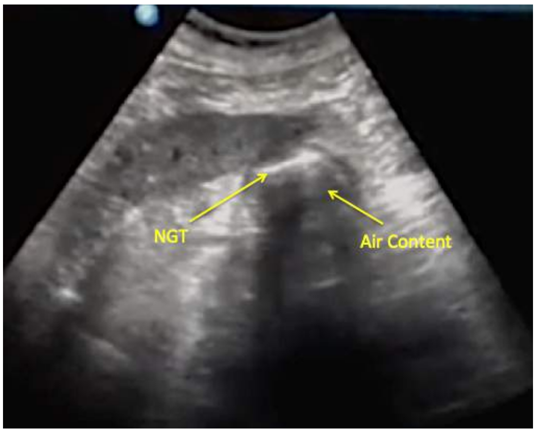

Figure 2. Nasogastric tube (NGT) ultrasound view at the moment of 20 ml gush of air

Daily POCUS was performed in all patients to evaluate stomach and bowel content. For stomach views, the US window was used as described above. For small and large bowel visualization, the transducer was placed at the periumbilical level and on both medium-low abdominal quadrants to observe both the right and left colon.

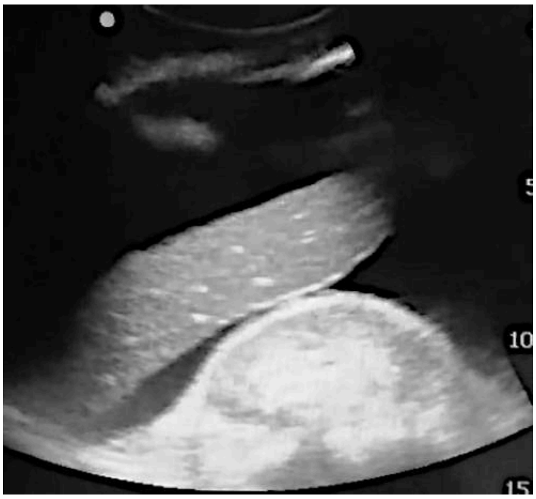

Figure 3. Right upper quadrant showing abdominal free fluid (ascites)

To screen for intra-abdominal free fluid, the POCUS landmarks were the right upper quadrant, left upper quadrant and hypogastrium (Figure 3) either with a longitudinal or transverse probe position. The various probe positions to enable the different POCUS windows is shown in Figure 4. Paracentesis was performed via the insertion of a sterile percutaneous needle with real-time direct ultrasound guidance.

Statistical analysis

All demographic and clinical data were recorded prospectively in an Excel spreadsheet. Descriptive statistical analysis was performed to summarize patient characteristics and study measurements. Continuous variables are presented as the mean (± standard deviation, SD) or median in the case of skewed distribution. Categorical variables are expressed as numbers and percentages for the group from which they were derived. Continuous variables were compared with the Student's t-test for normally distributed variables and the Mann Whitney test for non-normally distributed variables. The $\chi 2$ test or Fisher's exact test were used to compare ordinal variables. All p-values are two-tailed and a $p<0.05$ was considered statistically significant. Statistical analysis was done with IBM^{TM} SPSS (Windows version 21.0, 2016, Chicago, IL, USA).

Parameters	Participants (N=50)
Participants characteristics	
Mean Age (years)	55 (39-71)
Gender (Male)	29 (58%)
BMI (kg/m^2)	27
Clinical data	
Mean SBP (mmHg)	108.5 (83-134)
Mean HR (beats/min)	94 (60-128)
IMV (%)	50 (100%)
Mean admission IAP (mmHg)	23 (12-34)
Mean admission APP (mmHg)	85
Vasopressor use (n %)	42 (84%)
Admission diagnosis	
Bowell obstruction (%)	28 (56%)
Abdominal Sepsis (%)	12 (24%)
Gastrointestinal bleeding (%)	8 (16%)
Other (%)	2 (4%)

Table 2. Patients characteristics, clinical data and admission diagnosis

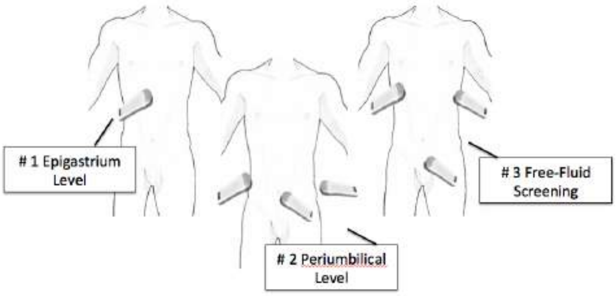

Figure 4. Probe position to access the different POCUS windows

Results

A total of 73 patients were included in the study. Twenty-three patients were excluded due to one or more of the following reasons: death, extubation or discharge from ICU before the third day of admission, normal IAP, and presence of an open abdomen. The mean age of study participants was 55 (±22.6) years old, 58% were men with one or more associated comorbidity such as hypertension, diabetes or dyslipidemia. The most frequent admission diagnosis was for post-operative care following abdominal intervention (Table 2). The majority of patients came from the emergency department (96%). Table 2 shows the data from the first three consecutive ICU days. Decompressive laparotomy for raised IAP was not necessary in any of the patients due to full recovery after clinical management.

During the first three consecutive ICU days we observed a decrease in IAP with medical treatment. In general, patients were critically ill and 84% received vasoactive drugs. Mean IAP on admission was 23mmHg (SD ±15.5). Seventy-four percent of patients were admitted after surgery. All admitted patients presented with some degree of IAH/ ACS during their ICU stay. Forty-six patients required a NGT for the first 48 hours following admission. Following step 1 of the WSACS medical management algorithm, ultrasound was used for NGT placement, confirmation of correct positioning, and to check stomach contents. Ultrasound was comparable to abdominal x-ray, but superior in determining gastric contents (fluid vs solid). Furthermore, POCUS allowed faster bedside determination of correct NGT positioning into the stomach (antrum), without exposure to radiation. There was 100% accuracy when using US to determine NGT placement and positioning, with no false negatives nor false positives observed. US also proved useful in patients on the third day of admission by confirming the safe removal of the NGT after screening demonstrated no gastric contents (Table 3).

	Day 1	Day 2	Day 3
Mean IAP (mmHg)	23 (12-34)	17.5 (10-25)	15 (8-22)
Mean APP (mmHg)	85.5	91.5	107
Mean SBP (mmHg)	108.5 (83-134)	109 (90-128)	122 (101-143)
Mean HR (beats/min)	113 (98-128)	89.5 (60-119)	82 (58-106)
Mean Urinary Output (ml/24h)	1500 (400-2600)	1105 (310-1105)	1200 (0-2400)
Fluid Balance (last 24h)	+ 2160	+1730	+ 2931
NGT tube need (n)	46	46	42
US gastric content observed (n)	50	50	50
NGT observed on US (n)	46	46	42
Positive bowel content (before enema) viewed on US (n)	50	50	50
Positive bowel content (after enema) viewed on US (n)	36	28	21
Bowel movements observed ON US (n)	42	47	50
Number of patients with free abdominal fluid seen on US (n)	27	24	23
Positive moderate to large amount of free abdominal fluid seen on US (n)	6	6	4
US guided paracentesis (n)	2	0	0

Table 3. Data from three consecutive days on IAH treatment

The second step in the WSACS guidelines addresses intraluminal evacuation through the administration of enemas. This strategy was followed in all patients in whom the IAP remained high (above 20mmHg) on the second measurement (6 hours after admission). US proved useful in many ways: Firstly, POCUS allowed assessment of bowel activity (movements); Secondly, it allowed identification of large bowel contents (right and left colon); Thirdly, POCUS allowed identification of patients that may benefit from continued enema-treatment to lower IAP. These aspects were considered important, as the majority of patients were post-operative. For example, bowel movements were present on average 8 hours post-operatively, even with negative bowel sounds on auscultation. Enema treatment was found to empty the bowel incompletely in 72%, 56% and 42% of the times on days 1, 2 and 3 respectively. Only one patient needed colonoscopic decompression, confirmed by US, clinically and with IAP improvement.

During the second stage of the WSACS medical management algorithm, US was a useful adjuvant tool for diagnosing moderate to large amounts of free intra-abdominal fluid. A small amount of fluid was expected as the majority of patients were coming from the OR. Special attention was given to cirrhotic patients that were admitted with upper gastrointestinal bleeding. Four patients in this group (out of a total of 8) were found to have large amounts of ascites and US guided paracentesis was carried out (Figure 2). The average amount of ascites removed was 3600 ml (SD±1.6) and resulted in a significant drop in IAP average from 21 (±4.1) mmHg to 13 (±2.0) mmHg in all four patients.

Discussion

Intra-abdominal pressure is an important physiological parameter that is still often neglected by the medical community (4). It should be measured regularly in critically ill patients, 4 to 6 hourly, according to guidelines (1). According to the 2013 WSACS guidelines, IAH is defined as a sustained increase in IAP equal to, or above 12 mmHg, that is frequently associated with abdominal (as well as extra-abdominal) pathology and complications (1, 5). A missed IAH diagnosis can lead to longer ICU length of stay, prolonged ventilation, and higher incidence of ventilator associated pneumonia, amongst other indirect consequences impairing patient recovery (2, 6). Therefore, it is paramount that ICU doctors and nurses are aware of the importance of IAH and ACS in both adults and children (7, 8). The presence of one or more risk factors for IAH should prompt appropriate IAP monitoring and help facilitate an early diagnosis. This monitoring should be included as a vital sign in the daily clinical evaluation of all critically ill patients.

The WSACS guidelines were updated in 2013, and included the Medical Management Algorithm as shown in figure 1. These guidelines recommend either continuous or intermittent IAP monitoring. Medical management for IAH and ACS is divided into 5 categories:

1. Evacuation of intraluminal contents
2. Evacuation of intraluminal occupying lesions or extra-luminal (intra-abdominal) contents
3. Improvement of abdominal wall compliance
4. Optimization of fluid administration
5. Optimization of systemic and regional perfusion

Ultrasound is a useful adjunct in several of these medical management options.

POCUS has become an indispensable tool in the management of critically ill patients (9, 10), however, no research has been published on its use in IAH or ACS.

A) Axial contrast enhanced abdominal CT demonstrates a large volume of ascites.

C) US guided abdominal drain insertion into a large fluid collection in the right flank.

B) POCUS confirms the correct position of the pigtail catheter within the ascites fluid

Figure 5 (panel A-C). 75 year-old male with an IAP of 25 mmHg secondary to pancreatitis

There are currently few point-of-care bedside confirmation investigations that can confirm some of the clinical goals proposed by the WSACS, including nasogastric tube confirmation, assessment of colonic content, OR evaluation of fluid removal from the abdomen. Based on this rationale, we have described the possibility of using POCUS in daily clinical practice, in the follow-up and treatment of critically ill patients with IAH / ACS diagnosis. We expanded the daily use of a portable Wi-Fi ultrasound device in patients with IAH/ACS in order to test the hypothesis that POCUS could be useful as an adjuvant treatment for IAH/ ACS.

This study focused on the first two stages of the WSACS algorithm and the specific steps in each stage (escalating from 1 to 4). Our main objective was to use POCUS as an adjuvant tool for IAH management and thus focused our efforts on steps 1 to 3 of stage one ("evacuate intraluminal content"), and steps 1 and 2 of stage two ("evacuate intraluminal occupying lesions or extra-luminal content").

Most of the included patients were from the emergency department and were either taken to the operating room or intensive care unit. All admitted patients with risk factors for IAH had their IAP measured as a component of their vital signs every four to six hours. Diagnosis of IAH was made with three sustained IAP measurements over 12mmHg. All possible clinical steps were taken, according to current guidelines, to lower IAP once a measurement of IAP was found to be over 12mmHg. Eighty four percent of the enrolled patients were admitted on vasoactive drugs, with a mean systolic blood pressure of 108.5mmHg. This information was required to calculate the abdominal perfusion pressure (11). As recommended by the World Society, abdominal perfusion pressure equals mean arterial pressure minus intra-abdominal pressure (APP = MAP – IAP), and its measurement is mandatory for every IAP obtained. However, there is no available evidence investigating the utility of the above-mentioned formula in patients on high doses of vasoactive drugs. The use of vasoactive drugs and the effect on the systolic blood pressure may mask the significance of underlying intra-abdominal malperfusion, a consequence of vasoconstriction caused by the vasoactive agents. Therefore, the relatively normal APP may not accurately reflect intra-abdominal perfusion and the significance of these readings is not known. We suggest that the APP is not a reliable marker when measured in association with vasoactive drug usage (12). Further research is necessary to investigate this hypothesis.

For patients with IAP above grade I, decompression of intraluminal content is recommended. In this study the WSACS medical management algorithm (stage 1, step 1) was implemented accordingly with NGT insertion. The NGT was passed under direct US guidance with the probe on the epigastrium, allowing for direct visualization of the tip of the NGT as it was directed to its ideal position close to the pylorus (figure 2). A one hundred per cent accuracy was observed when using the US to determine NGT placement and positioning. US was also useful on the third ICU day when screening showed no gastric content and NGTs were removed in some patients. All included patients with gastric content viewed through the use of the US had prokinetics added to their prescription in accordance with IAH management.

POCUS was also used to evaluate bowel movements and colonic content. This helped daily assessment of post-operative patients and nutrition could be initiated earlier than usual in some cases due to detectable bowel movements. In these patients, no bowel sounds were detected but bowel movement was detected with ultrasound. Likewise, POCUS was useful in detecting colonic material thus guiding the physician on the need for further enemas to decompress the colon. These findings may also facilitate early recognition of bowel wall oedema, a consequence of extravasation from fluid resuscitation. In future, this may help early management of patient fluid balances (13).

Regarding the first 2 steps of the second stage of the WSACS medical management algorithm, ultrasound identified moderate to large amounts of free intra-abdominal fluid. These cases of cirrhotic patients with ascites required ultrasound guided paracentesis. POCUS was also useful in patients with severe acute pancreatitis and IAH (figures 5A-C). Again, bedside ultrasound provided easy and prompt diagnosis and guided therapeutic management. All enrolled patients demonstrated reductions in IAP and subsequently better clinical performance during their first three days of admission. In figure 6 we outline the role for the POCUS within the WSACS medical management algorithm.

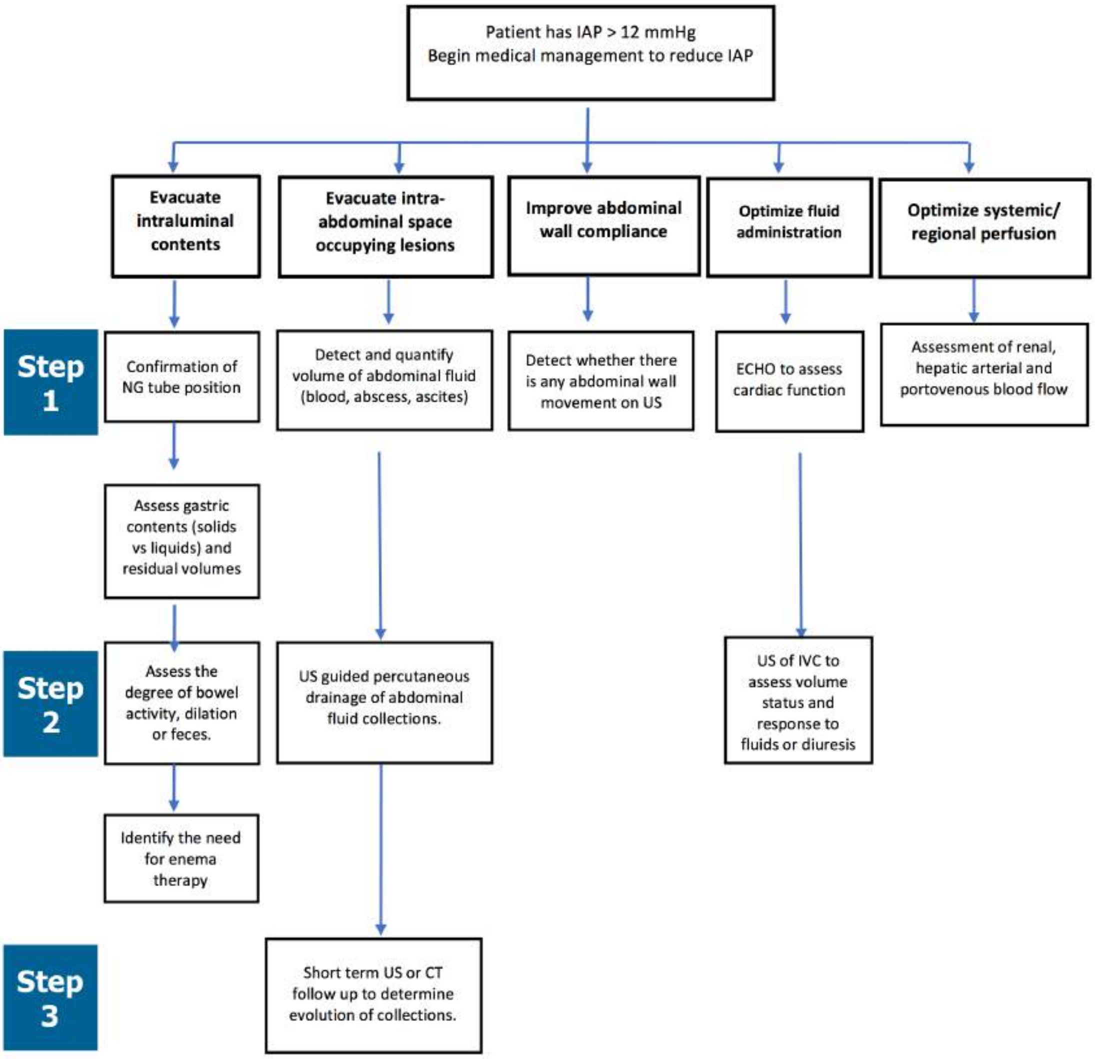

Figure 6. Role of POCUS within WSACS medical management

Limitations of the study include a small sample size, different skill levels of ultrasound operators, and the observational design of the study. A randomized trial is evaluating the clinical outcomes is required.

Conclusion

POCUS is a useful tool that should be used as an adjuvant in IAH management. It has the potential to be used in both diagnosis and treatment during the course of IAH, based on the Abdominal Compartment Society (WSACS) Guidelines.

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Notes

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CHAPTER 3

Ten good reasons to practice ultrasound in critical care

Daniel Lichtenstein, Simon van Hooland, Paul Elbers, Manu L.N.G. Malbrain

Intra-abdominal hypertension is a common complication in critically ill patients. Over the past decade, critical care ultrasound has gained its place in the armamentarium of monitoring tools. A greater understanding of lung, abdominal, and vascular ultrasound and an easier access to portable machines have revolutionized the bedside assessment of our ICU patients. Because ultrasound is not only a diagnostic test, but should be seen instead as a component of the physical exam, as such it has the potential to become the stethoscope of the 21st century. Critical care ultrasound is a combination of simple protocols with lung ultrasound being a basic application, allowing assessment of urgent diagnoses in combination with therapeutic decisions. The LUCI (Lung Ultrasound in Critically Ill) consists of identification of ten signs: the bat sign (pleural line), lung sliding (seashore sign), the A-lines (horizontal artefact), the quad sign and sinusoid sign indicating pleural effusion, the fractal and tissue-like sign indicating lung consolidation, the B-lines and lung rockets indicating interstitial syndromes, abolished lung sliding with the stratosphere sign suggesting pneumothorax, and the lung point indicating pneumothorax. Two more signs, the lung pulse and the dynamic air bronchogram are used to distinguish atelectasis from pneumonia. The BLUE-protocol (Bedside Lung Ultrasound in Emergency) is a fast protocol (<3 minutes), also including a vascular (venous) analysis allowing differential diagnosis in patients with acute respiratory failure. With this protocol it becomes possible to differentiate between pulmonary edema, pulmonary embolism, pneumonia, chronic obstructive pulmonary disease, asthma, and pneumothorax, each showing specific ultrasound patterns and profiles. The FALLS-protocol (Fluid Administration Limited by Lung Sonography) adapts the BLUE-protocol to be used in patients with acute circulatory failure. It makes a sequential search for obstructive, cardiogenic, hypovolemic, and distributive shock using simple real-time echocardiography in combination with lung ultrasound, with the apparition of B-lines considered as the endpoint for fluid therapy. An advantage of lung ultrasound is that the patient is not exposed to radiation, as such the LUCI-FLR project (LUCI favouring limitation of radiation) can be used in trauma patients. Although it has been practiced over 25 years, critical care ultrasound is still a relatively young but wide spreading discipline and should be seen as the stethoscope of the modern intensivist. In this review, the usefulness and advantages of ultrasound in the critical care setting are discussed in ten points. The emphasis is on a holistic approach, with a central role of lung ultrasound.

INTRODUCTION

Over the past decade, critical care ultrasound has gained its place in the armamentarium of monitoring tools (1). A greater understanding of lung, abdominal, and vascular ultrasound and an easier access to portable machines have revolutionized the bedside assessment of our ICU patients. Because ultrasound is not only a diagnostic test, but should also be seen instead as a component of the physical exam, as such it has the potential to become the stethoscope of the 21st century (2). Critical care ultrasound is a combination of simple protocols with lung ultrasound being a basic application, allowing assessment of urgent diagnoses in combination with therapeutic decisions. Ultrasonography is not a new technology. Already in 1942, Karl Dussik, a neurologist from Vienna, was the first to use ultrasound medically as a diagnostic tool to locate brain tumours and cerebral ventricles, however what he believed to be anatomical structures were later found to be artefacts (3). The Frenchman André Dénier was the first to describe possible diagnostic applications for ultrasound (4). Due to its bedside availability, absence of radiation, good reproducibility and cost-efficiency, ultrasound has since then gained widespread popularity in many specialties (5, 6). Data from health care registries show a rapid rise in the number of ultrasound studies being performed. And even more interestingly, an estimated 65% of these studies are being performed by clinicians instead of radiologists. This revolution can be explained by the huge advantages clinicians experience by performing bedside ultrasound. They can directly interpret the images in their clinical context and the examination can be performed 24/7, without the need of external consultants. In addition, ultrasound studies can be easily repeated, allowing assessment of therapeutic effects.

These advantages are of even greater value in the setting of critical care medicine, as immediate decision making can be life saving. Thus, the use of ultrasound is now rapidly spreading in ICUs worldwide. However, it is the development of lung ultrasound that has unleashed the true potential of the technique to the critical care provider (1, 5, 7-12). Until recently, the lung was considered “forbidden territory” for ultrasound and a mind switch was needed (11). It is true that direct visualization of the lung parenchyma is often difficult or impossible with ultrasound.

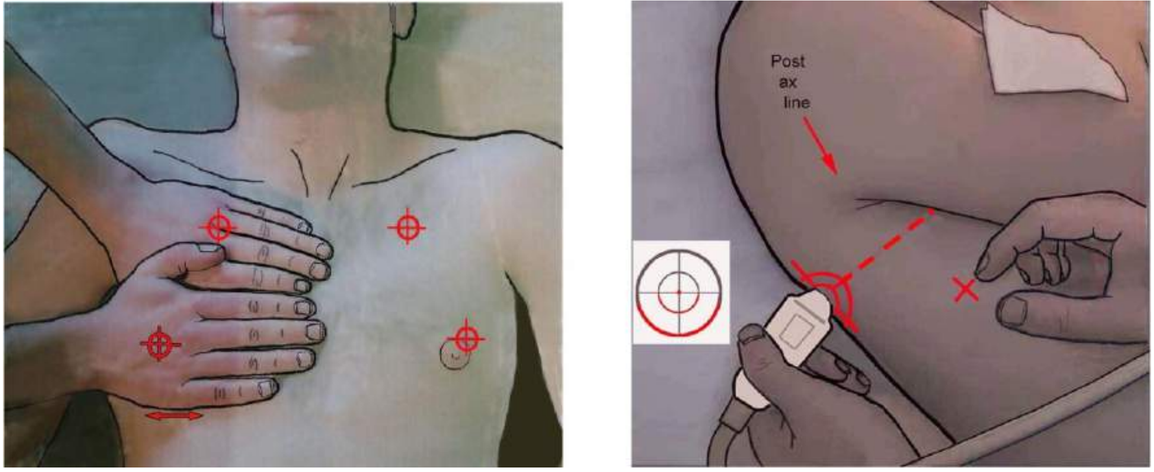


Figure 1. Areas of investigation showing the standardized examination BLUE-points.
Panel A. Two hands placed this way (size equivalent to the patient’s hands, upper hand touching the clavicle, thumbs excluded) correspond to the location of the lung, and allow three standardized points to be defined. The upper-BLUE-point is at the middle of the upper hand. The lower-BLUE-point is at the middle of the lower palm.
Panel B. The PLAPS-point is defined by the intersection of: a horizontal line at the level of the lower BLUE-point; a vertical line at the posterior axillary line. Small probes allow positioning posterior to this line as far as possible in supine patients, providing more sensitive detection of posterolateral alveolar or pleural syndromes (PLAPS). The diaphragm is usually at the lower end of the lower hand. Adapted from “Lung ultrasound in the critically ill” (11).

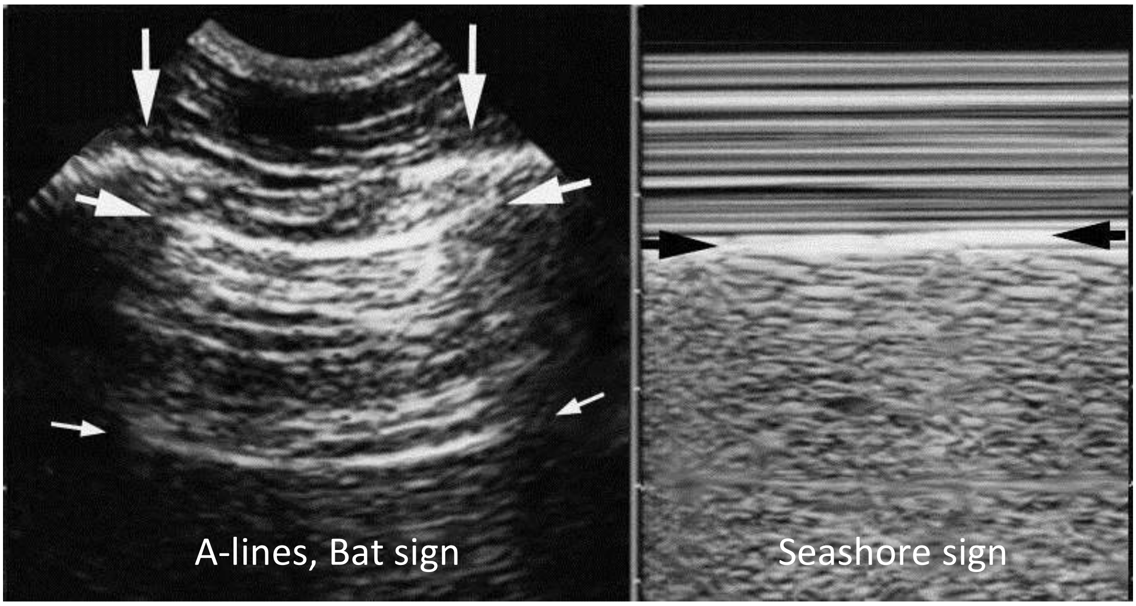


Figure 2. Ultrasound Scan of the anterior intercostal space: bat and seashore sign.
Panel A. The ribs (vertical arrows) with shadows are visualized. The pleural line (upper, horizontal arrows), is a horizontal hyperechogenic line, half a centimeter below the rib line in adults. The association of ribs and pleural line make a solid landmark called the bat sign. The pleural line indicates the parietal pleura. The horizontal repetition artifact of the pleural line is called the A-line (lower, small horizontal arrows). The A-line indicates that air is the main component visible below the pleural line. Panel B. M-mode reveals the seashore sign, which indicates that the lung moves at the level of the chest wall. The seashore sign therefore indicates that the pleural line also is the visceral pleura. Above the pleural line, the motionless chest wall displays a stratified pattern. Below the pleural line, the dynamics of lung sliding show a sandy pattern. Note that both images are strictly aligned, of importance in critical settings. Both images, i.e., lung sliding plus A-lines define the A-profile (when found at the anterior chest wall). Adapted from "Lung ultrasound in the critically ill" (11).

However, lung ultrasound interpretation is based on the analysis of sonographic artefacts that arise from interactions of the ultrasound beams with tissue media having different acoustic impedance. This has given rise to a new ultrasound language, including comet-tail reverberation artefacts, called B lines (13), the description of the interstitial syndrome (14) and the BLUE protocol (7). This not only has changed the way we work in intensive care medicine but most importantly it has helped to improve patient outcome. It is against this background, that we present you ten good reasons why you should start performing critical care ultrasound.

TEN GOOD REASONS

1. *Ultrasound is helpful in differential diagnosis of acute respiratory failure*

In the early days, lung ultrasound was considered not to be feasible. Yet all signs and symptoms of the artefacts would have been readily available with the 1982 ADR-4000 machine. Little by little, despite many rejections, the initial protocols and study material was published. The BLUE-protocol is one application among many other, describing the clinical relevance of lung ultrasound in the critically ill (LUCI), namely in the differential diagnosis of an acute respiratory failure (7).
In the BLUE-protocol three standardized examination points are the upper BLUE-point, the lower BLUE-point and the PLAPS-point (Fig. 1) (15).

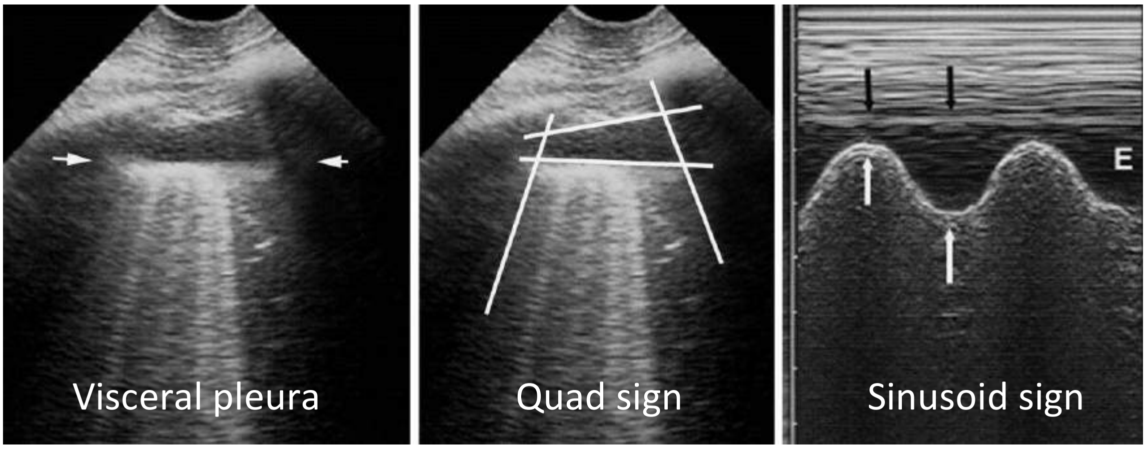


Figure 3. Examination of pleural effusions: quad and sinusoid sign.
Panel A. Ultrasound examination of pleural effusion at the PLAPS-point. Below the pleural line, a line regular and roughly parallel to the pleural line can be seen: the lung line, indicating the visceral pleura (arrows). Panel B. The visceral pleura (lung line), together with the parietal pleura (pleural line) and the shadow of the ribs, form a kind of quadrant: the quad sign.
Panel C. M-mode shows movement of the lung line or visceral pleura (white arrows) towards the pleural line or parietal pleura (black arrows) on inspiration, creating the sinusoid sign compatible with free pleural effusion. Quantitative data: this effusion found at the PLAPS-point has an expiratory thickness of roughly 13 mm, i.e., an expectedly small volume. A 15-mm distance is the minimum required for safe diagnostic or therapeutic puncture (47). E, indicates expiration. Adapted from "Lung ultrasound in the critically ill" (11).

The BLUE-protocol uses the *7 principles* of LUCI, shortly recalled here: 1) a simple technique, and the simplest machine is the most suitable; 2) in the thorax, air and water are mixed, generating specific ultrasound signs and signatures and artefacts; 3) The lung is the most voluminous organ, but adapted points for analysis, the BLUE-points (Fig. 1) allow for standardized scanning; 4) All signs and artefacts start from the pleural line, a basic landmark; 5) The artefacts, usually considered as annoying limitations of ultrasound, are of specific interest (16); 6) The lung is a vital organ that moves, therefore dynamic analysis is crucial with lung sliding being the basic dynamic sign of normality; and 7) All acute, life-threatening disorders are superficially located around the pleural line, creating a window for LUCI.

The BLUE-protocol is easy, if the user accepts to follow each simple step. The BLUE-protocol uses the 7th principle to identify and describe 10 signs allowing the diagnosis of the *6 most frequently seen acute diseases* (not the most easy to diagnose) by creating *8 profiles* yielding an overall 90.5% accuracy (7). The pleural line generates the **bat** sign, a permanent landmark indicating the parietal pleura (Fig. 2). Lung **sliding** and the **A-line** define the normal lung surface. They indicate gas movement and sliding of the parietal and visceral pleural with to-and-fro movements. M-mode helps to understand this movement and results in the **seashore** sign (Fig. 2). The **quad** sign and the **sinusoid** sign are standardized signs allowing the diagnosis of a pleural effusion, regardless their volume or echogenicity. The probe is applied at the PLAPS-point, a posterior area accessible in supine position (Fig. 1). The boundaries of the collection are regular and a quadriangular surface can be drawn (the quad sign). The sinusoid sign is drawn by the visceral pleura moving towards the pleural line during inspiration. This is illustrated in Figure 3. The **shred** (or fractal) sign and the **tissue-like** signs are used for diagnosing a lung consolidation. The shred sign corresponds to nontranslobar consolidations with an irregular border between aerated and consolidated lung regions.

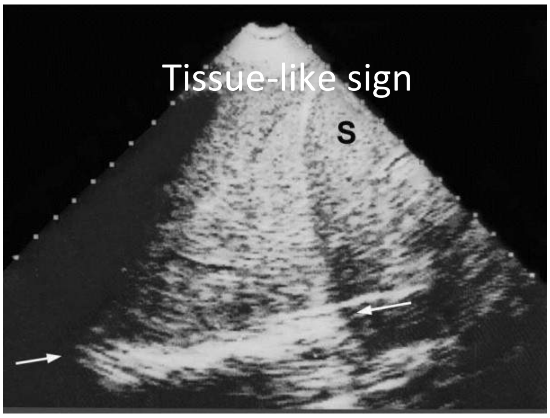


Figure 4. Lung consolidation: shred, fractal and tissue-like sign. Panel A. A massive consolidation (probe at the PLAPS-point) of the whole left lower lobe. No aerated lung tissue is present, and no fractal sign can be generated. The lower border is at the level of the mediastinal line (arrows). The pattern is tissue-like, similar to the spleen (S). The thickness of this image is roughly 10 cm, a value incompatible with a pleural effusion. Quantitative data: the 10-cm depth would correspond to a volume of roughly 1 L.

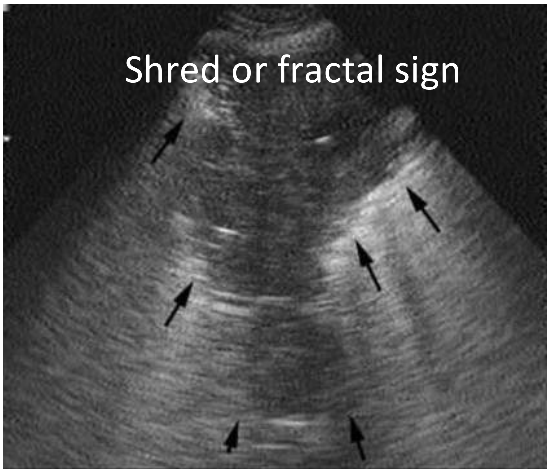


Figure 4. Lung consolidation: shred, fractal and tissue-like sign. Panel B. A partial right middle lobe consolidation. This generates a shredded, fractal boundary between the consolidation and the underlying aerated lung (arrows), this is the quite specific shred (or fractal) sign as opposed to the regular lung line in case of pleural effusion. This anterior consolidation generates the C-profile in the BLUE-protocol. Quantitative data: the thickness at the right image is 5.5 cm, corresponding to a 165-mL consolidation, roughly. Adapted from "Lung ultrasound in the critically ill" (11).

The tissue sign is seen in translobar consolidation as it looks liver parenchyma. This is illustrated in Figure 4. Lung **rockets** are the sign of interstitial syndrome with 93% accuracy (14). The B-line is always a **comet-tail** artefact, arising from the pleural line and co-incides with lung-sliding (17-23). B-lines are almost always long, well-defined, laser-like, hyperechogenic, erasing A-lines as illustrated in Figure 5. A rocket sign consists of 3 or more B-lines (5). **Abolished lung sliding** and exclusive A-lines are a basic sign of pneumothorax, with 95% sensitivity and 100% negative predictive value (24-26). In case of pneumothorax a motionless pleural line can be observed in M-mode generating the **stratosphere** sign as shown in Figure 6. Visualisation of the **lung point** allows to rule in pneumothorax (Fig. 7)(27).

In order to be clinically helpful, the BLUE-protocol defines *8 profiles*, correlated with *6 diseases* seen in 97% of the patients admitted to the ICU (7). A consolidation is not a diagnosis, but incorporated into a specific profile, it contributes to making the correct diagnosis (not necessarily pneumonia). The A, A', B, B', A/B and C-profiles can all be identified at the anterior chest wall in supine patients.

The **A-profile** defines a normal lung surface. Associated with a deep venous thrombosis, it makes the diagnosis of pulmonary embolism with 99% specificity. In combination with the absence of a deep venous thrombosis (DVT) and the presence of a postero-lateral alveolar and/or pleural syndrome (called PLAPS), it highly suggests the diagnosis of pneumonia (specificity 96%). In case of absence of DVT and PLAPS, this profile is called the **nude profile** which correlates with severe asthma or COPD (specificity 97%).

The **A'-profile**, defined as abolished lung sliding with exclusive A-lines, is suggestive of pneumothorax, and makes mandatory the detection of a lung point, a specific sign of pneumothorax. The lung point shows, at the area of inspiratory contact of the lung with the wall, sudden changes, from an A'-profile to lung sliding or lung rockets.

The **B-profile** associates anterior lung sliding with anterior lung rockets, and highly suggests acute cardiovascular pulmonary edema (specificity 95%).

The **B'-profile** combines abolished lung sliding with lung rockets, and is also correlated with pneumonia (specificity 100%).
The **A/B-profile**, i.e., unilateral lung rockets, suggests pneumonia (specificity 100%).

The **C-profile** defines anterior lung consolidations (from large parenchymal volumes to a simple thickened, irregular pleural line) and again suggests pneumonia (specificity 99%).

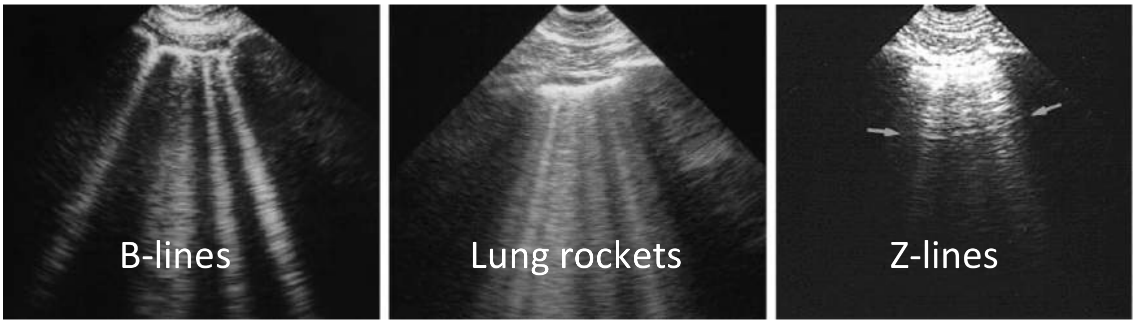


Figure 5. Interstitial syndrome: lung-rockets.
Panel A. Presence of four to five B-lines, called lung rockets (here septal rockets correlating with thickened subpleural interlobular septa), suggestive for lung edema. Panel B. Presence of twice as many B-lines, called ground-glass rockets. Suggestive for severe pulmonary edema (with ground glass areas on CT). Panel C. Z-lines for comparison. These "parasites" are ill-defined, short, and do not erase A-lines (arrows). Adapted from "Lung ultrasound in the critically ill" (11).

Each of these 8 profiles is supported by the pathophysiology (Fig. 8). Each profile can be assessed in less (sometimes far less) than 3 minutes, making the BLUE-protocol a really fast protocol. A recent meta-analysis confirmed the usefulness of lung ultrasound and concluded that, when conducted by highly-skilled sonographers, ultrasound performs well for the diagnosis of pneumonia (28). General practitioners and Emergency Medicine physicians should be encouraged to learn LUCI since it appears to be an established diagnostic tool in the hands of experienced physicians (28, 29).
There are of course limitations, like the presence of pulmonary embolism without DVT. This issue, and many other questions are discussed elsewhere (30, 31). Examination of the heart itself is not included, since the BLUE-protocol provides only a direct analysis of the lungs. Some rare conditions resulting in respiratory failure (like chronic interstitial syndrome, fat embolism, tracheal stenosis, etc.) are not included for simplicity. They are indeed numerous, but apply only to 3% of the patients seen in the ER for acute respiratory failure, and many of these conditions can be diagnosed with other classical tools. As an example, a massive pleural effusion is rare, but not difficult to diagnose. In bedside lung ultrasound, the operator should be aware and interpret double lung point, septate pneumothorax and hydro-point. The conventional diagnostic protocol of bedside lung ultrasound for pneumothorax should be occasionally adapted to such complex cases (32). Chronic interstitial diseases, yielding the B-profile, require identification of some subtle signs that will be incorporated in the Extended BLUE-protocol . It is important to realize that the BLUE-protocol is just a tool, at its best only when fully integrated in the clinical examination as the modern stethoscope. Clinical data will be included in the E-BLUE-protocol in the near future.

2. ***Acute circulatory failure: a nice, second good reason.***

One feature of holistic ultrasound is its ability to combine examination of lung and heart. This is referred to as emergency cardiac sonography that combines some elements of the BLUE-protocol, for the management of acute circulatory failure.

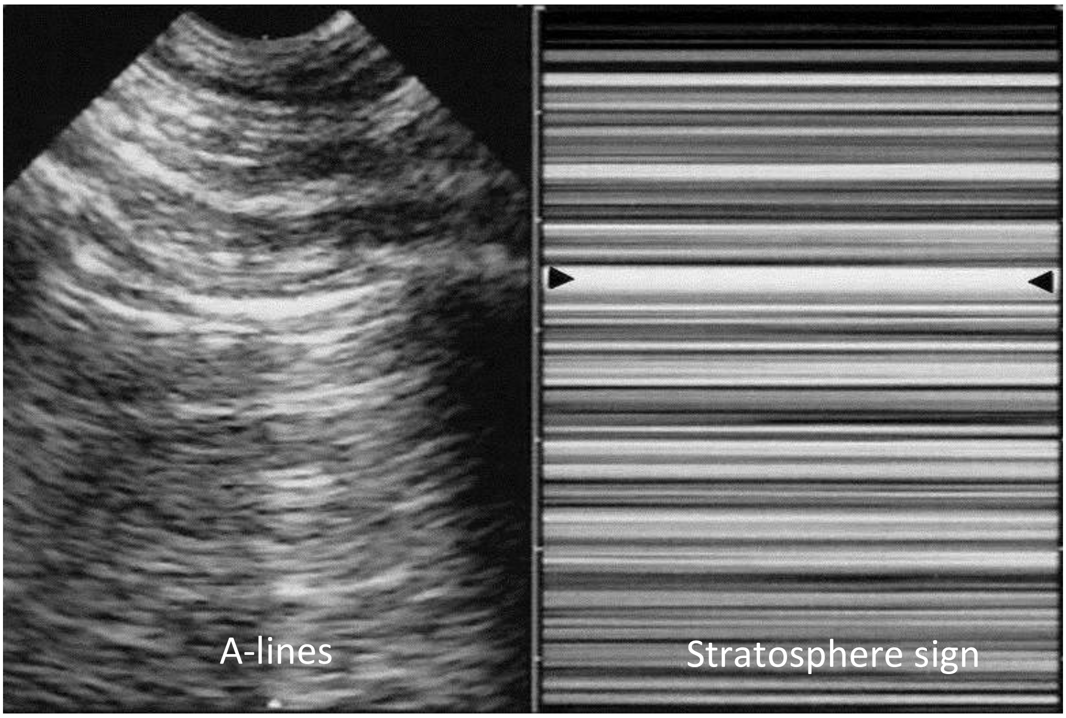


Figure 6. Pneumothorax: stratosphere sign.
Panel A. Pleural line with A-lines, indicating gas below the pleural line. Although not visible on the left image, lung sliding was totally absent. Panel B. On M-mode, the abolition of lung sliding is visible through the stratosphere sign (which replaces the seashore sign) and indicates total absence of motion. This suggests pneumothorax as a possible cause. Arrows indicate location of the pleural line. The combination of abolished lung sliding with A-lines, at the anterior chest wall, is the A'-profile of the BLUE-protocol (as opposed to the A-profile, where lung sliding is present, ruling out pneumothorax). Adapted from "Lung ultrasound in the critically ill" (11).

This is not "Echo" (an expert field for cardiologists), nor is it "ultrasound", a term which reminds too much of the radiological world. The FALLS-protocol (Fluid Administration Limited by Lung Sonography) uses the potential of lung ultrasound for early demonstration of fluid overload at an infra-clinical level (33). The FALLS protocol is based on Weil and Shubin's classification, considering first obstructive shock, followed by cardiogenic, hypovolemic and finally distributive shock (34). The decision tree is illustrated in Figure 9.

The FALLS-protocol searches sequentially for: 1) Substantial pericardial fluid; 2) A dilated right ventricle; and 3) An A'-profile. Obstructive shock is reasonably ruled out in case of absence of tamponade, pulmonary embolism, or pneumothorax; 4) The B-profile is sought for. In its absence, a cardiogenic shock from left origin (i.e., the far majority) is, by definition, ruled out. At this stage, the patient has neither the B-profile nor the A'-profile, and thus usually has the A-profile or its equivalents (A/B profile, C-on-A-profile) and is called a FALLS-responder. This patient can have either hypovolemic or distributive shock, and will benefit, in both cases, from fluid administration. This is the therapeutic part of the FALLS-protocol. The recovery of a circulatory failure under fluid therapy defines the hypovolemic shock. If the shock state persists despite fluid therapy, there will however be no indication for discontinuing. Ongoing fluid therapy may eventually generate a subclinical interstitial syndrome, that can be immediately detected as A-lines will change to B-lines. This change occurs at a pulmonary artery occlusion pressure (PAOP) value of 18 mm Hg (with 97% safety), or 13 mm Hg (with 93% safety).

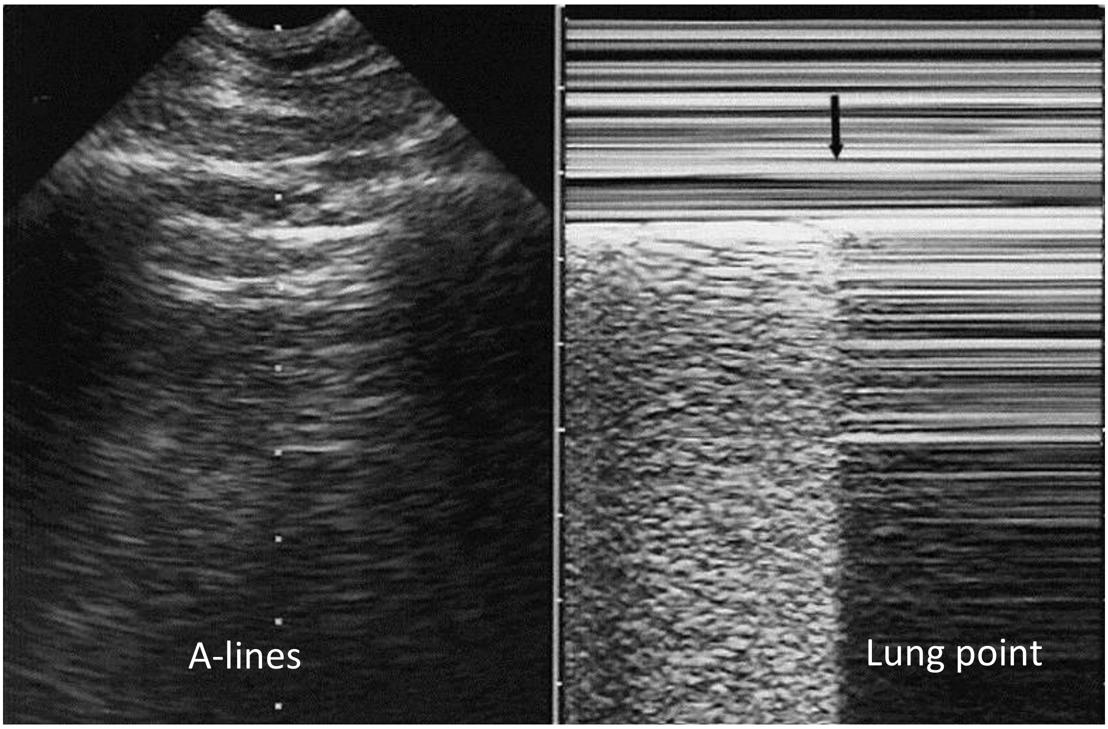


Figure 7. Pneumothorax at the lung point.
Panel A. Real-time mode allows detection of the inspiratory increase in volume of the collapsed lung. When reaching the chest wall where the probe is positioned, it makes a sudden change in the ultrasound image, from an A'-profile to an A- or B-profile usually. The change is sudden because ultrasound is a highly sensitive method, able to detect subtle changes, such as the difference between free gas and alveolar gas. Panel B. M-mode. The left-hand side of the image shows lung patterns (lung sliding) before the visceral pleura disappears. The arrow shows the exact moment the visceral pleura is no longer in contact with the pleura line. The right-hand side image shows the A'-profile (lung sliding abolished with A-lines). This sign has been called lung point, a specific sign of pneumothorax. Adapted from "Lung ultrasound in the critically ill" (11).

The transformation from A-lines to lung rockets defines, in the FALLS-protocol, the presence of distributive shock, i.e., in current practice, septic shock. Previous fluid therapy has proven to be inefficient in this situation, and the appearance of B-lines indicate to discontinue further fluid administration (this is the FALLS-endpoint) and other therapies should be initiated to improve the circulatory status (usually vasoactive drugs like dobutamine or norepinephrine).
This is a very schematical description of a protocol that of course needs much more development (comprehensive work in preparation). Among many frequently asked questions, we choose one, which will probably highlight the idea of the FALLS protocol: "Can the FALLS-protocol really manage a shocked patient without knowing the cardiac output?" By determining who should receive fluids, and when to discontinue fluids, the FALLS-protocol is able to support a diagnosis. Monitoring CO in a known condition is another setting with different rules.

3. *Cardiac arrest: a third, legitimate reason.*

In cardiac arrest every second counts. The idea of using ultrasound sounds maybe "crazy" in such a setting. But this is precisely what was done in the past to manage patients long before the advent of laptop machines. This is an opportunity to describe into more detail the 1992 Japanese ultrasound device used at our institution (last update in 2008). Thirty-two cm width, it can be brought immediately at the bedside, and we ask the readers to compare these dimensions with those of current laptops.

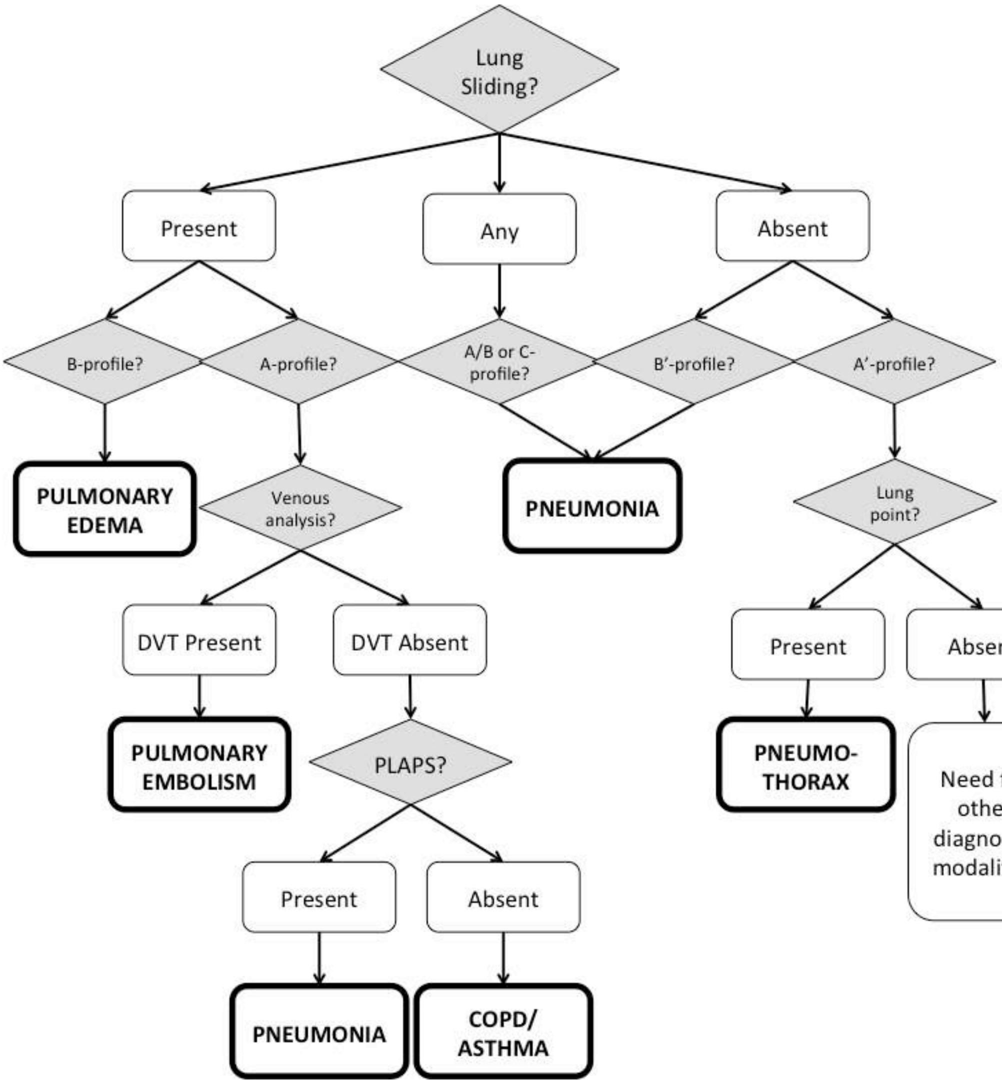
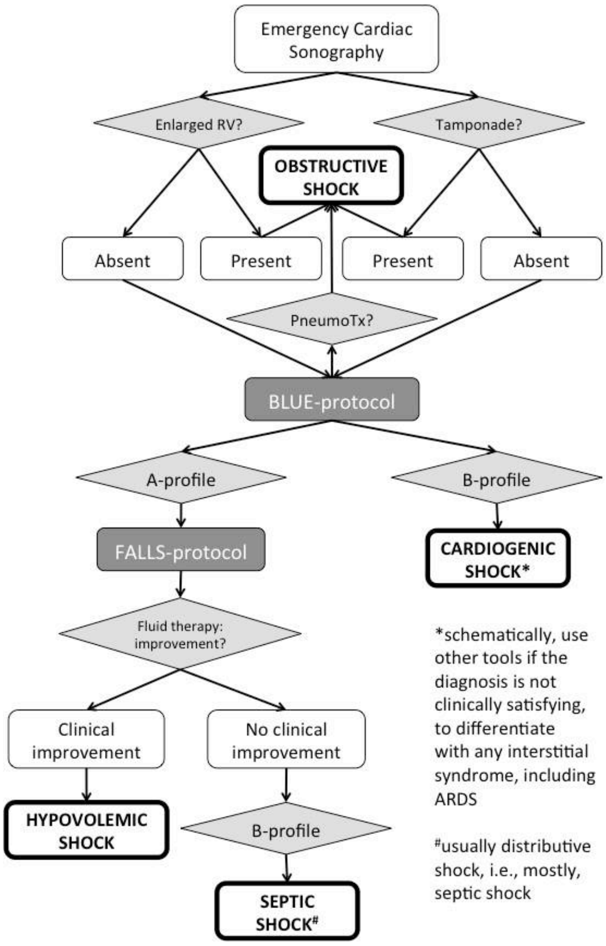


Figure 8. The modified BLUE-protocol starting at the upper and lower BLUE-points looking for lung sliding, and moving to the PLAPS-point, allows immediate differential diagnosis of the main causes of acute respiratory failure using lung and venous ultrasound. Adapted from (7). PLAPS = Postero Lateral Alveolar and/or Pleural Syndrome. See text for explanantion.

One probe that allows a whole body investigation: heart, lungs, veins, abdomen, i.e., our protocol for cardiac arrest. This probe, probably the probe of the future for the young community, is neither cardiac, nor vascular nor abdominal. Its microconvex shape allows its insertion at any site, very narrow as well as large, linear or not, deep or superficial (from one to 17 cm penetration). The machine has one setting, used for everyday applications, which means that no change is required for being immediately operational. No filter, no time lag, no harmonics that can confuse in detecting artefacts or analysing dynamic events.



*schematically, use other tools if the diagnosis is not clinically satisfying, to differentiate with any interstitial syndrome, including ARDS

#usually distributive shock, i.e., mostly, septic shock

Figure 9. The FALLS protocol.
A decision tree facilitating the understanding of the FALLS-protocol. According to Weil classification, cardiac and lung ultrasound sequentially rule out obstructive, cardiogenic (from left heart), hypovolemic and finally distributive shock, i.e. septic shock in current practice. Adapted from (33). Legend: FALLS-protocol = Fluid Administration Limited by Lung Sonography; BLUE-protocol = Bedside Lung Ultrasound in Emergency; RV = right ventricle; PneumoTx = pneumothorax

This is not the setting "lung" (as we can see increasingly available as preset on modern machines), this is the setting "critical ultrasound", i.e., not especially the lung but the veins, heart, abdomen, optic nerve etc. We need the same settings for a fast assessment of the whole body.

Now, we can scan this cardiac arrest, in a sequence adapted to its likely origin and to logic using the SESAME-protocol, a suitable abbreviation of the long abbreviation SESAMOOSIC, standing for "Sequential Emergency Scanning Assessing Mechanism Or Origin of Shock of Indistinct Cause". The SESAME-protocol suggests starting with a lung scan for three major reasons (35). First, pneumothorax (as a cause) can be ruled out. Second, half of the diagnosis of pulmonary embolism is done following the rules of the BLUE-protocol. Third, an immediate clearance for fluid therapy can be ordered, following the rules of the FALLS-protocol. All of this can be obtained in less than a few seconds or minutes, i.e., a minimal hindrance during the course of resuscitation. The SESAME protocol continues by scanning the abdomen in trauma patients for detecting a massive bleeding, or the lower femoral veins in non trauma patients for the second half of the diagnosis of pulmonary embolism (specificity 99%). Next comes the pericardium, which is easy in case of a pericardial tamponade as this usually creates a suitable window.

When pneumothorax, hypovolemia, pulmonary embolism and tamponade have been ruled out (four major and highly reversible causes), we must then scan the heart itself. Here, the user takes the responsibility of interrupting the cardiac compressions with no certitude of having a suitable window (as opposed to the lung step). The scan, best performed via subcostal window, or at worst, parasternally (necessitating removal of the hands during external heart compression), can detect various dynamical changes suggesting ventricular fibrillation, auriculo-ventricular blockade, or again asystole.
The SESAME-protocol does not require any validation, since these applications already belong to the domain of ultrasound. The user just has to work faster (with a suitable machine enabling to expedite this ultrafast protocol).

4. *Assistance during venous cannulation.*

Venous cannulation is a "natural" application, which can also be used in cardiac resuscitation. ICU physicians have all cannulated veins using the blind methods, and mostly succeeded. Yet the word "mostly" is not sufficient for those who would aim at a zero fault rate (i.e., getting inspired by the aviation rules). Since 1989, we got accustomed to cannulate our veins using ultrasound (the technology was suitable, at the bedside, before laptop machines). We have always preferred the subclavian (infraclavicular) vein because of its low rate of infectious complications. We have always preferred to see the whole needle through its route in the soft tissues, favouring our self-taught approach what was called later the "in-plane" technique (36). Our microconvex probe makes everything easier: it easily holds in the hand, can expose the vein at short-axis or long-axis easily (without condemning the user to follow anatomic constraints). Using permanent control, the risk of pneumothorax appears quite impossible (and in any case it would be detected immediately, by using the post-catheter ultrasound control). The infraclavicular subclavian vein is sometimes the only available venous access site in trauma patients with cervical collars, G-suits, etc.

Advantages of ultrasound-guided central **venous catheter** placement include correct identification of the vein, detection of variable anatomy and intravascular thrombi, and avoidance of in advertent arterial puncture (37). It is safer and less time consuming the classical landmark technique, especially in patients with coagulopathy or thrombopenia (38). In cardiac arrest, once a massive bleeding has been detected, if some intratracheal epinephrine has succeeded in a temporary return of spontaneous circulation (ROSC), it is certainly time to insert a catheter, if possible a large, but not necessarily long. Our use of ultrasound allows, without any probe change, during a SESAME-protocol, to make use of this application.

Ultrasound guided **arterial cannulation** helps in reducing the number of attempts, shortening procedure time and increasing success rate, also in children (37, 38)

5. Assessing ARDS (or any critically ill lung under mechanical ventilation):

Ultrasound can help to guide airway management in the patient with acute respiratory distress that needs to be intubated and mechanically ventilated, as it can predict the difficult airway or sleep apnoea, the proper ETT size, or confirm proper ETT placement, etc (37). The intensivist works most comfortably when the maximal amount of information on the patient is available. The lung is the first vital organ. The bedside radiograph, apart from the stethoscope, used to be the only tool for bedside assessment. CT is not an easy option in ARDS, as the patient in this setting is often ventilated and difficult to transport. This is why the concept of using lung ultrasound in ARDS may be coined as the PINK-protocol, by avoiding desaturation (and "blue" cyanosis) during CT. The PINK-protocol uses the 10 signs of LUCI, already described in the BLUE-protocol section, with no adaptation: they work in the same way in ARDS patients. The intensivists will therefore know, for a given patient, the amount of pleural fluid that can be withdrawn. We have never used ultrasound when inserting a needle for withdrawing pleural fluid, because it complicates a procedure, which, based on the logic, is extremely simple (on the other hand, we will never insert a needle without previous ultrasound done immediately before).

The amount of lung consolidation can be assessed semi-quantitatively, by determining the area of maximal consolidation (our consolidation index, based on simplicity), and can be followed-up on a daily basis, for example after changing ventilator settings. Baro- or volutrauma can be immediately detected with LUCI. Critical care ultrasound not only means to establish a diagnosis but also to install a specific therapeutic action. In ARDS, all types of pneumothorax can occur, from free cases (giving classical A'-profile and lung point) to more complex, septated cases.

6. Finding the cause of a fever in an ICU patient

FUO (fever of unknown origin) is frequent, however FUSO (fever of unknown sonographic origin) is rare! Fever in the ICU is one reason for performing whole body ultrasound in a sequential way, considering the most frequent and easy-to-diagnose causes, apart from the visible ones (skin troubles) and those which do not require first-line ultrasound (urinary infection) (39). Usually, we find a (possibly infected) jugular internal thrombosis, or a maxillary sinusitis, showing the sensitive and specific sinusogram (40), but the most substantial contribution is probably the acquired pneumonia. We benefit from the allocated space for developing simple ways for distinguishing pneumonia from atelectases as frequently seen after several days of mechanical ventilation.

The resorption atelectasis can be diagnosed as soon as it appears, as can be illustrated by a pseudo-experimental model of complete, bilateral obstructive atelectasis, i.e., a deep breath followed by apnoea. The saturation rapidly drops after apnoea, causing an unstable situation. During this manoeuvre, instantaneously, lung sliding is abolished, at the whole lung surface. Usually, equivalents of lung sliding such as the lung pulse are present, avoiding the regrettable diagnosis of pneumothorax. Abolished lung sliding with the lung pulse is one sign, immediate. With time passing (not many volunteer apneists would likely reach this stage), the gas in the lungs is resorbed, resulting in a whole lung consolidation with all criteria of volume decrease as evidenced by elevated diaphragmatic cupola and heart attraction. If gas is still present, it is supposed to be static causing the static air bronchogram. Any dynamic air bronchogram rules out obstructive atelectasis (41).

A substantial lung consolidation with conserved lung sliding, no loss of volume, and dynamic air bronchograms, is likely a pneumonia. The pleural fluid usually present can be punctured, although has low risks of showing positive cultures in patients drowned with antibiotics. Note that the distinction between pneumonia and atelectasis belongs to the domain of the PINK-protocol, not the BLUE-protocol (which does not deal with rare causes of acute respiratory failure). Abdominal causes are not so frequent causes of fever (as will be discussed further).

7. Decreasing radiation doses while improving the patient management (and contributing to huge cost-savings): the LUCI-FLR program

X-rays and CT-scans are of great interest, but have significant drawbacks too, i.e. the huge radiation doses – not insisting on some other side effects of CT (e.g. need for transportation, risks of iodine injection).

Lung ultrasound can answer clinical problems with more accuracy than bedside radiographs, and with roughly the same accuracy as CT. In some instances, ultrasound is superior (assessment of pleural septations, necrosis within consolidations, dynamic air bronchograms, diaphragmatic dynamics and lung sliding). Ultrasound provides accurate quantitative data, regarding the volume of pleural effusions, lung consolidations, pneumothorax (the lung point location gives a real-time idea of the pneumothorax volume) (27, 42, 43). LUCI therefore appears as a reasonable, fully operational bedside gold standard.

Lung Ultrasound in the Critically Ill Favouring Limitation of Radiation, the LUCI-FLR program, is a way of answering clinical questions, while bypassing traditional imaging tools (11, 30). The aim of the LUCI-FLR program is to decrease, in the 3 next decades, urgent X-rays by 1/3, urgent thoracic CT by 2/3. This is what one may call a “reasonable target”. We will explain some aspects of this project (which is no longer a project but increasingly a reality as it has already begun).

The LUCI-FLR project aims at limiting traditional radiographic diagnostic tools. The idea of eradicating bedside radiographs, heralded by some, indicates a limited knowledge of the limitations of ultrasound and would be a scary idea. On the contrary, we must keep all our skills in order to interpret correctly bedside radiographs. Ultrasound and radiography can on occasion be complementary. We give a basic example around a simple idiopathic pneumothorax. We admit that the first radiograph showing the disease, although not mandatory, makes an acceptable irradiation. The tube is inserted. The transformation from an A’-profile to an A-profile indicates that the lung is at the chest wall. No need for X-ray. The persistence of an A’-profile with a lung point indicates the opposite, even if a radiograph has been done and seems normal. No need for CT. In the first case, the tube will be clamped, with checking by lung ultrasound, and we will see one of the two previous possibilities: either the lung remains on the chest wall in spite of the clamping, or the culprit lesion in the visceral pleura remains unsealed.

All physicians using ultrasound this way are avoiding excessive irradiation in their clinical practice and are taking part in the LUCI-FLR program. There is no need for multicentre validations. All the relevant articles have been published and validated. One just has to choose the right tool that makes LUCI easy, and learn it the right way. This is the LUCI-FLR program. Safer for patients, limiting radiation and saving costs.

8. Practicing a holistic approach to the heart

In the 1950s, the heart was the only "raison d'être" for ultrasound, and cardiologists took advantage of this. One result was the development of an expert discipline. Even today, learning echocardiography for noncardiologists remains an adventure. One of the aims of LUCI and its protocols (BLUE-protocol, FALLS-protocol) is to help simplifying the cardiac part, just for the case suitable acoustic windows would be of poor quality (or even missing), or because the intensivist would not have finished this heavy curriculum. And remember that there are numerous ICU physicians who have no echocardiographic machine at all.

Sophisticated calculations of the systolic and diastolic function of the left ventricle, using up-to-date, costly machines, is one approach. Detecting an A-profile on lung ultrasound is another approach, as seen in the BLUE-protocol (if there is no B-profile, there is no pulmonary edema) and the FALLS-protocol (if there is no B-profile, there is no cardiogenic shock from left origin). We refer again to what we mentioned above regarding CO measurements, since we must treat the patient and not the numbers.
For confirming pulmonary embolism, powerful algorithms are developed, that work at the bedside, but the BLUE protocol has made the diagnosis readily available (by looking just at the lungs and the veins), while the heavy and powerful echocardiographic machine is still starting up. Npn-cardiologists like intensivists and emergency physicians currently develop guidelines for teaching the "basics" of echocardiography (44). Without adding the lung (and veins), these guidelines may contribute to an incomplete knowledge of critical care ultrasound.

9. Practicing medicine in a new way, a visualising modern tool for all

The patient is the first to benefit from an immediate, on-site, noninvasive visual diagnosis. Any physician will likely appreciate this new dimension, which allows a new feeling of comfort in the difficult ICU environment. Ultrasound is not only the modern stethoscope of the 21st century but may even be considered as an "anti-aging drug". Every step of the diagnostic process is made lighter, more confident, allowing for more sleep during on calls causing the brain to perform better when lives need to be saved. Using ultrasound is a challenging opportunity and should not be a cumbersome obligation. We saw an example previously (see above under reason nr 5), about the need of using ultrasound during thoracocenthesis. Having used the tool thousand times for decades, we are always glad to find a diagnosis without ultrasound, using just our clinical examination. Ultrasound is a wonderful tool, but only a tool. It can sometimes be difficult to handle, or can have a breakdown, or storage problems. But it helps the physician to improve his/her clinical skills: if a pleural effusion was clinically missed, but is confidently objectified using ultrasound, one can again perform percussion, auscultation, and learn to master these subtle signs. In a standard ICU, ultrasound is greatly appreciated by the nursing team, as many trips to the CT will now become unnecessary. Finally, the hospital CEO will be delighted to make savings.

10. Let the readers choose their own final "custom-made" reason

Ultrasound is such a multifaceted tool that any user will highlight one of its countless potentials. For some, it will be the comfort of knowing that this given patient has a free lower limb venous network. For others, knowing that the GI tract of this given patient receives oxygen (unless it would die from mesenteric infarction) as the visualization of a peristalsis is a reassuring dynamic sign. For doctors who make airborne missions, knowing that a patient who will be transported over the ocean has no floating venous thrombosis, no incipient bladder retention, no occult pneumothorax, or some other conditions, is priceless. It allows concluding that the flight will be safe (our ULTIMAT-protocol, Ultrasound Lump Test Initiating Medical Airborne Transportation). Other examples are countless: 1) In emergency medicine? Detecting free fluid (i.e., likely, blood) in a young patient admitted for apparently ordinary blunt abdominal trauma, immediately changes the management; 2) In anaesthesiology? Some doctors need to inject fluids around the nerves and want to see where they are: ultrasound provides good visual guidance (although alternative tools exist) during regional anaesthesia or neuraxial and chronic pain procedures, vascular access, airway management, neuro-monitoring (transcranial Doppler, optic nerve sheath diameter, pupillary light reflex), gastro-intestinal ultrasound (nasogastric tube positioning, peristalsis, gastric residual volume, ileus, colonic pseudo-obstruction), focussed transthoracic and transesophageal echocardiography (37); 3) In paediatrics? A child with fever and a fractal sign has pneumonia. In oncology? Looking at left heart contractility before injecting the first dose of cardiotoxic chemotherapy in an emergency setting, is a simple but contributively application, etc. We let the readers complete this very small paragraph, a very concise summary of the 300-page textbook (31).

ONE NEW LEARNING EXPERIENCE

Practical ultrasound training opportunities are still relatively scarce. For example, while The Netherlands has a national beginner's course and a consolidation track called Intensive Care Ultrasound (ICARUS) (www.frontierscriticalcare.nl), many other countries are dependent on pioneering hospitals or conferences that organize introductory meetings. This hampers true embedding of ultrasound in many ICUs. Therefore, an innovative approach may be needed. As described recently by Radmanesh et al, social media have found their entrance into the ultrasound community (45). An example is Handsonecho, a new ultrasound-teaching platform, combining social media and multimedia to spread educational ultrasound related information. This includes free learning experiences and the production of short ultrasound video snacks obtained by interviewing Prof. Lichtenstein (www.handsonecho.com/snacks). Other examples are echo courses preceding international meetings like the Course on Acute Care Ultrasound (CACU) held during the annual International Fluid Academy Days (http://www.fluid-academy.org), at ESICM, ISICEM, or the websites of 123sonography (http://123sonography.com), ceurf (http://www.ceurf.net), ICU sonography (http://www.criticalecho.com) etc. While these can never replace practical training, using information technology to guide critical care physicians in appropriate use of ultrasound may prove an invaluable contribution to the field.

BEFORE CONCLUDING

This short text, of little use for those who are daily users of critical care ultrasound, was written for two other groups of physicians. Some are still reluctant to see the use of this "specialized" tool in "non-specialized" hands. This wrong vision was transmitted by decades of misconceptions, making them see ultrasound as an expert field requiring high commitment and costly equipment. Others, too enthusiastic, go too fast, at the detriment of the scientific rigor that ultrasound needs. The future of ultrasound must likely lay between these two extremes, since both carry the potential of harm, a fate ultrasound does not deserve!

CONCLUSIONS

We feel privileged to have been invited to write a review on this elegant topic. Elegance is the reason we practice, or rather "love" ultrasound. Beyond yielding data of clinical importance, there is something fascinating in "discovering" one's patient. However, the bottom line is that our passion is truly based on scientific considerations. The lung takes a central place in our 10 reasons for performing critical care ultrasound (46). We hope that, once colleagues will be fully familiar with all different aspects of LUCI (the one probe philosophy, the definition of a holistic concept of critical ultrasound), they will agree that ultrasound is even more revolutionary than they believed, and as such they may even become more enthusiastic. Once a tool for visual medicine falls into the right hands (i.e. the intensivist's hands), finding 10 good reasons to use ultrasound is easy, but also challenging, as there are so many others. Our choice was based on what we believe that truly makes a difference in daily clinical practice at the bedside of our sickest patients.

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Notes

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CHAPTER 4

Ten good reasons why everybody can and should perform cardiac ultrasound in the ICU

Cyril Charron, Xavier Repessé, Laurent Bodson, Siu-Ming Au, Antoine Vieillard-Baron

Critical care ultrasonography (CCUS) has been defined as an ultrasound evaluation of the heart, abdomen, pleura and lungs at the bedside by the intensivist, 24/7. Within CCUS, critical care echocardiography (CCE) is used to assess cardiac function and more generally haemodynamics. Experts in haemodynamics have published a 'consensus of 16' regarding an update on haemodynamic monitoring. They reported the ten key properties of an 'ideal' haemodynamic monitoring system, which perfectly match the ten good reasons we describe here for performing CCE in critically ill patients. Even though unfortunately no evidence-based medicine study is available to support this review, especially regarding CCE-related improvement of outcome, many clinical studies have demonstrated that CCE provides measurements of relevant, accurate, reproducible and interpretable variables, is easy to use, readily available, has a rapid response time, causes no harm, and is cost-effective. Whether it is operator-independent is obviously more debatable and is discussed in this review. All these characteristics are arguments for the extensive use of CCE by intensivists. This is why experts in the field have recommended that a basic level of CCE should be included in the training of all intensivists.

Introduction

Over the past decade, critical care ultrasound has gained its place in the armamentarium of monitoring tools (1). A greater understanding of lung, abdominal, and vascular ultrasound Critical care ultrasonography (CCUS) has been defined as an ultrasound evaluation of the heart, abdomen, pleura and lungs at the bedside by the intensivist, 24/7 [1]. It has been recognised for many years, in collaborative publications and recommendations by international societies of intensive care medicine [2, 3] that general critical care ultrasonography (abdominal, vascular, pleural and lung evaluation), as well as critical care echocardiography (CCE, heart evaluation), is essential in modern intensive care units (ICUs). Furthermore, the inclusion of basic CCE in the curricula of all intensivists has been recommended [2].

Since most patients admitted to the ICU for cardiorespiratory compromise who die do so because of haemodynamic failure or fluid overload [4], haemodynamic monitoring is key to their management. Many devices are available for continuous or discontinuous haemodynamic monitoring. Repeated echocardiography has, in various situations such as septic shock, proven effective in determining the mechanisms of haemodynamic failure, such as hypovolemia, cardiac failure, or vasoplegia, or sometimes all three together [5].

This is why this review will exclusively focus on CCE and its ability to monitor haemodynamics, for which more data and clinical studies are probably available, even though general critical care ultrasonography is also of great importance.
In 2011, experts in haemodynamics published a 'consensus of 16' to update knowledge of haemodynamic monitoring [6], which emphasises the central role of echocardiography in managing a patient in shock. In the case of persistent haemodynamic instability, echocardiography is strongly recommended after a brief check for an obvious hypovolemic profile [6]. The experts also reported the ten key properties of an 'ideal' haemodynamic monitoring system, which perfectly match what we consider to be ten good reasons for performing CCE in the ICU [6].

Reason 1: Measures relevant variables

CCE plays a central role in functional haemodynamic monitoring [7]. Functional haemodynamic monitoring is a way to monitor haemodynamics more qualitatively, with fewer numbers, in contrast to what was done in the past with the pulmonary artery catheter, less invasively, and finally more centered on the appropriate treatment. A good illustration is the need for fluids. In the past, the main goal was to evaluate cardiac preload using pulmonary artery occlusion pressure or central venous pressure (CVP), neither of which is very relevant for fluid adaptation because of their well-known limitations [8].

With the functional haemodynamic monitoring approach, the goal now is to evaluate preload responsiveness, which echocardiography has been reported to predict well, using, as an example, vena cava respiratory variations [9] with good sensitivity and specificity. But CCE is also able to evaluate right heart function accurately [10], to detect acute cor pulmonale in different situations [11], and to recognise left ventricular (LV) dysfunction using the LV ejection fraction or its surrogate LV fractional area contraction [12]. All the potential causes of circulatory failure may be independently evaluated from the others, like direct visualisation of the cardiac chambers and heart function, in contrast to what can be done using other devices.

Reasons 2: Provides accurate and reproducible measurements

Whereas the first assertion is true, the second is debatable. As emphasised above, many echocardiographic parameters in critically ill patients have been reported to be accurate for evaluation of cardiac function and preload responsiveness. Reproducibility has also been studied for the usual echocardiographic parameters. Intra- and inter-observer variabilities of between 3 and 10% have been reported [5]. Logically, better image quality and acquisition result in better reproducibility.

Reason 3: Is operator-independent

This is why in our view transoesophageal echocardiography (TEE) in mechanically ventilated patients is probably more accurate and reproducible, and less operator-dependent, than transthoracic echocardiography (TTE). This was indirectly suggested by two studies. The first, in critically ill surgical patients, showed that TEE is more efficient than TTE, especially in patients with significant weight gain (> 10%), with a chest tube or ventilated with a positive end-expiratory pressure higher than 15 cm H_2O [13]. The second, in 200 patients ventilated for acute respiratory distress syndrome, showed that TEE is more efficient than TTE in detecting acute cor pulmonale [14]. Provided that physicians are correctly trained, and that CCE is used as a qualitative approach (see Reason 1 above), we suggest that TEE may be considered as nearly operator-independent [15, 16].

Reason 4: Provides interpretable data

Since echocardiography directly visualises the cardiac chambers and ventricular contraction, parameters are by definition interpretable, provided image acquisition is adequate. In a clinical study of 128 transthoracic procedures, Vignon et al. reported quality that was good in 55% of cases, suboptimal in 23%, and poor in 22% [17]. In the event of TTE failure, TEE was very efficient [17]. In our experience, images recorded using a transoesophageal route are rarely uninterpretable. The respective advantages and disadvantages of TTE and TEE are summarised in a recent international consensus statement [3].

CCE visualises what is really happening, whereas recording of cardiac pressures is limited since they are subject to intrathoracic pressure, which complicates interpretation in certain situations. For instance, CVP depends more on changes in intrathoracic pressure than on haemodynamic changes in acute asthma and in acute exacerbation of chronic obstructive pulmonary disease, where there are large swings in intrathoracic pressure.

Reason 5: Is easy to use

Compared to other devices for haemodynamic monitoring, echocardiography requires expertise and then training to acquire cognitive but also technical skills. From this point of view, echocardiography is not obviously easy to use. On the other hand, the global haemodynamic evaluation it allows and, unlike most other devices which focus mainly on cardiac output measurement, the balance it offers between interests and constraints, clearly favour echocardiography, even though no evidence-based medicine supports such an assertion.

CCE can be defined as basic or advanced [1]. Basic CCE, also called goal-directed echocardiography [18], is a procedure based on transthoracic echocardiography which allows a focused and rapid exam to diagnose obvious haemodynamic profiles, such as profound hypovolemia, severe LV systolic dysfunction, severe RV dilatation and extensive pericardial effusion [1]. Provided that appropriate skills acquisition is included in the training curriculum of all intensivists [2], one can say that basic CCE is (or will be) very easy to use. To acquire the necessary skills, a ten-hour course is recommended, divided into lectures and illustrative cases, plus at least 30 fully supervised TTE examinations in unstable patients [2].

Advanced CCE is quite different in that it allows a full haemodynamic evaluation [1]. Intensivists have to be competent in the use of TTE and TEE in mechanically ventilated patients. It requires formal certification following a 40-hour course, 100 supervised TTE and 35 supervised TEE examinations [3]. Given these requirements, it is hard to maintain that advanced CCE is currently easy to use, but there are an increasing number of certification courses (local or international) open to intensivists.

Reason 6: Is readily available

The recommendation is very clear: for CCE, the echocardiography machine has to be readily available, meaning in the ICU. Even though no recent survey has been done, one can nonetheless say that most ICUs now have one available 24/7. Similarly, TEE probe cleaning is better performed in the unit by the team itself.

Reason 7: Has a rapid response time

In a recent multicentre study of the ability of 41 trainees to evaluate haemodynamics adequately in mechanically ventilated patients using TEE, Charron et al. reported that after six months and 31 ± 9 supervised TEE examinations per trainee, they were able to perform a full haemodynamic evaluation adequately in about 13 minutes [16]. Once again, this requires the machine and the oesophageal probe to be available in the ICU, as recommended.
Using the pulsed wave Doppler technique, echocardiography can also be used to calculate the LV stroke volume and then the cardiac output. Compared to other techniques, it clearly has a rapid response time since it enables real-time evaluation of the response to passive leg raising, as recommended [19].

Reason 8: Causes no harm

Even though the 16 experts in haemodynamics in their consensus reiterated in principle no. 10 for haemodynamic monitoring that "noninvasiveness is not the only issue", and absolutely not a goal per se, they also said that it is preferable to be less invasive when possible [6]. Whereas TTE is completely noninvasive, TEE can be considered as minimally invasive. When contraindications are strictly respected, side effects are few. In a large study of 2,508 TEE examinations, Hüttemann et al. [20] reported a 2.6% incidence of complications. Most of these complications could actually be considered minor and most occurred in spontaneously breathing patients. The most serious complication, oesophageal perforation, was mainly described in awake patients breathing spontaneously, with an incidence of around 1/2,500 procedures.

Reason 9: Is cost-effective

To the best of our knowledge, no formal medico-economic study has been performed to evaluate the cost-effectiveness of CCE compared to other haemodynamic devices in critically ill patients. Some studies indirectly suggest that, by limiting fluid overload, CCE may reduce the length of stay in the ICU and mortality compared to management using central venous pressure [5].
The cost of echocardiography machines has significantly decreased over time and new 'pocket' machines are now available at a very low price (< \$10,000 US). Pocket echoscopic devices have proven efficient for basic CCE [21]. In general, compared to other haemodynamic devices, there are no costs for consumables once the machine has been bought. In an interesting study performed in critically ill surgical patients, Cook et al. tested the cost-effectiveness of three different scenarios [13].

In the first scenario, TTE was performed first, and if it was unhelpful TEE was done. The cost per patient was evaluated at \$858 US. In the second scenario, TEE was routinely performed first. Here, the cost per patient was significantly lower, i.e. \$677 US. Finally, in the third scenario, TTE was performed first in patients with a low risk of it failing, and TEE was done first in patients with a high risk of TTE failure. The cost per patient was \$752 US.

Reason 10: Should provide information that can be used to guide therapy

This section alone could probably be a large review in itself because of the mass of available data and clinical studies. Therefore we will not strive to be exhaustive. Briefly, in the 1990s, many studies reported a therapeutic impact in 20–68% of cases when TEE was performed in addition to the rest of the haemodynamic evaluation [17, 22–24]. In these studies, TTE also had a significant therapeutic impact when adequate images were obtained. In a study in 2,508 critically ill patients, Hüttemann et al. [20] reported a therapeutic impact of TEE of 68.5% of cases. In close to half of the patients, the indication for TEE was haemodynamic instability [20]. More recently, Bouferrache et al. [25] reported a very simple therapeutic protocol based on TEE examination in mechanically ventilated patients with septic shock. In particular, they demonstrated their ability to diagnose and to correct step-by-step hypovolemia, septic cardiomyopathy and vasoplegia [25]. They also reported discrepancies between the TEE approach and the recommendations of the Surviving Sepsis Campaign. In particular, the SSC approach based on ScVO2 was reported to be inaccurate, compared to echocardiography, in identifying patients with severe LV systolic dysfunction [25].

Conclusions

Although no clear evidence-based medicine study has yet confirmed the ability of CCE to improve outcomes in critically ill patients, several observational studies support its use as a true haemodynamic monitoring device. However, as also noted by the 'consensus of 16' experts in haemodynamics in their principle no. 1, no haemodynamic monitoring technique can by itself improve outcome [6]. We hope that this presentation, even though sometimes partial, of ten good reasons for using critical care echocardiography, will convince intensivists to seek training in, and to use, echocardiography at the bedside to optimise patient management.

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Notes

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Translational Ultrasound: 55 – 64

CHAPTER 5

Lung ultrasound in critically ill (LUCI): A translational discipline

Daniel Lichtenstein, Manu L.N.G. Malbrain

In the early days of ultrasound, it was not a translational discipline. The heart was claimed by cardiologists, others, like gynecologists, urologists and vascular surgeons claimed their part and the rest was given to the radiologists. Only recently, ultrasound transgressed and crossed the usual borders between the different disciplines like emergency and critical care medicine. The advent of portable machines in the early 1980's, allowed the critical care physician to perform bedside ultrasound, and the development of whole body critical care ultrasound (CCUS) was born. It may sound cynical that radiologists were the first to state that diagnostic sonography truly is the next stethoscope: poorly utilized by many but understood by few. Exactly the same radiologists abandoned the use of ultrasound outside the radiology department leaving a vast domain to other disciplines eager to welcome the modern stethoscope. In this review, we list the possibilities of lung ultrasound as a translational holistic discipline.

Introduction

Traditionally, ultrasound was not a translational discipline. The cardiologists claimed their part, and so did gynecologists and later on urologists and vascular surgeons. This was the case for decades. In the early 1980's, intensivists discovered ultrasound as a way to monitor heart function [1]. Initially radiologists were concerned that untrained doctors used ultrasound outside the radiology department. Dr Roy Filly, Professor Emeritus of Radiology, and chief of the department of diagnostic sonography in Stanford predicted in 1988 that ultrasound would likely become the new stethoscope: "As we look at the proliferation of ultrasound instruments in the hands of untrained physicians, we can only come to the unfortunate realisation that diagnostic sonography truly is the next stethoscope: poorly utilized by many but understood by few" [2]. The introduction of portable machines in the 1980's, allowed the intensivist to perform bedside ultrasound, and the development of whole body critical care ultrasound (CCUS). This movement likely inspired emergency physicians, who realized that the detection of blood collections could be of interest in trauma patients. By the same time radiologists let go and did no longer invest time, effort and knowledge in the use of ultrasound in the critically ill. Since the 2000's, critical care and emergency ultrasound has undergone a revolution. However, ICU and ER colleagues have shed new light on the most important piece of the puzzle, namely the lungs. CCUS of the lungs made ultrasound the stethoscope of the 21th century.

The consideration of lung ultrasound in the critically ill (LUCI) as a major point of interest makes ultrasound a true clinical tool [3, 4]. It makes CCUS a holistic discipline. A discipline is holistic when each of its components, apparently unconnected, work together for making a whole. If lung ultrasound is not considered, the portable characteristics of the ultrasound machine, the Doppler button, and modern filters have nothing in common. When the lung is added to the ultrasound examination, all of a sudden it can also be used in emergency situations, e.g. for demonstration of tension pneumothorax during cardiac arrest (obstructive shock). Therefore, a small portable machine is required, there is no time (nor need) to use Doppler, and any modern filter is a hindrance (as explained in the SESAME-protocol)[3].

Although there are many clinical examples for the holistic use of LUCI, we will illustrate with a simple case. In a patient with acute dyspnea due to hydrostatic pulmonary edema, LUCI will show the B-profile, indicating left heart dysfunction [4]. Traditional transthoracic echocardiography will not visualize the "pulmonary edema", but will show left ventricular dysfunction, which is not the actual problem but rather the cause.
The definition of holistic ultrasound points out that the use of LUCI can be extended to other settings, less critical but in daily practice. This makes the basis of a translational vision of LUCI. We here describe our experience from critical care to other, less critical disciplines.

What makes LUCI a translational tool?

Translational medicine is a popular term often used nowadays. Several disciplines may be interested by innovations, but who may be interested in LUCI? In fact, many disciplines are focusing on the lung, at one or another moment. Briefly, all doctors using a stethoscope may be interested in LUCI. We will elaborate on this in the next paragraphs.

The intensivist perspective

In the critically ill patient the lung is one of the most vital organs. Ironically, the lung was deemed as an obstacle to ultrasound use because of the artefacts caused by air [5]. Now all doctors know that ultrasound helps us to diagnose various conditions that may explain the cause of acute respiratory failure. The BLUE-protocol has been designed for rapid understanding of the etiology of respiratory failure, the FALLS-protocol for acute circulatory failure, the SESAME-protocol for cardiac arrest.

We briefly describe the BLUE-protocol. A few areas of interest (two anterior, one posterior) are used, allowing to analyze lung sliding, lung rockets, posterolateral alveolar and/or pleural syndrome (called PLAPS). By making associations between specific signs and the lung areas where they are present, the most frequent diagnoses can be made. This may be of interest when the clinical presentation is misleading. Hydrostatic pulmonary edema is defined by the B-profile, which combines anterior lung sliding with anterior lung rockets. Some pneumonias are detected through the B'-profile, a specific sign, when lung rockets are seen with abolished lung sliding. The A-profile (anterior lung sliding without anterior lung rockets) associated with an area of deep venous thrombosis has a 99% specificity for pulmonary embolism (in healthy lungs).

In the past many intensivists performed only echocardiography. However, recently, the BLUE protocol is also gaining its place. Some intensivists also "tried" the FALLS-protocol, in a more challenging field because this protocol handles acute circulatory failure, a setting with limited gold standard, if any. We briefly describe the FALLS-protocol. The Fluid Administration Limited by Lung Sonography (FALLS) protocol rules out sequentially obstructive shock (pericardial tamponade, pneumothorax, pulmonary embolism and other causes of dilated right ventricle), and cardiogenic shock from left origin (absence of B-profile). After exclusion of cardiogenic shock, fluid is administered, as it will be beneficial to all other sources of shock, hypovolemic and distributive. This is a therapeutic test. Hypovolemic shock should resolve under fluid therapy. In the FALLS-protocol, septic shock is defined by transformation of A-lines to B-lines under fluid therapy. We remind shortly that the FALLS-protocol allows to redefine hydrostatic pulmonary edema: when the circulating volume is under pressure, it creates "pulmonary edema", a term which is confusing, because this edema begins in the interstitial space which does not take part to the gas exchanges (French name, "puisards septaux")[6]. Many physicians wrongly understand "alveolar" edema when they hear of "pulmonary" edema. This is an opportunity for LUCI, which can detect interstitial edema through the lung rockets, at an early, infra-clinical step, one step ahead [7].

LUCI is holistic because it allows to simplify cardiac evaluation. The *Cercle des Echographistes d'Urgence et de Réanimation Francophones* (*CEURF*) teaches an extremely simplified use of echocardiography, called simple emergency cardiac sonography (not echography, which is too specific, not ultrasound, which reminds examination beyond the heart alone). The SLAM (section for the limitation of acronyms in medicine) skipped the need for an acronym. The combination LUCI/simple emergency cardiac sonography adds a new dimension in the assessment of the thorax (also called "black box") at the bedside. We say "new" although all this has been described and published since 1994 and before. This ultrasound combination of lung and heart will be of major interest for those who have not yet reached the necessary skills (no beautiful windows) – those who have the skill and the windows, but who have to face the gray zone – and the most numerous on Earth, those who still do not have any echocardiographic machine.

We introduce the SESAME-protocol in a few words. This approach to cardiac arrest is an opportunity for describing the seven requirements we ask to a machine in this setting but which works on less critical settings. Requirement 1: a very simple machine. Doppler for instance is not used here (and seldom in our emergency clinical work, the use of simple signs allows to have the clinical information). Filters are usually a hindrance when using LUCI. Requirement 2: a really small machine (for being rapidly on-site), smaller than those usual laptops which are too large. The ideal machine is slim (our machine, 32-cm width). Requirement 3: a fast start-up time (our machine, 7-seconds). Requirement 4: a universal probe for a whole body but goal-directed approach. Requirement 5: a perfect compromise for the image quality with the same probe and setting. This is required for the SESAME-protocol, but above all, it is the one we use daily for less urgent tasks (subclavian catheterization etc). Requirement 6 (a flat keyboard) is not critical for cardiac arrest but really mandatory in the daily life for working with a clean machine. Requirement 7: from the first and the 4th, a cost-effective machine, just allows to save more lives. Such a machine was already available since 1992, demonstrating that it was not necessary to wait for the laptop revolution. The 1992 (and even 1982) technology was perfect.

The SESAME-protocol is a really fast protocol since it rules out in a few seconds (shockable causes apart) four main reversible causes of cardiac arrest: tension pneumothorax (when the A'-profile is identified); pulmonary embolism (using the BLUE-protocol when the lower femoral vein is clotted); abdominal bleeding; pericardial tamponade. If none is positive, one has just to wish for a cardiac window, and mostly for the privilege of finding a reversible cause at this step.

Key messages:

- Lung and thoracic ultrasound in the critically ill, guided by different protocols (like BLUE, SESAME, FALLS,...) can help to evaluate the etiology of cardiopulmonary failure, to manage pleural effusion, pneumothorax
- Noteworthy: vascular ultrasound can be used to detect deep venous thrombosis, to guide central venous or peripheral venous and arterial access, to diagnose aortic syndromes

The neonatal intensivist perspective

Lung function in neonates is of critical concern. We have checked how far the signs observed and assessed in adults using suitable gold standards (i.e., CT) were visible in children [8]. The critically ill neonate shows exactly the same signs, not one more, not one less. With regard to lung ultrasound, the neonate's lung is a miniature of the adult's lung. Just imagine the change, just imagine how the physician will have critical information with minimal irradiation and no risk linked to transportation to radiology [9-11]. The neonate is one of the main targets of the LUCIFLR project (Lung Ultrasound in the Critically Ill Favoring Limitation of Radiation)[12].

Key message:
- The LUCIFLR project aims to limit in the next three decades the number of bedside radiographs by one-third, and mostly the number of urgent thoracic CTs by *two-thirds*.

The pediatrician perspective (neonates excluded)

If the signs assessed in the adult were seen in the neonate, this means that the intermediate ages (infant, toddler, young child, adolescent…) will likely have the same benefits from LUCI [9, 10].

The bottom line:
- The use of ultrasound in the pediatric population is virtually unlimited: from LUCI to diagnosis of ureter obstruction, intussusception, appendicitis to traumatic brain injury

The adult cardiologist perspective

Cardiologists use sophisticated approaches for assessing the left heart function. They have used ultrasound probes since decades and they studied carefully the heart, but only the heart. If the cardiologists would have tilted the probe a little bit more towards the left, they would also have visualized a small part of the lung, a vital organ so close to the heart. Imagine the potential of a discipline which can associate, or dissociate, cardiologic from lung findings (presence or absence of B-profile in patients with or without visible left dysfunction, or just in the grey zone, or just without cardiac window…). Fortunately, the cardiologic community is beginning to take interest in LUCI [13, 14].

What was valuable during the management of shock can be used in the same way in more stable conditions such as early diagnosis of cardiogenic (hydrostatic) pulmonary edema – at a sub-clinical level [7]. Examining the lung in addition to the heart should take less than one minute. In the BLUE-protocol, time devoted in search of a B-profile is roughly 30 seconds.

Key message:
- We are convinced that in the future, patients will have a combined heart/lung ultrasound examination, allowing simultaneous visualization of the cause and the consequence of a disease.

The pediatric cardiologist perspective

Cardiology is usually linked to an adult population, let us keep one sentence for those who deal with congenital heart diseases in children, a small and huge world. LUCI should have a major place in this population as well.

The anaesthesiologist perspective

As some anaesthesiologists are also intensivists, they may have already read the section devoted to the intensivist. Outside the critical care setting, there is a huge field of application. With the compact ultrasound machines that were already available since 1982, anaesthetists could have been able to use CCUS to insert central venous catheters with nearly zero fault, to control the fluid and bleeding losses during surgery, just to name a few examples. Transesophageal echocardiography (TEE) is very useful where there is no access to the thorax. Lung ultrasound can be a nice alternative, provided a small space is devoted at the level of the upper lungs. Enough for performing a FALLS-protocol – also in conditions where the thorax has been opened (which is a limitation of TEE, since the pleural variations are altered).

Key messages:
- Ultrasound allows recognizing high-risk patients before surgery: by scanning the lung, the anesthesiologist will better recognize patients with clinically occult left heart dysfunction.
- Ultrasound allows assessment of fluid status during general surgery in order to replace correctly the losses using indirect tools.

- New habits in the OR should include scanning of the lungs during abdominal surgery. We wrote since 1992: *"If ultrasound succeeds penetrating the prestigious operating room, it can initiate a small revolution"* [4]. Fortunately, ultrasound has gained its place in the OR, it only took a long time.

The thoracic surgeon perspective

Before surgery it is important to detect adhesions (by abolished lung sliding). During surgery, a lung exclusion should be checked with ultrasound. After pulmonectomy, the initial pattern is the A'-profile. This is logic, since in fact we face, stricto sensu, a "pneumo-thorax". The cavity is little by little filled with fluid/blood. In case a "swirl sign" would be visible and the physician would interpret this sign as a classic pneumothorax, needle insertion would not have dramatic consequences. After a pulmonectomy, the intra-thoracic pressures must be balanced, between the residual air and the contralateral lung. The gold standard (mediastinal location on bedside radiography) can be replaced by ultrasound.

Key message:

- Lung ultrasound can be the new stethoscope for the thoracic surgeon in the postoperative follow-up after pulmonectomy

The nephrologist perspective

Nephrologists are interested in the volume status of their patients (especially if they are oliguric or anuric and on chronic dialysis). Some may use the stethoscope in search for crepitations to predict the need for dialysis, although this may be a sign of alveolar edema. Others may use changes in dry and body weight or bio-electrical impedance analysis. Using LUCI they will have a subtler vision of lung function, detecting interstitial edema at an early stage... Likewise, lung rockets indicate wet lungs, A-lines dry lungs [15]. Ultrasound also allows to measure renal resistive index which has been shown to be correlated to intra-abdominal pressure [16].

Key message:

- In patients with cardio-renal dilemma or cardio-abdominal renal syndrome (CARS) LUCI combined with abdominal ultrasound can help to identify patients with congestive heart failure that may be at risk for worsening renal failure [17]

The emergency care physician

Developing ultrasound use in the emergency room (with a fast protocol) has a special interest, both in critically ill unstable patients but also in non-critically ill patients presenting with lung problems.
It seems that emergency physicians only took interest in ultrasound because ultrasound machines became at last "small", able to be used outside the radiology department. This is one of the misconceptions in the history of acute medicine, since machines from 1992 and even 1982 were, not only as small or smaller than the modern laptops, but even... technically better for CCUS. It has to be noted that the concept of modern laptop machines was mostly guided by radiologists or cardiologists, unaware of the potentials of LUCI. Therefore, they focused on minimizing the artifacts caused by the lungs, as well as the subtle dynamic signs of LUCI. This explains a 30-year step backward, a unique phenomenon in medicine. In the first years of the laptop revolution, emergency physicians had to deal with large machines, poor image quality, long start-up times, complex keyboards devoted to specialists, with the three usual probes but not the universal one, harmonic filters, and last but not least increased costs. In retrospect, we paved the way much earlier, since 1985 using bedside technology dating from 1982 which laid the basis of the first publication on the BLUE-protocol [18].

The bottom line:

- Ultrasound in the emergency room includes not only LUCI but all critical care ultrasonography, extended abdominal, testicular, early obstetric, musculoskeletal, and ocular [19]
- Typically, single examination is necessary for diagnosis and disposition

- Frequently leads to decision to discharge from hospital

Pre-hospital medicine

In 1994, the company Dymax (Pittsburgh) produced a 3,5 kg portable TM-18 machine allowing us to use ultrasound in an African mission from a helicopter. With this device, the first pre-hospital ultrasound diagnosis of pneumothorax was made in the Saharan desert [20]. Off course, if ultrasound was possible in the sky, even more can it be of value in a simple ambulance. We are glad to have given the idea of pre-hospital ultrasound to the community [20].
Later on, we have been using a portable machine (1850 g with its unique probe, holding in a box of 15 x 12 x 12 cm) during airborne missions since 1998. Although this unit came from the veterinary domain, it allowed us to save human lives.

Key messages:
- The traditional dilemma "scoop and run" versus "play and stay" is solved when visual medicine is used on-site.
- We recommend that young ER doctors start their CCUS training with the lungs before trying to perform expert echocardiography in emergency setting, as holistic ultrasound allows to use the lung to answer cardiac questions (as explained above).
- Investing in the heart without examining the lung is not holistic ultrasound.

The flying doctor's perspective

Ultrasound can be helpful during medical retrievals. The ULTIMAT-protocol (ultrasound limited test initiating medical airborne transportation) is an approach that we use routinely when transporting critically ill patients. The focus is on occult but possible lethal conditions: mainly pneumothorax, floating DVT, pericardial effusions close to the tamponade, amongst others.

Key messages:
- Diagnosing a pneumothorax clinically during flight is very difficult.
- The ultrasound approach, on the contrary gives a proper visualization, which does not suffer from the background noise making auscultation or percussion of the chest difficult to interpret.
- These settings where space is really a hindrance are a good opportunity for using hand-held machines.

The gyneco-obstetrician perspective

These doctors are often faced with severe conditions such as (pre)eclampsia, toxemia of pregnancy, amniotic pulmonary embolism, critical hypovolemia from bleeding (HELLP syndrome, hemolysis elevated liver enzymes and low platelets). In case of ovarian hyperstimulation syndrome, ascites can be detected and drained [21]. The simple question regarding pulmonary edema is solved in 30 seconds using the BLUE-protocol.

Key messages:
- In pulmonary embolism, the BLUE-protocol allows the diagnosis in most cases.
- In cases of massive blood loss, the FALLS-protocol can guide between the risks of hypovolemia and fluid overload (therapeutic dilemmas).

Internal medicine perspective

All internal medicine physicians have without exception a stethoscope. Yet some diseases have no known findings on physical examination. Except from the presence of fine crepitations, "cris des petits oiseaux" (the chirp of a little bird) or squeeks [22] the stethoscope is of no use when assessing interstitial disease (extrinsic allergic alveolitis, lung fibrosis,...), whereas ultrasound can document the presence or absence of lung rockets rapidly.

Key message:
- The time is right for internists adopt the handheld ultrasound device, without the intent of replacing the traditional stethoscope

Pulmonologist perspective

In the word "pulmonology", there is "pulmon", i.e., lung. Therefore, it is likely, that they will use ultrasound one day. It is true that they are accustomed to high-resolution CT images, which outlines subtle details of chronic interstitial diseases better than ultrasound.
The pulmonologists could take some responsibility in decreasing the radiation doses [23].

Key messages:

– By definition, pneumologists or lung specialists should be the ambassadors for LUCI
– The diagnosis and management of pleural syndromes, biopsy of subpleural lesions are possible applications
– Recently, they begin to appreciate the potential of ultrasound.

Family doctor's perspective

In full winter, family doctors often have to deal with a febrile child carried in their mother's arms. With LUCI, she will not need to go out with a prescription for a radiograph. With LUCI, she will have a diagnosis and treatment on-site.

Key message:

– In patients presenting with vague respiratory symptoms, LUCI can detect chronic interstitial syndromes.
– In other situations, time can be saved (differential diagnosis of chest pain, etc).

Trauma surgeon's perspective

In some areas, the doctor managing a trauma patient is the surgeon. In trauma, physical examination is usually aspecific.

Key message:

– LUCI, will provide trauma surgeons with an immediate and correct diagnosis (pneumothorax, lung contusion, hemothorax…).

Geriatrician's perspective

This is a young discipline [24]. Imagine how many times they rely on physical signs and auscultation. LUCI can be used without adaptation to detect disorders that are at best treated at an early stage.

Key message:

– LUCI has a real future in this growing population

Ultrasound of the (developing) world

Probably here is the largest number of patients. A simple radiography is a luxury. As a developed world, we must embrace the people living in these deprived and remote areas. We just present the SHUFLES program (Simple Holistic Ultrasound For Low-Economy Settings) as a holistic and translational vision. The SHUFLES program uses the same simple machine, one single probe and no Doppler nor sophisticated modalities, but allowing similar diagnostic possibilities than a mini-bedside CT.

Key messages:

– This is one application of holistic ultrasound: no adaptation is necessary between sophisticated Western ICUs and these remote areas.
– The signs are the same. A consolidation is a consolidation. Whole body ultrasound could make a major difference in the therapeutic decisions.

Other "isolated" doctor's perspective

Some doctors work on cruise ships. The possible patients usually can afford extra care. These doctors need to master physical examination, as this is often the only thing they can rely on. Only few have a real "small hospital" available on board with X-rays, a lab, possibility of urgent coronary care. So, why not add an ultrasound machine. Some doctors work in the jungle, or in settings with really poor facilities. They will enjoy small, light equipment.

Miscellaneous

People performing acupuncture are sometimes nervous because, rarely, they create a pneumothorax. But asking a traditional imaging after each session would be a disaster. Asking a radiograph would generate irradiation, cost, loss of time… with only minor advantage if the pneumothorax is initially not detectable radiologically. A rapid ultrasound view would allow select in a few seconds those who need to be transferred to hospital.

Whilst performing functional evaluations, doctors will better understand lung physiology, as lung sliding is a dynamic sign that can only be demonstrated by ultrasound.

During palliative care, diagnostic escalation is not the first option, but ultrasound is precisely the opposite. It will on occasion highlight reversible causes of severe discomfort.

Many respiratory therapists are interested in LUCI, as it is perfectly devoted for bedside real-time assessment. Sonographers may play a role, as they are familiar with the technique.

Medical student's perspective

The best for making LUCI a reality would be to implement it in medical education. Not whole-body ultrasound, because this would result in making longer medical studies with small benefit (which percentage of them will ever benefit of a mastery of the biliary tract ultrasound?). But why not start with lung ultrasound, because it is simple, and because all future doctors dealing with the lung will benefit from it.

All doctors

The LUCIFLR project regards all those who ask for chest X-rays or CTs. Imagine that the access to CT may become restrained in the future in order to limit radiation [12]. As this is not hypothetical one can better be prepared (especially in specific settings, if for instance the only question is presence or absence of pneumothorax).

"Last but not least" LUCIA, lung ultrasound in the critically ill animals. The veterinarian perspective

We remind that the pocket machine we used since 1998 was ironically from the veterinarian world. As LUCI works perfectly in humans, without known side effects, we could also apply this discipline to our pet animals. Each animal with lungs can benefit from LUCI. We extrapolate exactly the same signs. Like critically ill patients, animals do not speak. Just imagine the benefit.

Conclusions

Each time the word "lung" is pronounced, i.e. many times a day in the above listed disciplines, ultrasound has a place, at the bedside, to solve clinical questions. This results in rapid diagnosis, cost savings, less suffering, and the birth of a new form of medicine based on visual bedside observations. Within practiced hands, ultrasound can replace CT (and of course X-rays), this is called the LUCI-FLR project. As the official imaging specialists, the radiologists have now an important role to play as they need to accept the importance of lung ultrasound. This would add another specialty to the long list. Some clinicians are still reluctant to perform lung ultrasound as the air in the lungs is perceived as a major limitation while intensivists and emergency physicians use these artefacts to make a proper diagnosis [25]. More effort is needed to facilitate the widespread adoption by the medical community of lung ultrasound.

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Notes

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Cardiac Monitoring: 65 – 74

CHAPTER 6

Cardiac Ultrasound: A True Haemodynamic Monitor?

Jan Poelaert, Manu L.N.G. Malbrain

Cardiac ultrasound has been used in the critically ill since more than thirty years. The technology has made enormous progression with respect to image quality and quantity, various Doppler techniques as well as connectivity, transfer of data and offline calculations. Some consider cardiac ultrasound as the stethoscope of the twentieth century. The potential of eye-balling moving cardiac structures gives an undeniable power to this diagnostic and monitoring tool. The main shortcoming is the discontinuous mode of monitoring and the fact that optimal information acquisition can only be obtained when well-trained and experienced. Cardiac ultrasound has become an indispensable tool, especially in hemodynamically unstable patients. This review summarizes some important aspects of cardiac ultrasound with use of Doppler monitoring for assessment of the three most important pillars of hemodynamics, namely cardiac preload, afterload and contractile function.

Introduction

Cardiac ultrasound has been used in the critically ill since more than thirty years. The technology has made enormous advances with respect to image quality and quantity, various Doppler techniques as well as connectivity, transfer of data and offline calculations. Because this technological progression, the technique has developed as an all-round and versatile tool, offering haemodynamic information at the bedside regarding major cardiac and vascular issues. Furthermore, in the critical care setting, this tool can be utilized as a haemodynamic monitor. Whereas transthoracic echocardiography (TTE) is mostly used in ICU and postoperative patients, transoesophageal echocardiography (TEE) and Doppler is used more often intra-operatively. The latter is even so utilized to answer specific questions and as monitoring tool in ventilated ICU patients.

Not one monitoring tool can offer more information, permitting assessment of ventricular and valvular function, flow and flow velocities and regional wall motion abnormalities, pressure gradients and even information on intra-cardiac pressures (1). The potential of moving cardiac structures gives an undeniable power to this diagnostic and monitoring tool.

The main shortcoming is the discontinuous mode of monitoring.

Variable	Abbreviation	Formula	Normal value - units
Systemic vascular resistance	SVR	MAP-CVP/CO	800-1200 dynes.s.cm^{-5}
Total arterial compliance (49)	C	SV/PP	ml/mmHg
Effective arterial elastance	E_a	P_{es}/SV	1.5 – 2.5 mmHg/ml
Pulmonary vascular resistance	PVR	(PEP/AcT)/ET	40 -250 dynes.s.cm^{-5}
Pulmonary arterial elastance	E_{pa}	RVESP/SV	mmHg/ml

Table 1. Various afterload variables and the respective formulas

It goes without saying that most optimal information acquisition can only be obtained when well-trained and experienced not only on the level of cardiac ultrasound imaging and technology but also in the understanding (patho)-physiology of different disease states. A major difficulty of cardiac ultrasound is obtaining and recognizing the different images and structures to allow confident Doppler/2-D imaging, which permits correct estimation of pressure gradients, flows across valves or regional wall motion abnormalities. All these need a learning curve to attain a level of proficiency.

Left and right ventricular systolic function and cardiac output are determined by contractility, preload, afterload and heart rate. The present report reviews consecutively systolic function and contractility, preload and afterload as pivotal haemodynamic variables from cardiac ultrasound in the critically ill and how these variables can be accomplished straightforward with the help of echo-Doppler techniques.

Ventricular systolic function

Systolic function of both left ventricle (LV) and right ventricle (RV) can be quickly assessed by eye-balling at different levels of the heart using short or long axis views. Systolic failure is the first issue to be assessed in shock patients and whenever hypotension occurs and persists notwithstanding a rapid filling manoeuvre such as passive leg raising or Trendelenburg position (2). Managing unexplained hypotension is always a great challenge. In this respect, echo-Doppler is a great help: the short axis of the LV is an interesting view to obtain an idea of global ventricular function, preload, regional wall motion abnormalities, left ventricular hypertrophy or pericardial fluid. Furthermore, a first impression of RV function can also be acquired.

Although most frequently used, eye-balling necessitates a lot of experience, which can be attained only throughout lots of training. Different methods are available to assess LV systolic function easily. Most of these methods are load dependent, and therefore preload conditions should be taken into account to interpret LV systolic function correctly. The echo analogue of ejection fraction (EF) is the *fractional area contraction* (FAC), which can be estimated when end-diastolic and end-systolic area, assessed at the endocardial border at a short axis level, are taken into the following formula:

$$FAC = (LVEDA - LVESA) / LVEDA$$

Increase of preload (LVEDA) will augment fractional area contraction. A LVEDAI (LVEDA indexed for body surface area) < 5.5% cm^2/m^2 suggests low preloading conditions (3). In the presence of regional wall motion abnormalities, the value of LVEDA to circumscribe preloading conditions decreases. Therefore, increased susceptibility on regional wall motion abnormalities in the apical regions against the basis of the heart is important in this respect (4).
Stroke volume (SV) is another measure to assess indirectly systolic function of the LV. It can be calculated from the following formula:

$$SV = TVI \times AVA$$

TVI, time-velocity integral, resembles the area under the Doppler curve as a distance one erythrocyte is projected forward with one heart beat if the sample volume is set at the aortic valve cusps;

AVA, effective time-averaged aortic valve opening area (cm^2). Whereas blood pressure remains remarkably constant during the early phases of hypovolemic shock, stroke volume declines are the earliest warning of compromised circulation. TVI monitoring is a handsome monitoring tool in this respect. From SV, cardiac output could be calculated. A good correlation was found between Doppler-based estimations and non-invasive uncalibrated pulse-contour assessment of cardiac output (5).

$$CO = SV \times HR = HR\ (bpm) \times AVA\ (cm^2) \times TVI\ (cm)$$

Doppler-based SV methodology can also be utilized when aortic valve stenosis is present. The continuous wave Doppler across the aortic valve will demonstrate a double envelope image as depicted in figure 1.

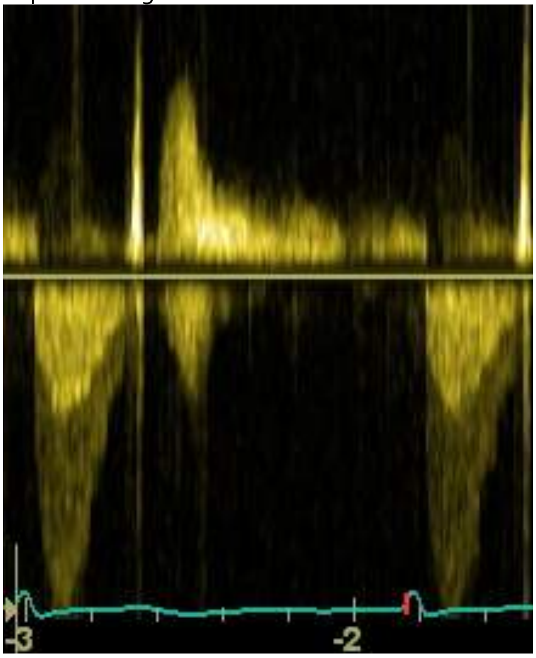

Figure 1. Double envelope of aortic flow (5 chamber view)

The dense Doppler signal demonstrates the stroke volume of the left ventricle whereas the external contour of the peak Doppler signal depicts the pressure gradient, calculated from the modified Bernoulli equation:

$$\Delta p = 4 \times v^2$$

Global LV systolic function can also be circumscribed by a physiologic variable, derived from the regurgitation flow across the mitral valve, assuming no gradient across the mitral valve. DP/dt max is assessed during catheterization and provides a flow-derived, load-dependent descriptor of global systolic LV function. The continuous wave (CW) Doppler signal of a flow wave depicting the regurgitation flow into the left atrium could be analyzed as a pressure change in time (dP/dt mean), utilizing the modified Bernoulli equation (6). Figure 2 shows how to assess dP/dt mean from the ascending limb of the mitral regurgitation CW Doppler flow signal. An alternative option is the presence of a significant aortic regurgitation CW Doppler flow signal, which allows assessment of dP/dt mean from the descending limb of the continuous wave Doppler signal.

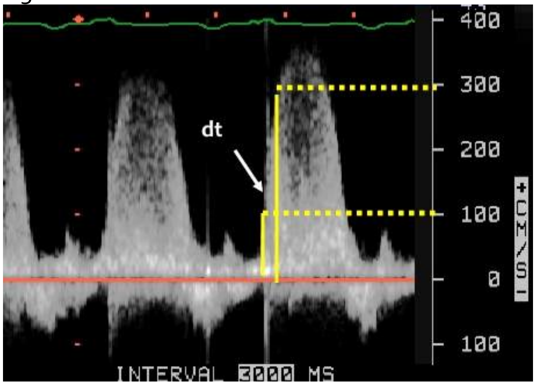

Figure 2. Calculation of dP/dt mean by echo-Doppler. At two different Doppler velocities, the marker is set, from which the time difference (dt) could be estimated. The modified Bernoulli equation is utilized calculating the dP. In this example, we choose 3 and 1 m/s, respectively: $3^2 - 1^2$/dt.

The advantage of this variable is that it could be assessed across the mitral valve, even with small high-velocity jets. It has to be remembered this variable is preload dependent and relatively afterload independent (7). A normal value lies between 800 and 1200 mmHg/s. Often the Doppler technique will underestimate the true value of dP/dt mean.

The myocardial performance index has been introduced by Tei et al., providing an index circumscribing both systolic and diastolic performance of the left or right ventricle (8, 9).

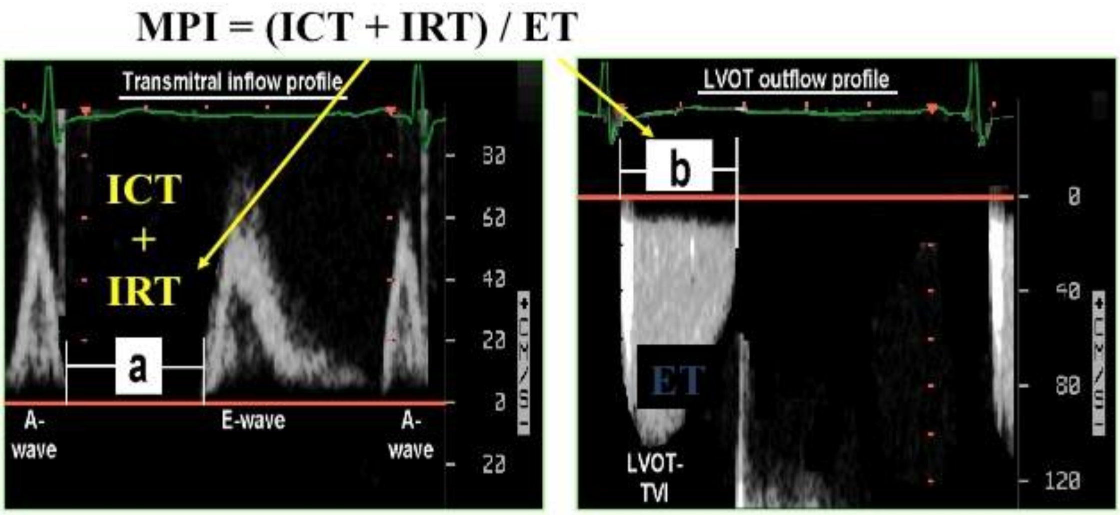

Figure 3. Calculation of myocardial performance index (MPI). MPI is calculated utilizing the formula a-b/b, with *a* being the difference in time between the end of the atrial contraction wave and the start of the early diastolic inflow; *b* being the ejection time (estimated from the flow wave across the aortic valve). MPI close to 1 shows a severely decreased function.

The index is calculated from time intervals as shown in the following formula:

$$MPI = (a - b) / b = (ICT + IRT)/ET$$

with a, time interval between end of atrial contraction wave and start of the early diastolic filling wave; b, ejection time (cfr. ET); ET, ejection time (measured in Doppler mode of the flow across the aortic valve); ICT, isovolumetric contraction time; MPI, myocardial performance index. Figure 3 depicts the practical aspects of the calculation of this index.

The index is preload dependent, as demonstrated by several authors (10-12) and in fact there is a close relationship with dP/dt max (13). MPI is independent of ventricular geometry and therefore has been utilized grading ventricular function in congenital heart disease (14-17), in particular in univentricular surgery (14, 16, 18), ischaemic heart disease (19) and dilated cardiomyopathy (20).

Tissue Doppler imaging provides another variable, which appears extremely useful in clinical practice to assess global ventricular function, both at the left and right side (21, 22). Tissue Doppler utilizes high filter low-velocity signals to depict velocities within the myocardial wall. If the sample volume is set at the mitral annular ring at the lateral or median border, tissue Doppler shows the velocities during systole and diastole (Figure 4). The systolic velocity of the myocardial tissue is a measure of systolic function. A normal value for the LV is > 12 cm/s, whereas decreased LV systolic function offers values < 8 cm/s. Again, this measure is load dependent, as demonstrated by our group (23) and others (24). With decreasing systolic LV function, load dependency is lower. This variable can be utilized as a continuous monitoring tool intra-operatively with transesophageal echocardiography (25) or in the ICU.

More complicated function assessment is also available when integrating cardiac ultrasound technology and arterial pressure tracing. Examples can be found relating time-based altering LV areas, a surrogate of ventricular volumes, with their relative arterial pressure time point to determine Emax, as an offline measure of ventricular contractility (per definition load independent) (26, 27).

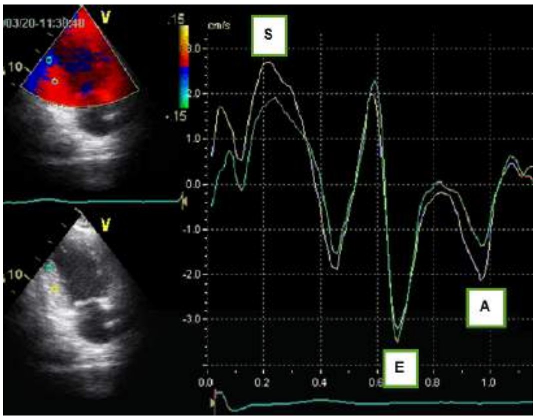

Figure 4. Tissue Doppler image at the level of the mitral annulus. A, atrial contraction induced velocity wave of the mitral annulus; E, velocity wave following early filling; S, systolic velocity wave, following contraction of the left ventricle.

Furthermore, preload-adjusted maximal power is a single-beat index of ventricular contractility, relating arterial pressure and peak transaortic flow velocity (28), which can be clinically replaced by preload-adjusted peak power (29). The pumping heart is seen as an energy source generating hydraulic energy, exerting a certain amount of ventricular work (power). Both approaches have been abandoned because of the complexity to assess contractility (30). In addition, preload-adjusted maximal power has some important physiologic shortcomings, related to the correction factor and correct preload estimation, both at the level of the left (30) and right ventricle (31). Both methods, however, clearly demonstrate the potential within cardiac ultrasound in conjunction with an arterial pressure trace analysis.

Preload and filling pressures

Filling status of the patient is a static variable, which does not per se imply filling necessity. Each two-dimensional or three-dimensional measure of the LV, such as left ventricle end-diastolic diameter (LVEDD), LVEDA or left ventricle end-diastolic volume (LVEDV), serves as a static variable of preload. Fluid responsiveness is the predictability of a beneficial consequence of filling, without an association with filling necessity.

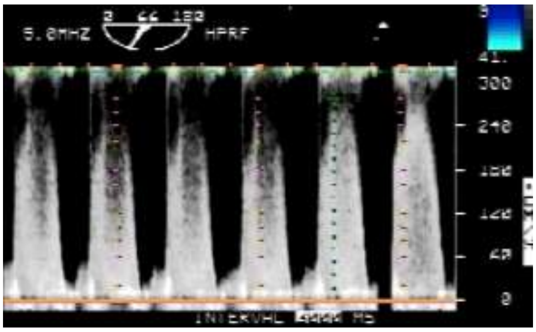

Figure 5. Tricuspid flow velocity. Right ventricular end-diastolic pressure can be estimated from tricuspid flow velocity, applying the modified Bernoulli equation ($p = 4 \times v^2$).

Introduction of a (reversible) fluid challenge allows testing a static variable in a dynamic manner.

Whereas echo-Doppler is mostly directed towards flow assessment, this technology is able to estimate pressures. Echo-Doppler often indirectly offers information of right atrial pressures and the pulmonary circulation using right atrial or/and ventricular (RV) dilatation and presence of tricuspid or/and pulmonary valve regurgitation. RV dilatation is defined as RV diameter >0.6 of the LV diameter and significant RV dilatation as RV diameter > LV diameter. Though RV dilatation is sometimes related with severe RV dysfunction after acute myocardial infarction, most often RV dilatation is related with increased RV afterload. Right ventricular end-systolic pressure (RVESP) is a good ultrasound measure of the pulmonary artery systolic pressure (Figure 5). Quantification of pulmonary valve regurgitation is often more difficult and could be most easily be assessed in a deep transgastric view (120°).

Since many years, dynamic variables have been introduced and discussed during mechanical ventilation with altering intra-thoracic pressures, such as pulse pressure (PPV) or stroke volume variation (SVV). The echo-Doppler analogue is TVI variation, as a measure of SVV, with the sample volume across the aortic valve. In a rabbit model of hypovolemic shock with controlled bleeding during mechanical ventilation, Slama et al. demonstrated a decreasing TVI. Intra-thoracic pressure variations induced increased TVI variations, which coincided with augmented systolic pressure variations (SPV) (32). Also, the 2-D and 3-D measures of static preload could be assessed in a dynamic way: after basic estimation, a passive leg raising manoeuvre can be performed examining the evolution of the particular variable with a filling volume of ±300 ml. An overview of different approaches at the bedside to assess preload responsiveness in an elegant approach with echo-Doppler was published recently (34). Mean right atrial pressure is the consequence of venous return, right ventricular systolic function and pulmonary artery pressure (PAP). It is seldom estimated with echo-Doppler (35). In particular, right atrial dilation is a measure of overload as well as a permanent shift of the inter-atrial septum towards the left atrium.

In contrast, pulmonary artery pressure is often assessed. Pulmonary artery systolic pressure can be derived from RVESP, which is estimated from the regurgitation flow across the tricuspid valve (Figure 5). Since three decades, a clear relationship has been demonstrated between these two pressures (36). If significant pulmonary valve regurgitation is present, right ventricular volume will increase and result in severe tricuspid insufficiency, from which pulmonary artery systolic pressure could be estimated. If pulmonary stenosis is present (very rare in our regions), RVESP will underestimate true pulmonary hypertension. Pulmonary capillary wedge pressure (PCWP) can be estimated from the ratio of the transmitral early filling wave velocity (E) versus the tissue Doppler analogue (e’) (37-39). There is no direct correlation between E/e’ and PCWP, but can be derived from the following formula (40):

$$PCWP\ (mmHg) = 1.24 \times (E/e') + 1.9\ mmHg$$

Important to remark that E/e’ is easily and rapidly obtained at the bedside with transthoracic echo-Doppler, without any invasiveness. This variable has been shown to be a very practical monitoring tool in various situations: predicting successful weaning off the ventilator (41), filling status in hypertrophic cardiomyopathy (42), and predictability and stratification of survival in sepsis and septic shock (43, 44).

Afterload

The determinants of arterial afterload are arterial compliance and systemic vascular resistance; both are derived from arterial pressure and flow. They reflect the primary and steady pulsatile component of arterial load, respectively. Both in cardiac failure and septic shock, large and small artery elastic dysfunction occur and, as they are both contributing to an increased cardiovascular risk, monitoring is warranted. More than 60% of total arterial compliance resides in the ascending and thoracic aorta, focusing monitoring of this variable to these parts of the aorta (45). Traditional haemodynamic monitoring offers only limited access to afterload indices. Echo-Doppler, in conjunction with arterial tracing characteristics, could result in a more appropriate approach of afterload.

End-systolic meridional wall stress $\sigma_{m(es)}$ is calculated from the following formula:

$$\sigma_{m(es)} = 1{,}33 \times RRs \times (A_m/A_c)\ (dyne\ .\ cm^{-5})$$

in which A_c, left ventricular short axis end-systolic area within the endocardial borders; A_m, left ventricular short axis end-systolic area of the myocardial wall; RRs, systolic blood pressure. It exemplifies the end-systolic wall stress and increases with hypertrophy of the myocardial wall and with systolic blood pressure (46). Table 2 offers more insight in the contrasting differences of information obtained from the systemic vascular resistance versus end-systolic meridional wall stress.

Another measure which could be used in clinical practice to circumscribe ventricular afterload can be derived from the end-systolic pressure-area product:

$$SVR \approx RRs \times LVESA$$

with LVESA, left ventricular end-systolic area and RRs, systolic blood pressure.

HD variable	Normal LV	Dilated LV
Wall thickness (cm)	1	0.5
Area diameter (cm)	2	4
RRs (mmHg)	100	100
MAP (mmHg)	75	75
CO (l/min)	5	5
SVR ($mmHg.s.cm^{-5}$)	1200	1200
$\sigma_{m(es)}$ ($dynes.cm^{-2}$)	45	270

Table 2. Comparison of information provided by systemic vascular resistance and end-systolic meridional wall stress in a normal left ventricle versus a dilated left ventricle

It is obvious that afterload estimation by means of echo-Doppler techniques is not at all easy and simple, as many factors have to be taken into account: not only 2-D image and Doppler signal quality, but in particular the alignment of area changes and pressure change, suggesting the most complex assessments and calculations cannot be conveyed properly. Two-D imaging is in particular hampered at the level of the ascending aorta, especially in postoperative cardiac surgical patients (45). Therefore, the most useful afterload descriptors in clinical practice can be reduced to SVR as a measure of steady components of arterial load, and E_a, being a measure of main pulsatile components of arterial load (45, 47). Both incorporate flow components (cardiac output and stroke volume, respectively) and arterial pressure.

At the right side, pulsed wave Doppler of the pulmonary artery permits the calculation of the pulmonary vascular resistance (PVR) in a simple formula:

$$PVR = (PEP/AcT)/ET$$

with AcT, acceleration time, the time from baseline to peak pulmonary artery pulsed wave Doppler velocity; ET, ejection time, measured during the complete systole of the pulmonary artery pulsed wave Doppler signal; PEP, pre-ejection period, time interval from QRS on the ECG till start of ejection on the pulmonary artery pulsed wave Doppler signal.

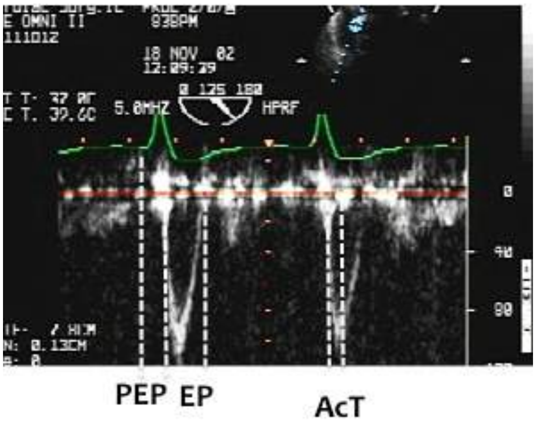

Figure 6. Pulmonary artery flow velocity.
AcT, acceleration time (time from start of ejection till peak velocity is reached); EP, ejection period, from start of ejection across the pulmonary valve until end of ejection; PEP, pre-ejection period, from start of QRS (ECG) until start of ejection phase

Figure 6 depicts the different time intervals used in this formula. Finally, pulmonary arterial elastance (E_{pa}) could be estimated from:

$$E_{pa} = RVESP/SV = RVESP/(TVI_{ao} \times AVA)$$

with AVA, mean aortic valve area; RVESP, right ventricular end-systolic pressure; SV, stroke volume; TVI_{ao}, time velocity integral of aortic flow (48).

Conclusions

Echo-Doppler provides important bedside monitoring facilities. Traditional invasive haemodynamic pressure monitoring offers haemodynamic information in an only incomplete manner, without any knowledge of ventricular performance, pressure gradients or any valve regurgitation. This review summarizes some important aspects of echo-Doppler monitoring in view of monitoring the three most important pillars of haemodynamics.

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Notes

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SESAME Protocol: 85 – 98

CHAPTER 7

Critical care ultrasound in cardiac arrest: Technological requirements for performing the SESAME-protocol, a holistic approach

Daniel Lichtenstein, Manu L.N.G. Malbrain

The use of ultrasound has gained its place in critical care as part of our day-to-day monitoring tools. A better understanding of ultrasound techniques and recent publications including protocols for the lungs, the abdomen and the vessels has introduced ultrasound at the bedside of our ICU patients. However we will prove in this paper that early machines dating back more than 25 years were perfectly able to do the job as compared to modern laptop machines with more features but little additional advantages. Ultrasound is not only a diagnostic tool, but should also be seen as an extension to traditional physical examination. This paper will focus on the use of the SESAME protocol in cardiac arrest. The SESAME-protocol suggests starting with a lung scan to rule out possible causes leading to cardiac arrest. First, pneumothorax needs to be ruled out. Second, partial diagnosis of pulmonary embolism is done following the BLUE-protocol. Third, fluid therapy can be guided, following the FALLS-protocol. The SESAME-protocol continues by scanning the lower femoral veins to check for signs of deep venous thrombosis, followed by (or before in case of trauma) the abdomen to detect massive bleeding. Next comes the pericardium, to exclude pericardial tamponade. Finally, transthoracic cardiac ultrasound is performed to check for other (cardiac) causes leading to cardiac arrest. The emphasis is on a holistic approach, where ultrasound can be seen as the modern stethoscope needed by clinicians to complete the full physiological examination of their critically ill unstable patients.

Introduction

Traditionally, ultrasound was not a translational discipline. **Introduction**

The use of ultrasound has gained its place in critical care as part of our day-to-day monitoring tools (1). A better understanding of ultrasound techniques and recent publications including protocols for the lungs, the abdomen and the vessels has introduced ultrasound at the bedside of our intensive care unit (ICU) patients (2-7). Ultrasound is not only a diagnostic tool, but should also be seen as an extension to traditional physical examination (8).

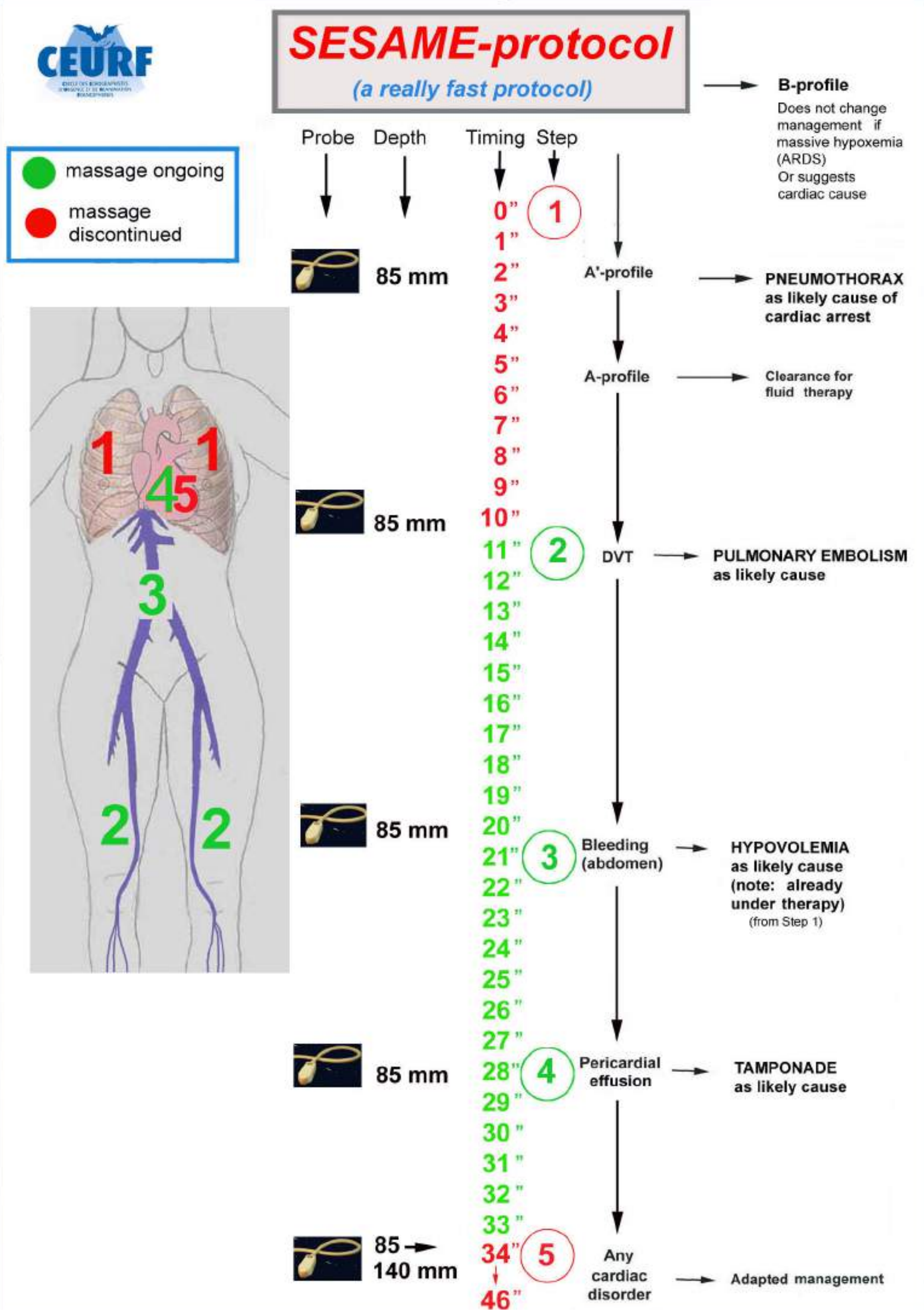


Figure 1. The SESAME-protocol
This apparently complex figure just shows, from left to right, simple features. On the far left, the five areas of investigation are shown. Next the type of probe used is listed, i.e., only one probe. Then the depth used, i.e., a standard distance (85 mm) in most steps. Then the timing, for ruling out, sequentially, tension pneumothorax, lower femoral DVT, free abdominal fluids (or massive GI tract fluid), followed by pericardial tamponade. When the heart comes to analysis, most reversible cases have been assessed. Adapted with permission from Lichtenstein D (15).

This paper will deal with the most "critical" application of critical care ultrasound, namely patients in cardiac arrest. The task of any ICU or emergency physician is to recognize reversible causes *as fast as possible*, since time equals life. To achieve this goal, physical examination is too limited and the final diagnosis is often made only at autopsy. There is no time at all for any traditional test (X-rays, CT scan, laboratory evaluation…) but ultrasound is readily available (9). To expedite the diagnosis of reversible causes of cardiac arrest, (shockable rhythms excluded), is the full domain of critical care ultrasound (2, 10).

Who will find most interest in this article? First, colleagues in performant ICUs, who will appreciate to have two ultrasound machines available: one comprehensive echocardiographic-Doppler equipment, with transesophageal echocardiography (TEE) and all facilities for hemodynamic assessment, and one very simple, elementary machine for the rest (the "rest" includes the BLUE-protocol, the FALLS-protocol, and the present SESAME-protocol, among others). Second, colleagues who don't possess an ultrasound machine at all (like most doctors in the world) but still believe that costly laptop machines are mandatory: they will see that these may not be fast nor small enough. Third, educated colleagues who know the power of holistic ultrasound, i.e., a half technical, half philosophical approach, focusing on the lung first in order to obtain useful information that can normally only be acquired by expert echocardiography.

The emphasis is on a holistic approach, where ultrasound can be seen as the modern stethoscope needed by clinicians to complete the full physiological examination of their critically ill unstable patients.

The role of ultrasound in cardiac arrest

The SESAME-protocol is an abbreviation of the mnemotechnic SESAMOOSSIC, that stands for "Sequential Echographic Scanning Assessing Mechanism Or Origin of Severe Shock of Indistinct Cause". This indicates that the clinician following this protocol takes into account both mechanism and cause, according to what comes first in the sequential SESAME screening. As an example, the presence of A-profile on lung ultrasound or a hypercontractile heart suggests a mechanism for hypovolemia, whereas free abdominal fluid may suggest abdominal bleeding as the cause for hypovolemic cardiac arrest. The SESAME-protocol was initially designed for patients with extremely severe shock or imminent cardiac arrest, but was rapidly extended to the situation of established cardiac arrest.

In order to make this article easy to read, we will explain the philosophy of the SESAME-protocol, step-by-step. The reader should imagine the critical situation of cardiac arrest in slow motion, because things happen too fast in real time when a cardiac arrest occurs. For simplicity, we will focus on intra-hospital use (in the ER the OR, the ICU or the ward), when the intensivist deals with a cardiac arrest situation at the bedside (Figure 1).

We understand the interest of the younger generation of doctors for the "fancy" laptop machines with three probes, therefore we advice them to take the best out of this article for their personal practice. It should also be understood that in situations where the mechanisms and causes leading to the cardiac arrest, e.g. pneumothorax, are clinically obvious the use of the SESAME-protocol is not mandatory and one should proceed directly to appropriate treatment to reverse cardiac arrest (e.g. insertion of a chest tube).

Ideal ultrasound equipment specifications

In order to perform the SESAME-protocol in a timely manner, the operator should benefit from a suitable ultrasound device (2).

Size. The machine should arrive rapidly on-site. Laptop machines are fascinating but are usually too large (personal measurements showed up to 68-cm width) to run through the hospital corridors with multiple lateral obstacles, therefore we decided to continue to use our 1992 machine, whose last update, in 2008, was only cosmetic: with its 32-cm width (cart included), we will arrive more rapidly on site (Figure 2).

Figure 2. Two concepts**.** To the left, our 1992 (updated 2008) unit. To the right, a standard laptop machine. Note, among several points, that both machines have wheels, i.e., portability. Note that laptop machines are never separated from their cart in the real-life hospital setting. Note mainly that the 1992 machine is slimmer than the laptop, among other advantages (including immediate start up time). Please bear in mind that in a hospital, space is usually lacking in the lateral dimension, not in the vertical one (while ceilings are high enough).

The **cart** is an important factor, as a machine without cart will be heavy to carry whilst running towards the patient with cardiac arrest. Thanks to the cart, the machine is at working height, an important ergonomic detail. The role of pocket machines connected to a smartphone has yet to be established in this setting, as will be discussed further.

The machine should **switch on** immediately. We work since 1992 with a 7-seconds start-up time, i.e., time for taking the probe and the conducting gel: *not one second is lost.*

The **probe** should be suitable for lung ultrasound, but also for the next steps of the SESAME-protocol without having to change probes in between the different steps (Figure 1). Changing the probe needs to be avoided for several reasons. Any "choice" will cost precious time (The vascular probe for the lung? The cardiac for the heart? The abdominal for an abdominal bleeding?). If many probes are connected, cables will be disordered, another possible loss of time. A unique microconvex probe which covers a 0.6-17 cm area will do the job in most cases.

The **image quality** should be suitable. Nowadays, many digital machines do not have the optimal quality (as can usually be found on older analogic systems). Others have a correct vision of plain organs, but at the expense of inferior views on the lung. All filters are more or less destructive for an optimal SESAME-protocol: the averaging, dynamic noise, or smoothening filters will all destroy the subtle dynamic changes of lung sliding. Harmonics, and compound filters will destroy the lung artifacts. Filters that create a lag-phase between acquisition and reconstruction of the images will create confusion. Critical care ultrasound works best in realtime and with natural "unfiltered" views.

The **setting** is an important detail, but it is very simple, as there is no specific "Lung" setting, the setting is the same for lungs, veins, abdomen and heart, and we refer to this as the "SESAME" or "critical care" or the "no filter" setting. Ideally the ultrasound machine should be used with absent filter and 85-mm depth by default, a depth which allows in adults to visualize the pleural line, a part of the Merlin's space, the veins, the important parts of the abdominal cavity, and the pericardium.

The **keyboard** should be really simple. In cardiac arrest, at least during the 4 first steps as will be discussed further, *no button is touched.* In daily practice apart from cardiac arrest, we don't use more than 3 buttons: First, overall gain (normally not to be changed); second, depth (as discussed previously); and finally, the B/M mode (time-consuming and thus not indicated in a cardiac arrest situation). Each additional button increases the risk for confusion.

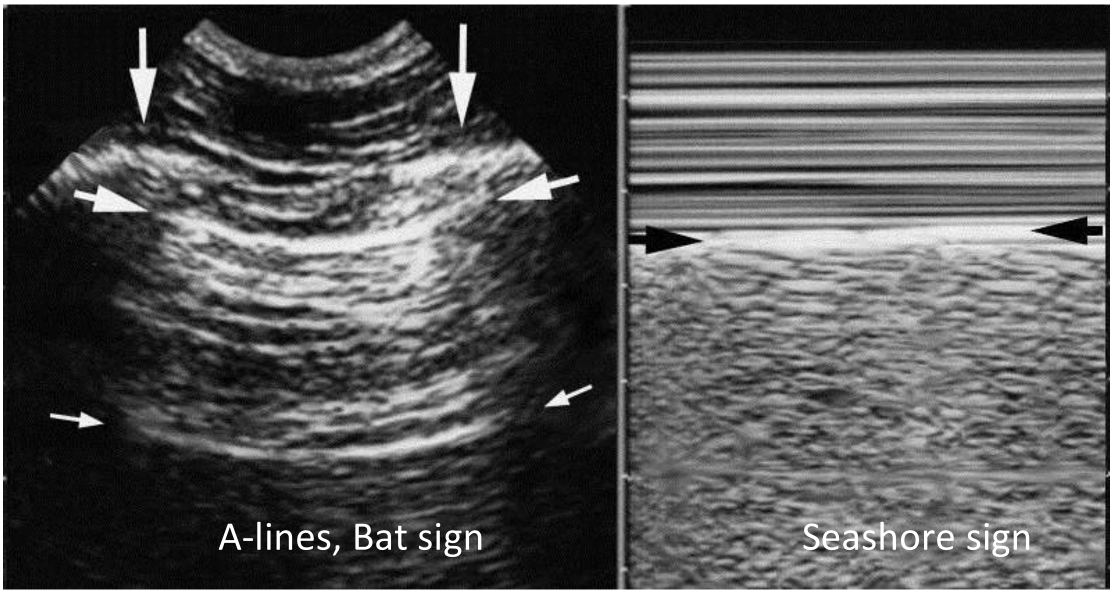


Figure 3. Ultrasound Scan of the anterior intercostal space: bat sign and seashore sign. Panel A. The ribs (vertical arrows) with shadows are visualized. The pleural line (upper, horizontal arrows), is a horizontal hyperechogenic line, half a centimeter below the rib line in adults. The association of ribs and pleural line make a solid landmark called the bat sign. The pleural line indicates the parietal pleura. The horizontal repetition artifact of the pleural line is called the A-line (lower, small horizontal arrows). The A-line indicates that air is the main component visible below the pleural line. Panel B. M-mode reveals the seashore sign, which indicates that the lung moves at the level of the chest wall. The seashore sign therefore indicates that the pleural line also is the visceral pleura. Above the pleural line, the motionless chest wall displays a stratified pattern. Below the pleural line, the dynamics of lung sliding show a sandy pattern. Note that both images are strictly aligned, of importance in critical settings. Both images, i.e., lung sliding plus A-lines define the A-profile (when found at the anterior chest wall). Adapted from "Lung ultrasound in the critically ill" with permission (3).

A cost-effective machine has one major advantage, namely its availability. Nowadays, it is common practice to see many ultrasound machines in the hospital, but in the early years when ultrasound was introduced into the ICU, machines were lacking mainly because of cost-related issues. However if doctors had used holistic ultrasound as soon as it was technically accessible, i.e. 1982, they would have found cost-effective machines at a time where cardiac machines were really expensive and therefore unavailable.

We will now explain the philosophy of the SESAME-protocol in 5 simple steps that can be used when you are confronted with a cardiac arrest patient.

Step 1. Ruling out pneumothorax

Lung ultrasound

The SESAME-protocol is a sequential protocol which first scans the lung, mainly for ruling out pneumothorax (4, 11-13). This is probably not the most frequent cause, but missing it would be unforgivable. Why the lung first? Well first, because lung ultrasound exists and it is able to identify specific pathology at the bedside, in spite of what others still believe (14). Second, because the accurate window is obtained in less than two seconds (the bat sign, immediately indicating the lung surface or the seashore sign) (Figure 3). Third, because pneumothorax with cardiac arrest is usually large so that it can be detected regardless of where the probe is applied on the anterior thorax (Figure 4). Fourth, because only less than two seconds are neeeded for detecting the characteristics of lung sliding and/or B-lines (4).

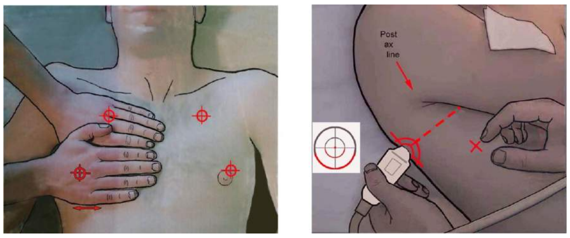


Figure 4. Areas of investigation showing the standardized examination BLUE-points. Panel A. The left figure shows the four anterior BLUE-points, drawn from the projection of the hands, and labelled upper BLUE-point and lower BLUE-point. Two hands placed this way (size equivalent to the patient's hands, upper hand touching the clavicle, thumbs excluded) correspond to the location of the lung. The upper-BLUE-point is at the middle of the upper hand. The lower-BLUE-point is at the middle of the lower palm. They are suitable for diagnoses of pneumothorax, pulmonary edema, pulmonary embolism and hypovolemia.Panel B. The PLAPS-point is defined by the intersection of: a horizontal line at the level of the lower BLUE-point; a vertical line at the posterior axillary line. Small probes allow positioning posterior to this line as far as possible in supine patients, providing more sensitive detection of posterolateral alveolar or pleural syndromes (PLAPS). The diaphragm is usually at the lower end of the lower hand. The PLAPS-point (posterior approach following the lower BLUE-point) is not routine in the SESAME-protocol. Adapted from "Lung ultrasound in the critically ill" with permission (3).

Fifth, because the diagnosis is particularly easy as the patient is in quiet breathing via manual bag ventilation, i.e., enough dynamics and and no interference due to dyspnea, i.e., the best conditions. Finally, because the detection of the A-profile (as illustrated in
ure 5) with the BLUE-protocol will be an argument for fluid therapy, if you subsequently follow the logic of the FALLS-protocol (4, 5).

Technical considerations

The patient has been intubated. The probe is applied at the anterior chest wall, roughly at the lower BLUE-point, while the hands of the physician performing CPR are properly positioned. As fast and as far as possible, the lungs are scanned, after which the cardiac compressions are continued. If CPR is started before ultrasound, a rib fracture can occur, preventing to differentiate whether the pneumothorax was cause or consequence of cardiac arrest. If compressions are done before ultrasound, they must be briefly interrupted for the lung scanning, which is far from perfect with regard to hemodynamic stabilisation and coronary perfusion pressure.

The A'-profile of the BLUE-protocol strongly suggests pneumothorax (Figure 6). Specialists can search for the pathognomonic lung point sign, however this may be time consuming with little additional therapeutic implications and thus should be avoided in the setting of cardiac arrest (Figure 7). The CEURF has made suggestions to solve this issue (15). The "Australian variant" (an idea that came to mind whilst travelling in Sydney) indicates that the A'-profile on ultrasound in combination with the slightest clinical signs suggestive for pneumothorax makes the diagnosis almost certain (15). In a cardiac arrest patient, the A'-profile in combination with specific findings upon auscultation of the thorax (e.g. slightest homolateral tympanism or decrease in breathing sounds) confirms the diagnosis. Using these tools before ultrasound would be more risky, because they are not easy to interpret when used in isolation, and valuable time may be lost in case there is no pneumothorax. When the Australian variant is positive, there is ample time for finding a large bore needle (on-site in the crash-cart), to perform a life saving procedure. In summary if after step 1 pneumothorax is excluded then you can move to step 2 of the SESAME-protocol.

Step 2. Searching for pulmonary embolism

A venous approach

Pulmonary embolism as a cause of cardiac arrest is more frequent than tension pneumothorax. The use of echocardiography as an initial step raises some concerns. First, the user must master the technique – and this expertise may take years. Second, a good cardiac window must be available, and sometimes this is technically impossible. If time is lost whilst trying to find a good ultrasound window, the cardiac compressions are delayed.

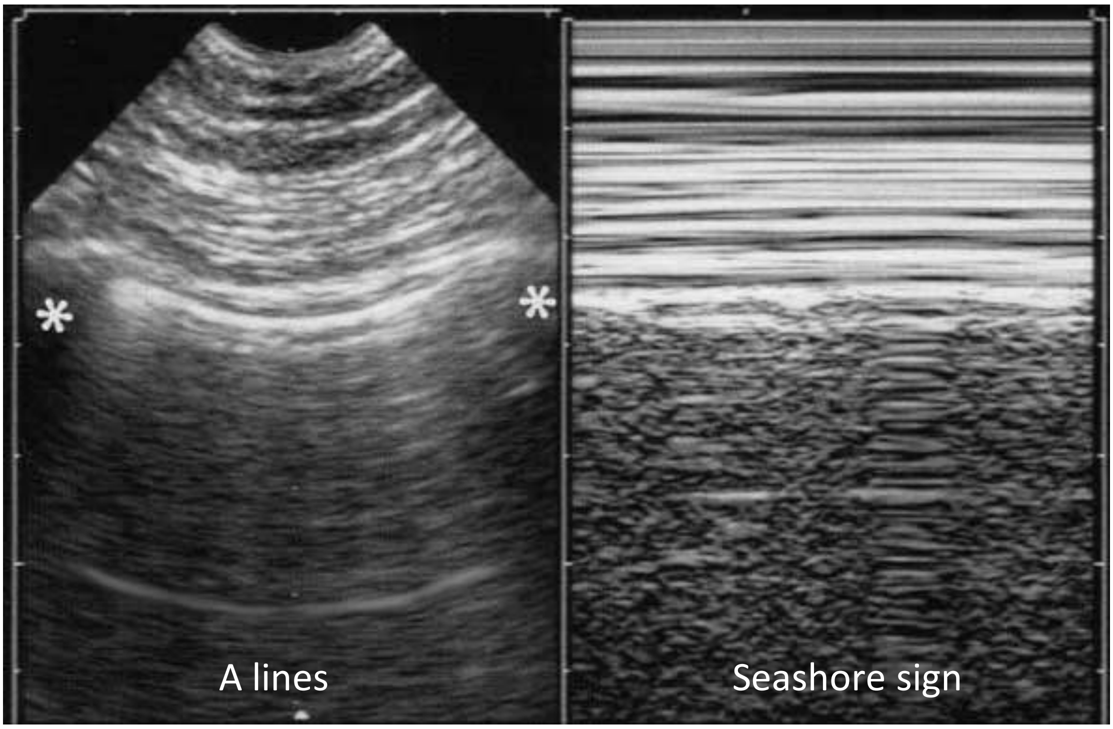


Figure 5. The A-profile. In this quietly ventilated patient with a cardiac arrest, the A-profile is displayed, i.e., lung sliding with predominant A-lines in each of the four anterior BLUE-points. This indicates first, correct tracheal intubation (not esophageal, not one-lung intubation); second, absence of pneumothorax; and third, clearance for a fluid therapy. Clearly visible on M-mode is the total absence of dyspnea: the Keye's space is regularly stratified, showing complete absence of motion of the respiratory muscles. The Keye's space is the name given to this rectangular upper area, located exactly above the pleural line - the exact location of the pleural line is standardized without any confusion using the bat sign from the left, real-time image (between the two stars). Adapted from "Lung ultrasound in the critically ill. The BLUE-protocol" with permission (21).

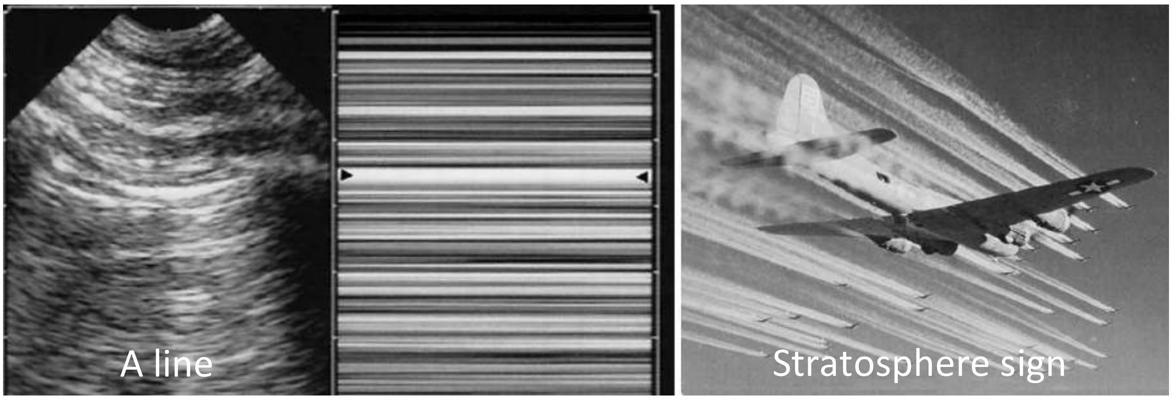


Figure 6. A'-profile. The prime of the A'-profile is like a break, indicating the abolition of lung sliding, clearly visible on this M-mode view showing the stratosphere sign: not the slightest difference is observed between the Keye's space and the space below. Of importance, there are exclusive A-lines in the A'-profile on B-mode. No B-lines can be observed in case of massive pneumothorax. Note again the absence of dyspnea in the Keye's space. Adapted from "Lung ultrasound in the critically ill. The BLUE-protocol" with permission (21).

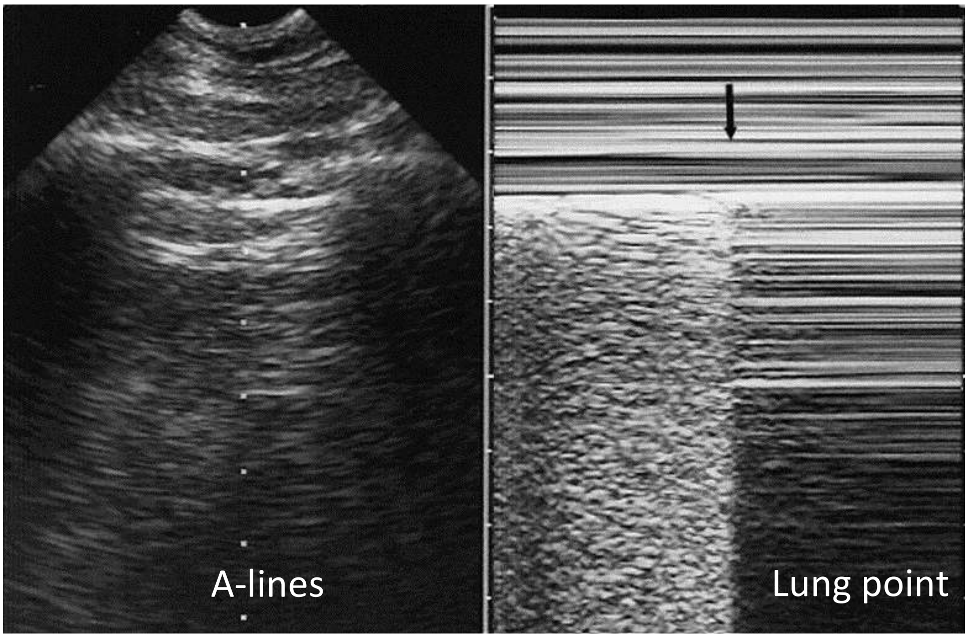


Figure 7. Pneumothorax at the lung point.

Panel A. Real-time mode allows detection of the inspiratory increase in volume of the collapsed lung. When reaching the chest wall where the probe is positioned, it makes a sudden change in the ultrasound image, from an A'-profile to an A- or B-profile usually. The change is sudden because ultrasound is a highly sensitive method, able to detect subtle changes, such as the difference between free gas and alveolar gas.

Panel B. M-mode. The left-hand side of the image shows lung patterns (lung sliding) before the visceral pleura disappears. The arrow shows the exact moment the visceral pleura is no longer in contact with the pleura line. The right-hand side image shows the A'-profile (lung sliding abolished with A-lines). This sign has been called lung point, a specific sign of pneumothorax. Adapted from "Lung ultrasound in the critically ill" with permission (3).

To circumvene these issues, some would use transesophageal echocardiography (TEE). This could be an option if TEE is immediately available, and without the drawbacks as stated above (start-on time, size of machine, skill, costs…). The SESAME-protocol proposes an approach already validated in the BLUE-protocol, where the combination of lung plus venous analysis provides 99% specificity (adding the echocardiographic data would likely improve this rate). The BLUE-protocol is a fast protocol that can be performed within three minutes, or less, but during cardiac arrest, we count rather in seconds. The SESAME-protocol hence focuses on the lower femoral vein, an area very accessible using the microconvex probe, called the V-point to confirm the diagnosis of deep venous thrombosis (DVT) (Figure 8).

Considerations

Around half of the patients with massive pulmonary embolism also have DVT at this level - which can be identified within a few seconds. Typical signs on B-mode are the presence of a visible clot and the uncompressible character of the vein, in addition to the usual extra but more time-consuming information that can be obtained with Doppler (and as such not to be included in the SESAME-protocol) like the absence of respiratory flow variations and the absence of venous flow increase during compression of the calf muscles. Well-trained users may prefer to assess the calf veins (again using the same probe), which are more sensitive than the V-point (roughly around 66%).

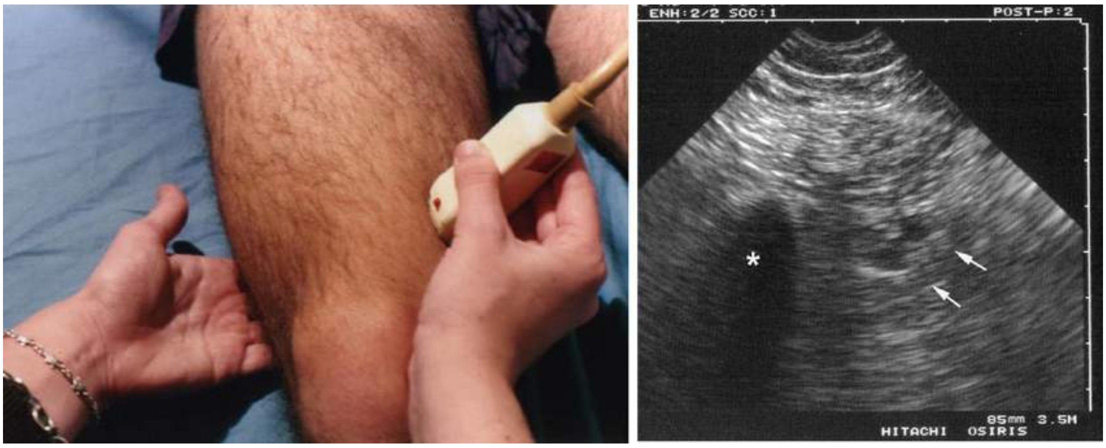


Figure 8. The V-point. Using the microconvex probe allows to analyse the complete venous system and not only the linear areas. Here, the probe assesses the lower (superficial) femoral vein. As indicated, and using the free hand ("Doppler hand"), this assessment is done, without Doppler, in a few seconds. This area is the best compromise for an immediate venous assessment (shown by arrows) in case of cardiac arrest, of interest only when showing a DVT. Adapted from "Lung ultrasound in the critically ill. The BLUE-protocol" with permission (21).

When DVT is excluded at the V-point, pulmonary embolism is less likely, and we will check the heart in a few steps to look for typical right ventricular (RV) dilatation. Meanwhile, we must move on to step 3 to exclude other reversible causes.

Step 3. Diagnosis of hypovolemic cardiac arrest

Abdominal ultrasound

Once the probe has been used to check the femoral veins, it can be moved upwards toward the heart, but when "flying" over the abdomen, it can make a short "landing", to check for fluid collections (free abdominal fluid or blood, ascites,, massive fluids in the GI tract, or even an ultrafast assessment of inferior vena cava collapsibility…). No standardized, traditional protocol (e.g. like the FAST) is required here because we must proceed quickly. The pleural cavities can also be rapidly checked according to the clinical context. In trauma, multiple small areas of blood leakage can create hemorragic shock, even leading to cardiac arrest. If no free fluid or other collections have been seen in the abdomen and before checking the heart we move on to step 4..

Step 4. Ruling out pericardial tamponade

Pericardium ultrasound

Just before the heart, a really holistic use of the SESAME-protocol, is to check the pericardium. The pericardium is completely distinct from the traditional cardiac analysis.

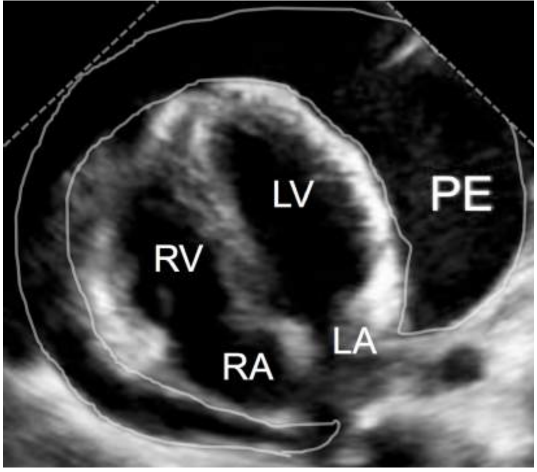


Figure 9. Pericardial effusion**.** Apical 4 chamber view in a patient with massive pericardial effusion (PE), showing the classical "two" hearts sign.
Legend: LA: left atrium, LV: left ventricle, PE: pericardial effusion, RA: right atrium, RV: right ventricle

The SESAME-protocol considers five good reasons for looking at the pericardium separately. First, ultrasound of the pericardium can be teached in one morning: in case of pericardial effusions you see “two hearts” instead of one (Figure 9).

The heart per se is a specialized field, reserved to a respected elite, the cardiologist or the intensivist with great “echo” expertise. Second, the pericardial window is usually present, by essence (the fluid enlarges the mediastinum), as opposed to the cardiac window when an effusion is absent. Third, a substantial pericardial effusion in a cardiac arrest is likely tamponade with obstructive shock. Fourth, unlike the heart, the pericardium is a superficial structure without the need to change the 85-mm depth, the default setting of the SESAME-protocol. Finally, pericardial tamponade is a perfect illustration of holistic ultrasound, because the same microconvex probe which has allowed the diagnosis will be used for detecting the needle to guide the therapeutic intervention. Without losing any time, the needle is inserted under sonographic guidance, and the microconvex probe we use is perfectly suitable for its detection. Some manufacturers claim to provide microconvex probes which are not universal because of their depth or resolution as opposed to the microconvex probe we have described above. With usual cardiac probes, the users are obliged to follow sophisticated and time-consuming protocols (e.g. microbubbles injection). Abdominal or vascular probes will not be helpful. This is a critical advantage of the concept to use a unique probe. This, is what holistic ultrasound is all about. The complete technique can be adapted, with a detailed description as recently published (15). A subcostal approach can be tried first, which is usually contributive because of the abdominal hypotony. If pericardial effusions are excluded it is time to check the heart in the final step of the SESAME-protocol.

Step 5. The heart

Transthoracic echocardiography

During decades, despite the fact that ultrasound existed in suitable, mobile units, it has not been used in cardiac arrest. During the previous decade, ultrasound has been used for looking at the heart (but only the heart). The previous steps showed us how four highly reversible causes can rapidly be detected or excluded (Figure 1). Finally, the focus is now at the heart. Some considerations need to be taken into account. First, the user must master echocardiography. Second, it is impossible to predict whether or not a good cardiac window will be present. Third, performing transthoracic echocardiography (TTE) implies the interruption of the cardiac compressions. Before looking at the heart the settings need to be adapted as the heart is a deep organ, and a few seconds are devoted for changing the depth from 85 to 140 mm. If we are lucky and have a cardiac window, we can see, from simple to subtle, various patterns as explained below.

Patterns on TTE

First, the simplest pattern is asystole, a rather easy diagnosis, with a rather disappointing prognosis. Second, a dilated RV suggests pulmonary embolism (Figure 10). Around half of the cases have already been confirmed after Step 2. If the V-point was free of thrombosis on the contrary, detecting such a pattern is highly relevant.

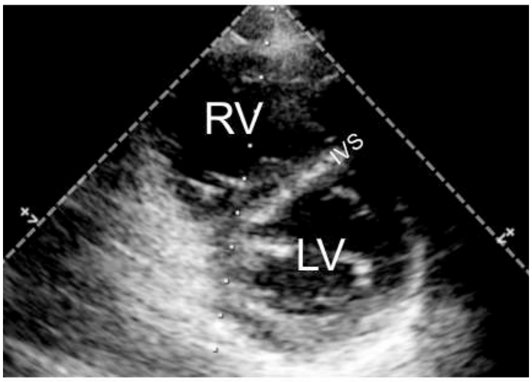


Figure 10. Cardiac ultrasound in cardiac arrest due to pulmonary embolism**.** Panel A: Parasternal short axis view. Dilated right ventricle (RV) with a RV cross section area that becomes larger than the left ventricle (LV) cross section area. The RV cavity becomes more round-shaped with the intraventricular septum (IVS) moving into the LV cavity during part (early diastole) or whole of the cardiac cycle. This causes the typical round-shaped cross section area of the left ventricle to become more "D-shaped".

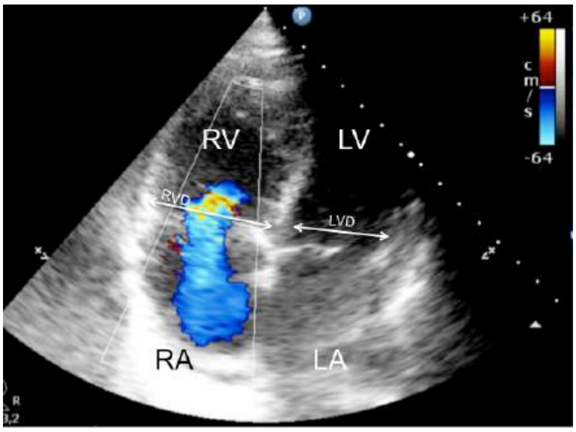
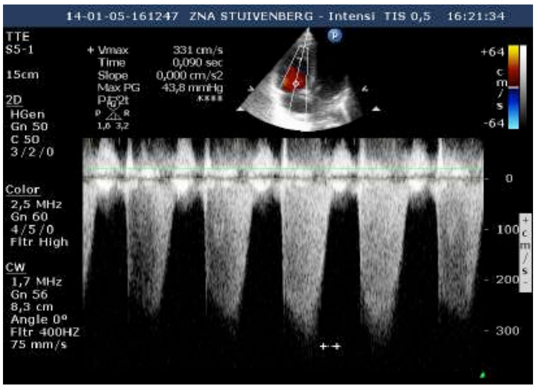


Figure 10. Cardiac ultrasound in cardiac arrest due to pulmonary embolism**.** Panel B: Apical 4 chamber view. Normally, the right ventricle (RV) diameter is smaller than the left ventricle (LV) diameter in the 4 chamber view (normal ratio < 0.6). If the view is frozen in end-diastole, a ratio of RV/LV diameter of > 0.6 to 1.0 suggests mild enlargement of the RV, while a ratio of 1 to 2 suggests severe and > 2 extreme enlargement of the RV. However, sometimes it is difficult to achieve a perfect 4-chamber view and the RV area hence may be underestimated. More practically, if the RV cavity appears to be as large as or larger than the LV cavity on this view, the RV is considered to be significantly enlarged. In addition, the RV loses its usual triangular shape and becomes more oval. In severe RV enlargement, the RV apex may extend beyond the LV apex. In our patient with pulmonary embolism the RV/LV diameter (D) ratio was 1.2, also note the important tricuspid regurgitation (3 to 4 on 4).



Panel C. Example of continuous wave Doppler over tricuspid valve showing severe triscupid regurgitation. The Vmax was 331 cm/sec and the corresponding maximal pulmonary artery pressure was 60 mmHg (44 mmHg + central venous pressure of 16 mmHg). This is more time-consuming and not part of the routine SESAME-protocol.

This case of pseudo-pulseless electric activity can be seen on occasion. The detection of collapsed right cavities makes the diagnosis of tamponade quite certain, in practice. Fourth, a left ventricular hypercontractility because of massive hypovolemia has already partially been ruled out with Step 3 (blood or any fluid in the serous cavities) and even Step 1 (the A-profile is a relative indication for fluid therapy). Finally, several subtle diagnoses can be identified, (in some of them TEE may have a possible role). Ventricular fibrillation is usually an electric diagnosis, but sometimes more easy to detect visually (false-negatives with ECG mimicking asystole). Auriculo-ventricular block of high degree is sometimes obvious, if the window is favorable. Torsade de pointes usually does not lead to a cardiac arrest. However, clinical experience in this field is needed (16-19).

SESAME-protocol and timing

From the moment the ultrasound unit is at the bedside and switched-on, just time to take the probe and the contact product: 7 seconds (Figure 1). For pneumothorax detection: 5 seconds per lung, or thus 10 seconds. For DVT detection at the V-point: 5 seconds per side (can be initiated during cardiac compressions) or thus 10 seconds in total. For massive fluid collections in the abdomen: less than 10-12 seconds (can be initiated during cardiac compressions). For detecting pericardial fluid: less than 8-10 seconds. The cardiac step can therefore already be done after less than 40 seconds of scanning. If no window is seen after 12 seconds, it seems wise to resume the cardiac compressions, and try again later. Some recent concepts suggest that the right ventricle enlarges after several minutes of rescuscitation, but the SESAME-protocol assesses the heart long before. This timing also includes the time for changing between the different regions of interest. The system that will soon be commercialized allows to make each change in roughly one second (from lung to leg etc). Of importance in this setting, is that the viscosity of the transducing gel can be resumed just after a transthoracic cardiac scanning is performed, avoiding unnecessary time loss to remove the wet slippery gel.

Limitations of the SESAME-protocol

Not having the ideal machine and probe is a relative limitation. The user just needs to adapt and prepare the equipment. When the above described difficulties with regard to the equipment (probe, cart, size, start-up time,...) accumulate, which sometimes happens, it is advised not to use ultrasound as a first line and to continue traditional resuscitation first. Ultrasound should help but may never delay classic CPR. Most limitations come from the body habitus of the patient. Some veins are difficult to assess. Bariatric patients have easily accessible areas (lung, paradoxically), and more difficult areas. The cardiac window can be completely missing. Again, in this setting where nothing can be planned or checked in advance, unexpected limitations can occur, and the user must keep constant attention and a "critical" mindset when using the SESAME-protocol.

Finetuning the SESAME-protocol

Above was a practical summary. Now follow some elements allowing to better understand the philosophy of the SESAME-protocol. The ultrasound cart contains also a special 6-cm long and 16-Gauge large catheter. It is used for inserting a venous line in extreme emergency, maybe more elegant (and less cumbersome) than an intraosseous device. Note that the microconvex probe we use works better than vascular probes as it can be applied on any vein, including the subclavian vein (through an infraclavicular approach as previously described) (16, 20). The same type of needle can also routinely be used for decompression of a tension pneumothorax, or a pericardial tamponade. This detail, amongst others, explains why our first choice should not be a pocket machine. Ultrasound is not only a diagnosis, it also supports treatment. All these items, including the automated external defibrillator (AED) can be kept permanently on-site in the ultrasound cart. This fits within the concept of the PUMA (polyvalent ultrasound and management apparatus), a cart with most live-saving tools, including also a simple gray-scale ultrasound unit. The usual management and ABC's (check for airway patency, sternal punch, AED) is done as per good clinical practice. A suprasternal approach, facilitated by the shape of the microconvex probe we use, can sometimes visualise the right pulmonary artery in favorable cases, and can show, rarely but immediately, a floating clot within the pulmonary artery. Local adjustements can be made according to the expected pathology within the specific clinical situation. As an example, searching for a venous thrombosis makes little sense in trauma, and those dealing with neonates will search rather for a bleeding from difficult delivery (abdominal, cerebral). Likewise, technical details can be adapted accordingly (15).

Those accustomed to work with the "4H's-4T's" (the 4 H's refer to Hypoxia, Hypovolemia, Hypo- or hyperkalemia, and Hypothermia, where the 4 T's refer to Tension pneumothorax, Thrombosis (DVT or PE), Tamponade, and Toxic causes) in the differential diagnosis of cardiac arrest with pulseless electrical activity (PEA) can easily adapt it. They just need to replace tension pneumothorax by Step 1, thrombosis of pulmonary artery by Step 2, hypovolemia by Step 3, tamponade by Step 4. Other causes (hyperkalemia, toxic causes etc) are diagnosed with other traditional diagnostic tools. While the SESAME-protocol has not yet been validated in the clinical setting, it uses validated applications in a specific manner, where each detail has been worked out in order to facilitate smoothness. In the future pocket machines may have a role, but for the time being we are used to work at bedside, with *both our hands* when scanning critically ill patients.

Pocket machines can be interesting for patients lying on the ground or in really tiny spaces (airborne medical evacuation). Some gray-scale pocket machines have technical features more compatible with the practice of SESAME-protocol than more sophisticated pocket machines. The SESAME-protocol may have a psychological impact for the caregiver as the visualisation helps to understand the situation and may help to cope with the sometimes poor outcomes seen after cardiac arrest, in the understanding that reversible causes were not missed.

Integration of the SESAME-protocol within the concept of holistic ultrasound

The physician who has understood the philosophy, reasoning and the technical requirements of the SESAME-protocol will master also other fields beyond cardiac arrest. For instance, the simple detection of A-lines, at the first step of the SESAME-protocol, suggesting "room" for fluid therapy (as a very rough indicator, to be refined with the FALLS-protocol) can be used as a first step in many areas of medicine, critical care and emergency care. The technique, probe, and signs used to exclude pneumothorax are exactly the same in many other situations like the critically ill after a thoracic procedure (pleurocenthesis, insertion of deep venous catheter), in emergency medicine for limiting radiation in the management of spontaneous pneumothorax, in internal medicine after thoracentesis, in multiple trauma as routine care, etc... The same approach to confirm the diagnosis of deep venous thrombosis can be done more elaborate, more comprehensively (common femoral vein, calf veins, upper extremities), and this technique can be of interest in several disciplines, including geriatrics, obstetrics, emergency medicine... Searching for free abdominal fluid is a classical issue in trauma patients, but can be used in many other settings as well. The same can be said for pericardial effusions. Regarding echocardiography and considering holistic ultrasound (i.e., mainly, the integration of the lung), we can describe an alternative, the simple emergency cardiac sonography. This label indicates that a partial view of the heart analysis can be sufficient provided the lung surrounds this approach. As the simplest example, if left ventricle function is difficult to assess, the detection of an A-profile indicates the absence of pulmonary edema, even at a silent, early, interstitial step, probably indicating a normal left heart function.

Conclusions

The SESAME-protocol is a very fast protocol, preferably performed using simple equipment, that is not always present currently. Many enthusiastic colleagues use the term "disruptive" when speaking about the revolution of bedside ultrasound. This is, indeed an unprecedented evolution, but from our perspective, it is rather a victory of the laptop machines, with their usual three probes and complex functions. In the light of the SESAME-protocol, simple machines using one distinct, universal probe should be used in order to achieve a really disruptive change. The present technical note on the SESAME-protocol was the opportunity to show some of the advantages of holistic ultrasound, where simple concepts do have a place in critical care ultrasound. By analyzing the illustrative case of cardiac arrest, we just described what we do already without any difference in daily clinical practice in the ICU, but here only more slowly. Last but not least it is noteworthy that this article could have been written in 1982, a time where the technology and mobility of some units was less performant than modern machines, but just because of their simplicity and width they were perfectly suitable for use in cardiac arrest. Modern machines may have advantages regarding better resolution for plain organs like the heart (in a sophisticated Doppler approach) but apart from this and some other modern features (like the presence of a USB port) they have no major advantages over the machines that were constructed more than 35 years ago. With this statement we want to give the reader some food for further thought.

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Notes

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CHAPTER 8

Assessment of Loading Conditions with Cardiac Ultrasound

Jan Poelaert

Optimization of the preloading conditions and concomitant determination of endpoints of fluid administration are the most frequent therapeutic actions in critically ill patients. Besides a clinical appraisal, reproducible data should be acquired at the bedside to estimate adequacy of fluid resuscitation. The dynamic assessment and determination of fluid responsiveness plays a major role in this respect. Right sided cardiac variables as inferior and superior caval vein diameter variation during mechanical ventilation are easily obtained with cardiac ultrasound. Also, left sided variables, including aortic flow variation, with intermittent swings of intrathoracic pressure during mechanical ventilation, could be achieved non-invasively with Doppler-echocardiography. Both in terms of resuscitation as well as correct interpretation of various two-dimensional and Doppler variables, it is essential to acquire a clear understanding of the filling status of a patient. Doppler-echocardiography plays herein a pivotal role.

Introduction

Over the past decade, critical care ultrasound has gained its place in the armamentarium of monitoring tools (1). **Introduction**
Adequacy of volume resuscitation and assessment of fluid administration are daily questions in critically ill patients. Fluid loading is the most frequent therapeutic handling performed in anaesthetized and critically ill patients. Appropriateness of loading conditions includes some clinical signs such as low perfusion pressure, low diuresis, malperfusion of tissues. However, clinical estimation of filling and subsequent optimization needs more than some subjective and rough clinical parameters.

Fluid status determination could be performed by either static or dynamic variables, which should be integrated within the clinical findings. Static variables include preload descriptors without any dynamic component. Dynamic variables include more a physiological approach testing fluid responsiveness.

Cardiac ultrasound allows bedside assessment of haemodynamics and has been shown to provide invaluable information on ventricular systolic and diastolic function, loading conditions (preload and afterload), valve morphology and function and the status of the great vessels [1]. Whereas traditional haemodynamic monitoring relies on assessment of pressures and cardiac output, echo-Doppler techniques provide insight in volumes and flows. Therefore, incorporation of cardiac ultrasound into clinical practice offers a much more complete and detailed picture of the haemodynamic status, in a non-invasive manner. Furthermore, correct interpretation of many echo-Doppler parameters obliges determination of optimal filling status each time an echo-Doppler assessment is performed, because of the load dependency of many of these ultrasound variables (table 1).

Left ventricular end-diastolic area indexed for body surface area (LVEDAI)
Right ventricular end-diastolic area indexed for body surface area (RVEDAI)
Systolic Doppler flow wave in a pulmonary vein (S)
Early filling wave across the mitral valve (E)
Systolic Doppler tissue wave, obtained in the mitral annulus (S')

Table 1. Static load dependent variables, obtained with cardiac ultrasound

As with other monitoring tools, correct handling of cardiac ultrasound needs extensive knowledge of anatomic and physiologic features, besides the handling to obtain the imaging and signals in the most optimal and trustful manner.

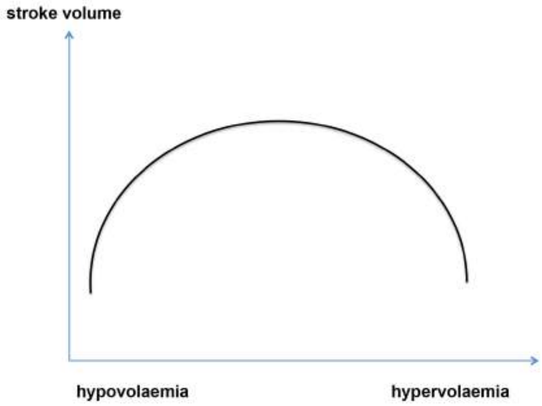

Figure 1. Frank-Starling relationship. Relationship between stroke volume and the critical optimal zone between hypovolaemia and hypervolaemia. Neither a low filling state nor hypervolaemia will result in an optimal cardiac output.

Assessment of ventricular function has been well described. However, correct interpretation of ventricular systolic function needs estimation of loading conditions; optimization of preload often improves ventricular function.

The aim of assessing fluid responsiveness should be an objective determination of loading conditions in order to have fluid loading only being reserved for those patients who will benefit and prevent from excessive fluid loading (fig. 1). This analysis aims to review the correct interpretation of the different variables describing loading conditions in a critically ill, being obtained with echo-Doppler techniques, besides indication of clinical confounders, hampering correct analysis of each technique.

Physiological understanding of loading conditions

In essence, preload is a static variable, describing loading conditions of the heart before muscular contraction occurs. It is related to left ventricular end-diastolic pressure (LVEDP) and, through some simplifications, also to left atrial and pulmonary artery occluding pressure (PAOP). Nonetheless, the relationship between pressure and loading conditions is hampered mainly by ventricular compliance. The latter is governed by the function of the opposite ventricle, mostly though not only by the interventricular septum, coronary perfusion pressure, pericardial constraint and intra-thoracic pressure. End-diastolic pressure relates to volume whenever ventricular compliance is normal. Hence, in only a few critically ill patients it follows that LVEDP could be a useful descriptor of preloading conditions.

The balance between optimal preload, contractility and afterload is the mainstay of haemodynamic management and becomes more important whenever the pump (contraction) is failing. Sedation relieves the sympathic tone, reduces afterload and unloads the heart from the preloading side, inducing a total imbalance with haemodynamic deterioration when pump failure is present. Therefore, estimation and optimization of preload is essential and the first measure in enhancing haemodynamics and even prevailing haemodynamic deterioration (fig. 1). However, when preload irresponsiveness is present, volume resuscitation may also aggravate pulmonary oedema, with subsequent respiratory failure and weaning difficulties.

Whereas static variables of loading conditions provide a momentary tableau, which could suggest hypovolaemia only in conjunction with some general measures, as listed above, it becomes clear that, nowadays, a dynamic aspect should be included to optimally assess and predict fluid responsiveness. Several possibilities exist, such as an internal transfusion with passive leg raising [2], a mini bolus of 100 ml colloids [3], or usage of intra-thoracic pressure swings owing cyclic mechanical insufflation to safely determine fluid status of the critically ill [4].

Static variables of preload

As with haemodynamic monitoring including assessment of various intra-cardiac pressures like central venous pressure (CVP), pulmonary artery occlusion pressure (PAOP), left ventricular end diastolic pressure (LVEDP), several static variables have been described in cardiac ultrasound. Table 1 provides a list of examples of static load dependent variables in this respect. All of them give a momentary insight of preload, often in conjunction with a measure of systolic function. Is a temporary picture worthless in view of estimating optimal preloading conditions in a haemodynamically unstable patient? As with various filling pressures, static variables may offer adequate understanding of global volume status, if interpreted in a correct context [5]. The most classical example is left ventricular end-diastolic area, indexed for body surface area (LVEDAI). There is no relationship between PAOP and LVEDAI [5-7]. In cardiac surgical patients, LVEDAI has been demonstrated to be sensitive to detect alterations of blood volume, even in patients with regional wall motion abnormalities. Though eyeballing is generally accepted in clinical practice, it has been described that a LVEDAI < 5.5 cm^2/m^2 depicts clearly a low preloaded status [8], though this finding could not be confirmed in an intensive care unit (ICU) setting [6]. Presence of an end-systolic obliteration in a patient with a hypertrophic left ventricle – with normal contractility - suggests clearly a low filling state, though compliance of the left ventricle should be taken into account with respect to the amount and the velocity of loading [9].

Fluid infusion could induce an increase of LVEDAI up to a certain level, after which it will remain constant, concordant with stabilization of cardiac output [10, 11]. PAOP, however, will rise further, concomitant with further filling. Therefore, LVEDAI is superior to pressure related static preload descriptors, such as CVP or PAOP, to predict fluid responsiveness in a cardiac surgical setting [12]. Left ventricular end-diastolic diameter [13], taken in a short axis view, or – with 3-D echocardiography – left ventricular end-diastolic volume, in a mid-oesophageal (ME) long axis view, can also be utilized as a static variable.

An important shortcoming is the fact that LVEDA always should be assessed at the same position. Though the papillary muscles have been used as an easy marker of position, inclination of the probe within the oesophagus could interfere with a correct estimation of the LVEDA, in particular in those patients with severely depressed left ventricular systolic function. Hence, a dynamic evaluation of loading conditions is urged.

Fluid responsiveness

Traditional measures of preload, such as CVP and changes of CVP with volume loading, have failed to predict responsiveness to fluids [14, 15]. Assessment of loading conditions in patients with increased intra-thoracic or intra-abdominal pressures, intraoperative Trendelenburg positioning (major pelvine surgery), pericardial constraint or right ventricular failure particularly appears an indication for dynamic load evaluation, rather than using static preload characteristics. Furthermore, only dynamic variables followed the changes induced by transfusion in a rabbit model [13].

Either mechanical ventilation induced alteration of intra-thoracic pressure and passive leg-raising or mini bolus could be used to determine fluid responsiveness in sedated or anaesthetized patients on a mechanical ventilator.

Passive leg raising and stroke volume

Passive leg-raising has been utilized already many decades and offers the possibility to safely transfuse 150-200 ml of whole blood into the central circulation [16]. A rapid increase of ventricular preload and hence cardiac output could be achieved whenever preload dependency is present. In addition, this technique offers complete reversibility by returning the legs horizontally. Important with this technique is the definition of positive response, which is often set at an increment of 10-15 % [16, 17]. LVEDAI could be monitored by transthoracic or transoesophageal approach, assessing increase of this measure during passive leg-raising. Therefore, invasive arterial pressures are not directly necessary to determine fluid responsiveness.
Reversibility of the testing with short-term increase of preload underlines the safety of this technique. Nevertheless, it should be taken into account to evaluate global ventricular function previous to a passive leg-raising test. A dilated right or left ventricle certainly will hamper the effects of rapid filling.

Several mechanisms interplay with the increased preload. First, increased systemic venous return is achieved in preload dependent patients. Second, stimulation of atrial baroreceptors with inhibition of vagal outflow and stimulation of sympathetic efferent fibers to the heart could also leads to haemodynamic changes during passive leg raising [18]. Third, awakening could induce reflexes during sedation. Finally, choice of sedation could interfere with presence of preload responsiveness: propofol was shown to increase preload responsiveness whereas dexmedetomidine had no impact [19].

Mechanical ventilator induced intra-thoracic pressure changes and the right heart

During mechanical ventilation in a well-sedated adult patient, cyclic alterations of intra-thoracic pressure induce changes of the diameter of the venous inlet into the thorax, i.e. inferior and superior caval veins (fig.2 and 3). With transthoracic echocardiography, it is easy to demonstrate the dilation and decrease of diameter of the inferior caval vein (IVC) with inspiration and expiration, respectively. Barbier C et al. and Feissel M et al. demonstrated clearly that respiratory variation of the IVC reliably predicts fluid responsiveness [20, 21]. Conversely, in acutely decompensated heart failure patients, the rate of fluid withdrawal during haemodialysis can be guided by intermittent evaluation of the respiratory induced alterations of the IVC diameters [22]. In this particular study, hypotension was observed in those patients with IVC variation of > 30%.

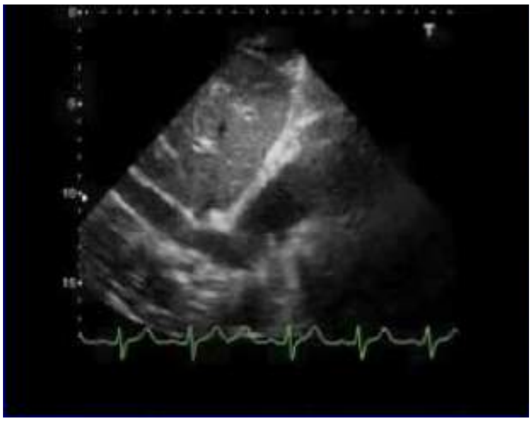

Figure 2. Variation of inferior vena cava, IVC with cyclic swings of intrathoracic pressure, e.g. during mechanical ventilation. Panel A: Fluid responsive. Responsiveness is defined as ΔIVC > 18% according to the formula below:

$$\Delta IVC = 100\ x\ \frac{IVCinsp - IVCexp}{IVCinsp} > 18\%$$

Figure 2. Variation of inferior vena cava. Panel B: Fluid non-responsive.

Superior caval vein (SVC) variation during mechanical ventilation can be monitored by means of transoesophageal echocardiography in a minimally invasive manner [23]. Collapse of the SVC during inspiration has been related with low intra-thoracic blood volume [24]. A collapsibility index (CI) has been defined [25] as:

$$CI = SVC\ max - SVC\ min / SVC\ max$$

Figure 3. Variation of superior vena cava, SVC with cyclic swings of intrathoracic pressure, e.g. during mechanical ventilation. Panel A: Fluid responsive. Responsiveness is defined as ΔSVC > 36% according to the formula below:

$$\Delta SVC = 100\ x\ \frac{SVCexp - SVCinsp}{SVCexp} > 36\%$$

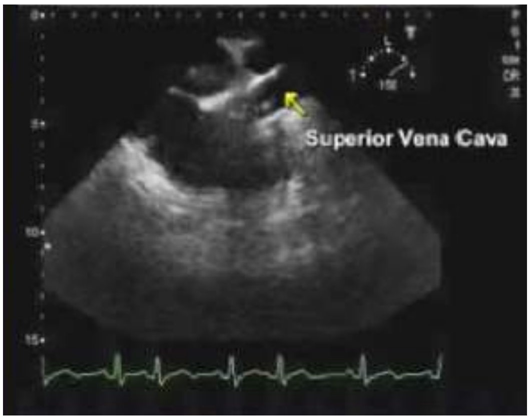

Figure 3. Variation of superior vena cava. Panel B: Fluid non-responsive.

It has to be noted that SVC max is observed during expiration (lowest intra-thoracic pressure), owing the position of the SVC in the thorax. This CI index exceeds 36% providing a good discrimination of responders to blood volume [25].

Recently, a simultaneous comparison between IVC (by transthoracic approach) and SVC (by transoesophageal echocardiography) variation in mechanically ventilated patients showed a better performance of SVC variation in predicting fluid responsiveness [26]. The threshold for the SVC was found to be 29% (sensitivity 54% and specificity 89%). Apparently, the impact of intra-thoracic pressure changes during mechanical ventilation, including increased right atrial pressure, squeezing the inter-alveolar capillaries and hence, increased right ventricular impedance, was larger upon the SVC than the influence on backflow or at least delayed filling of the right atrium, as assessed in the IVC. The anatomical position of the SVC inside the thoracic cavity could explain this better performance of this vessel in demonstrating fluid responsiveness. Nevertheless, in many critical situations with mechanical ventilation, it is clear the transthoracic approach assessing cyclic IVC variations is easy and clinically useful. Therefore, it appears logical that the IVC-view has been integrated in FAST imaging protocols [27] and is the first choice. Only in those situations where transoesophageal echocardiography and Doppler is used, SVC imaging will guide decision making with respect to fluid management.

Of note, both IVC and SVC diameter variations with altering intra-thoracic pressure during mechanical ventilation do provide insight in right ventricular fluid responsiveness. Correct interpretation will be hampered whenever right ventricular failure [28], increased abdominal pressures [29], open chest (during or after cardiac surgery)[30, 31], too small shifts of intra-thoracic pressure (low tidal volume [32, 33], increased intra-thoracic pressures, increased work of breathing). In contrast, increased respiratory rate (neonates and small children) allow still correct estimation of fluid responsiveness by means of IVC variation [34].

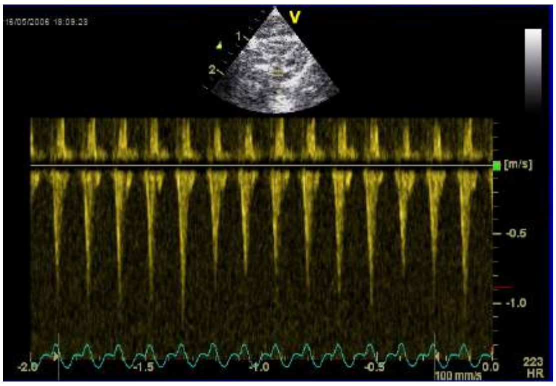

Figure 4. Variation of trans-aortic flows, assessed with continuous wave Doppler, with cyclic swings of intrathoracic pressure.

Mechanical ventilator induced intra-thoracic pressure changes and the left heart

Stroke volume variation is the physiological effect of cyclic altering intra-thoracic pressure during mechanical ventilation at the left heart. Stroke volume can be derived from the area under the curve of transaortic valvular Doppler signal (velocity time integral, VTI), obtained in deep transgastric view [35, 36]. VTI is actually a distance of which one red blood cell is pushed with a single contraction of the left ventricle. The following formula permits calculation of SV:

$$VTI * AVA = SV$$

AVA could be determined by calculation of this area at the level of the aortic valve (π * diameter/2) or using the mean aortic valve area over the whole ejection cycle [37], which is a more practical approach in daily clinical practice.
An increase of SV with > 15% induced by passive leg raising was shown to have a specificity of 93% and a sensitivity of 81%, a positive predictive value of 91% and a negative predictive value of 85% [2]. The whole estimation could be simplified by replacing SV by VTI; this has the advantage that SV is much more rapidly estimated. Furthermore, this approach is far less prone to mistakes and over- or underestimations by omitting the issue of aortic valve area. The magnitude of the mechanical ventilation induced alterations of VTI accurately predicts the changes of cardiac output during acute bleeding or transfusion [13]. Hence, the formula to be determined in estimating fluid responsiveness could be rewritten as follows:

$$\Delta VTI\ (\%) = 100*(VTImax - VTI\ min)/[(VTI\ max + VTI\ min)/2]$$

with a responder variation of 20% [38]. Fig. 4 shows clearly the mechanical ventilation induced variations in the aortic Doppler signal. Delta down could be noted; the latter is endorsed by a decline of systemic venous return or an increased right ventricular afterload. Only echocardiography may differentiate between the two phenomena: collapse of the IVC or SVC suggests a preload effect, whereas intermittent dilation of the right ventricle supports the idea of increased right ventricular impedance.

Delta up is the consequence of a squeezing of the alveolar capillaries during inspiration of blood into the left atrium or/and a decrease of left ventricular afterload in patients with afterload dependent hearts [39].

SVV has been shown to be an adequate predictor of fluid responsiveness in various studies [40]. ΔVTI has been compared with Vigileo (Edwards Lifesciences, Irvine, USA) derived SVV with similar performance in a setting of liver transplantation and vasopressor support [4], though with normal systemic vascular resistance. The area under the ROC curves to discriminate volume responders versus non-responders by both methods, were not different. Nevertheless, caution have to kept as different monitors use different algorithms and stroke volume monitors have never been validated for rapid changes of stroke volume during one breath [41]. A major contraindication of the use of ΔVTI to estimate fluid responsiveness is aortic valve disease (stenosis, insufficiency), even with low trans-aortic pressure gradients. Then right-sided measures should be utilized in this respect.

Similarly, in spontaneously breathing patients, increases of stroke volume by means of passive leg raising, assessed by cardiac ultrasound, has been shown to correlate with those changes estimated by a Vigileo system [42]. In intermittent spontaneous breathing, interpretation is more difficult as the swings of intra-thoracic pressure will be not always equal. Longer periods of evaluation should be included to gather the required information.

Conclusions

Both right-sided as left-sided dynamic descriptors of loading conditions could be obtained with Doppler-echocardiography. Whereas the SVC variations with changing intra-thoracic pressures appear to be more accurate, both SVC and IVC diameter variations are useful in this setting. Velocity-time variation is more difficult to obtain across the aortic valve albeit this physiological signal offers similar and often non-invasive information of stroke volume variation. Cardiac ultrasound offers the huge advantage to estimate fluid responsiveness in a mostly non-invasive and fast manner at the bedside. Three-dimensional cardiac ultrasound of left and right-sided ventricular volumes could result in an easy and quick assessment of preloading data. Association of a mini-bolus of fluid loading or passive leg raising will help to identify fluid responsive patients.

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Notes

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CHAPTER 9

Cardiac Ultrasonography in the critical care setting: a practical approach to assess the cardiac function and preload for the “non – cardiologist

Guy L.J. Vermeiren, Manu L.N.G. Malbrain, Jeroen M.J.B. Walpot

Cardiac Ultrasonography has become an indispensible tool in the management of hemodynamically unstable critically ill patients. Some consider it as the modern stethoscope. Echocardiography is non-invasive and safe and the modern portable devices allow for use at the bedside in order to provide fast, specific and vital information regarding the hemodynamic status and the function, structure and anatomy of the heart. In this review we will give an overview of cardiac function in general followed by assessment of left ventricular function using echocardiography with calculation of cardiac output, left ventricular ejection fraction (EF), fractional shortening, fractional area contraction, M mode EF, 2D planimetry and 3D volumetry. We will briefly discuss mitral annulus post systolic excursion (MAPSE), calculation of dP/dt, speckle tracking or eyeballing to estimate EF for the experienced user. In a following section we will discuss how to assess cardiac preload and diastolic function in 4 simple steps. The first step is the assessment of the systolic function. The next step assesses the left atrium. The third step evaluates the diastolic flow patterns and E/e' ratio. The final step integrates the information of the previous steps. Echocardiography is also the perfect tool to evaluate right ventricular function with tricuspid annular plane systolic excursion (TAPSE), tissue Doppler imaging, together with inferior vena cava dimensions and systolic pulmonary artery pressure and right ventricular systolic pressure measurement. Finally methods to assess fluid responsiveness with echocardiography are discussed with the inferior vena cava collapsibility index and the variation on left ventricle outflow tract peak velocity and velocity time integral. Cardiac ultrasonography is an indispensible tool for the critical care physician to assess cardiac preload, afterload and contractile function in hemodynamically unstable patients in order to fine-tune treatment with fluids, inotropes and/or vasopressors.

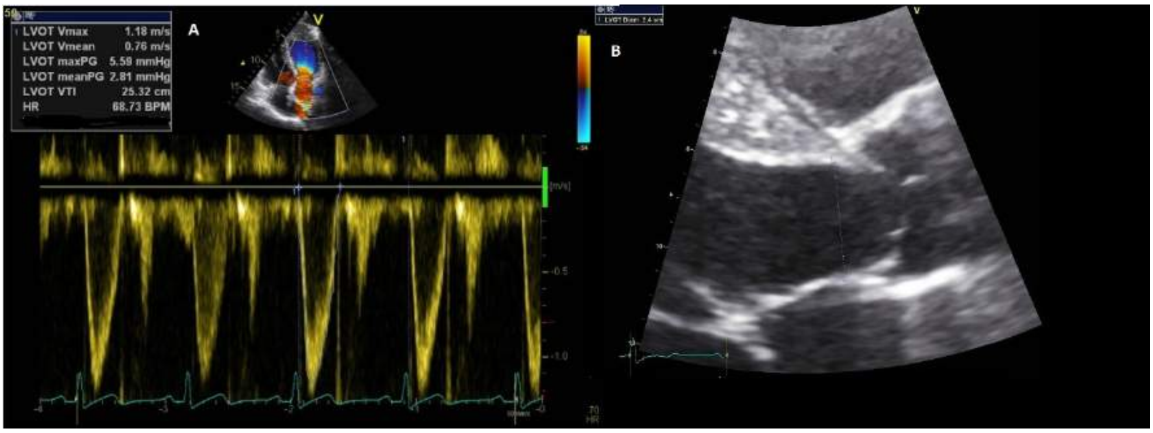

Figure 1. Calculation of stroke volume. Panel A shows the velocity time integral (VTI) of the left ventricular outflow tract (LVOT) obtained from an apical 5 chamber window. Panel B demonstrates the measurement of the diameter of the LVOT. CSA (Circumferential Surface Area) = (Diameter LVOT/2)^2 x π = (2.4/2)^2 x 3.14 = 4.5 cm^2. Stroke volume = VTI LVOT x CSA = 25.3 cm x 4.5 cm^2 = 113.83 cm^3. Cardiac output = stroke volume x heart rate = 113.83 cm^3 x 68.7 beats per minute = 7820 cm^3/minute.

Introduction

The past decade we have witnessed the introduction of bedside ultrasonography in the critical care setting (emergency room (ER), operating room (OR) and intensive care units). All over Europe intensive care unit (ICU) physicians are participating in ultrasound courses to further improve their knowledge and skills; in order to rapidly establish a diagnosis and provide optimal treatment (1).

The use of cardiac ultrasound proves to be invaluable in order to assess hemodynamic function and preload. Pulmonary artery catheters (PAC) have been replaced by less invasive continuous cardiac output (CO) measurements, either calibrated like transpulmonary thermodilution or uncalibrated like pulse contour analysis or a combination of both. In most cases however, these CO measurements need to be completed by cardiac ultrasound. It is by far the most complete, comprehensive and vital investigation. It is crucial for correct clinical decision making.

Some ultrasound techniques require more expertise and advanced skills than others. It is our aim to describe the *most practical* measurements, their validation and their usefulness in the ICU ward and the broader critical care setting (ER and OR). We will refrain from tedious measurements that may require profound acquisition skills or significant post-processing time. Guidelines for cardiac ultrasound in emergency settings have already been issued and updated (2,3). In order to facilitate fast diagnosis in emergency care, pocket-held devices have been developed and are widespread used today (4).

1. Cardiac function in general

Cardiac function can be measured by several parameters. In the ICU the most implemented parameter is CO. This can readily be measured with the PAC catheter and its later derivatives e.g. transpulmonary thermo- or dye dilution techniques as with the PiCCO (Pulsion Medical Systems, Feldkirchen, Germany), the EV1000 (Edwards Lifesciences, Irvine, USA) or the LiDCO (LiDCO Group plc, London, UK). These devices use a surrogate gold standard (calibrated) technique based on the Stewart Hamilton method. The newer less invasive devices using uncalibrated pulse contour analysis cannot be recommended in unstable patients, with frequently changing preload, afterload or contractility.

ICU clinicians are focused on cardiac function in general. Cardiac output is a real-time measurement, regardless of regional hypokinesia and/or valvular dysfunction. Cardiologists and ultrasound technicians prefer ejection fraction (EF) and rather prefer to describe regional wall motion. The cardiologists' main task is to diagnose the aetiology of cardiac dysfunction. In his area of expertise CO measurement per se is too limited and vague.

2. Assessment of LV systolic function

2.1. Cardiac Output (CO)

Cardiac output is measured, by convention, in the left ventricular outflow tract (LVOT) using pulsed wave (PW) Doppler velocity ***(figure 1).*** Since we can measure the LVOT diameter, we can calculate it's cross sectional surface area (CSA) and derived stroke volume (SV).

- $CSA = 3.14 \times (D/2)^2 = 0.785 \times D^2$
- SV = VTI x CSA, with VTI the velocity time integral

The first description of CO measurement with ultrasound at the LVOT was described and validated by Otto in 1988 (5). CO can also be measured at other locations (mitral valve annulus (6), ascending aorta (7,8), the right ventricular outflow tract (RVOT) (9) and pulmonary artery (10)), but this has been less validated. The cross section of the LVOT at diastole ($LVOT_d$) can also be measured (11), but large inter-observer variability exists up to 0.2 cm (12). There also exists a difference between LVOT measured by transthoracic (TTE) and transesophageal echocardiography (TEE). It has been revealed that TTE tends to underestimate the LVOT by 0.1 cm (12). Variation of LVOT in the general population ranges between 18 and 22 mm (13,14) and is related to body surface area. Therefore it can be estimated by a given formula, which is time-effective and reduces error (15):

- $LVOT_d = 5.7 \times BSA + 12.1$

Some ultrasonography labs use fixed values like 1.8 for female and 2.0 for male patients.
The calculated CSA, using these values, varies between 2.6 – 3.1 cm^2. The velocity time integral (VTI) can be derived with *pulsed wave Doppler* measured at the LVOT. A normal VTI varies between 20-25 cm (13). This implies that a VTI > 20 cm refers to a normal CO, without the need for further calculation.

- $CO\ (cm^3/min) = SV \times HR = HR\ (bpm) \times CSA\ (cm^2) \times VTI\ (cm)$

In order to facilitate quick bedside calculation in the ICU, CSA can be assumed to be around 3 cm^2, which simplifies the equation to:

- $CO\ (ml/min) = 3 \times HR \times VTI_{LVOT}$

This equation is easy to memorize, heart rate is readily available on the ICU monitor and VTI measurement can be mastered without extensive tedious training.

2.2. Ejection Fraction (EF)

Ejection fraction is very popular in cardiology literature. The measurement is, although not really complicated, very user-dependent and prone to a lot of errors. The physiological basis of left ventricular ejection fraction (LVEF) is simple: the ejected volume is related to the left ventricular end-diastolic volume (LVEDV). Normal LVEF is above 55%.

- LVEF = (LVEDV-LVESV) / LVEDV

Fractional Shortening

Fractional shortening (FS) can be derived by calculating the linear shortening of the following measurements:

- FS = (LVEDD - LVESD / LVEDD) x 100, with LVEDD as the left ventricular end-diastolic diameter and LVESD as the left ventricular end-systolic diameter

This measurement in itself is correlated tot LVEF, without further calculation. Normal FS is between 25-40 %. Unless one is familiar with this measurement, this number never gives an intuitive "correlation" with other known variables in the ICU.

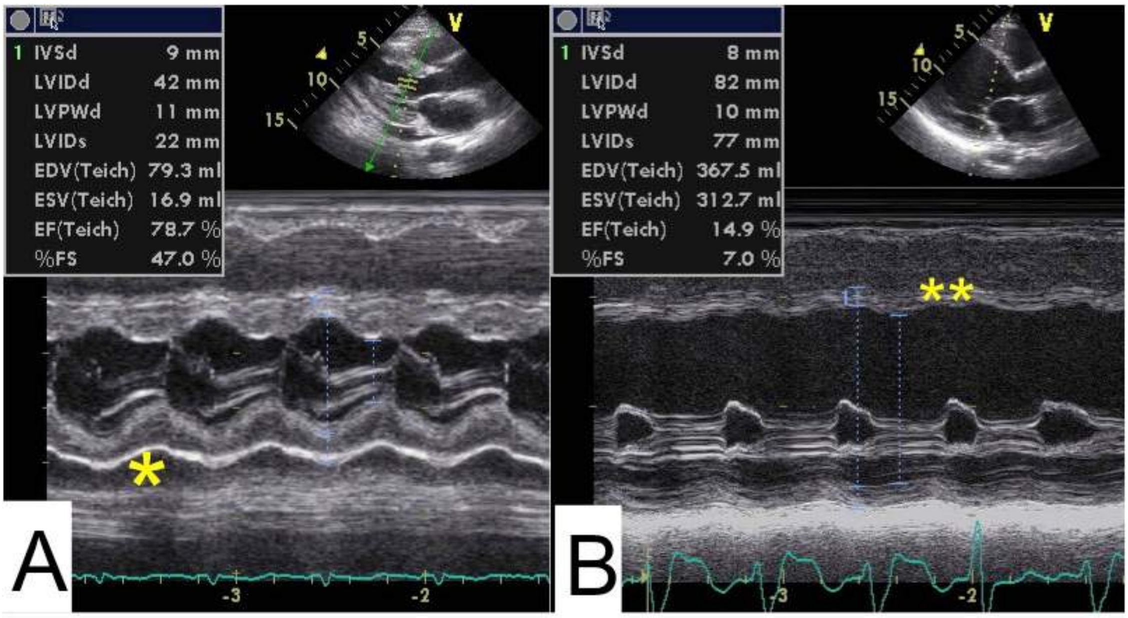

Figure 2. M Mode Left Ventricle and Fractional Shortening. Panel A shows an M Mode are obtained from the parasternal long axis of a patient with preserved left ventricular function. This patient suffered from cardiac amyloidosis. Remark also the small amount of pericardial fluid indicated by the asterix (*). Panel B shows a patient with an anteroseptal myocardial infarction with severely diminished LV contractility. The septum is thin scar tissue. Remark the absence of systolic thickening of the interventricular septum.

Fractional Area Contraction (FAC)

Fractional area contraction (FAC) can be derived by calculating the linear shortening of the following measurements:

- FAC = (LVEDA - LVESA / LVEDA) x 100, with LVEDA as the left ventricular end-diastolic area and LVESA as the left ventricular end-systolic area

As for FS, this measurement is also correlated tot LVEF, without further calculation. Normal FAC is between 35-45 %.

M Mode LVEF

Fractional shortening can subsequently be used to calculate an actual LVEF. All these calculations require linear acquisition of ventricular diameters. After determination of the end-diastolic and end-systolic left ventricular diameters, several methods can be used to estimate LVEF. Cubed formula's, like Teichholz formula (16) and modified Quinones formula's (17) have been described previously, and are usually programmed on most available ultrasonography equipment. Several pitfalls make these methods less desired in the critical care setting ***(Figure 2)***:

- M Mode acquisition requires a lot of expertise, and is not always easy to perform in dorsal decubitus
- M Mode border identification is not easy in non-expert hands
- Only 2 segments out of a total of 17 cardiac segments are used to calculate LVEF

2D Planimetry

This is, according to the current guidelines, the method of choice to estimate CO (18,19). This method needs area tracings of the left ventricle in two perpendicular views. In this way it makes no geometrical assumptions of the ventricle.

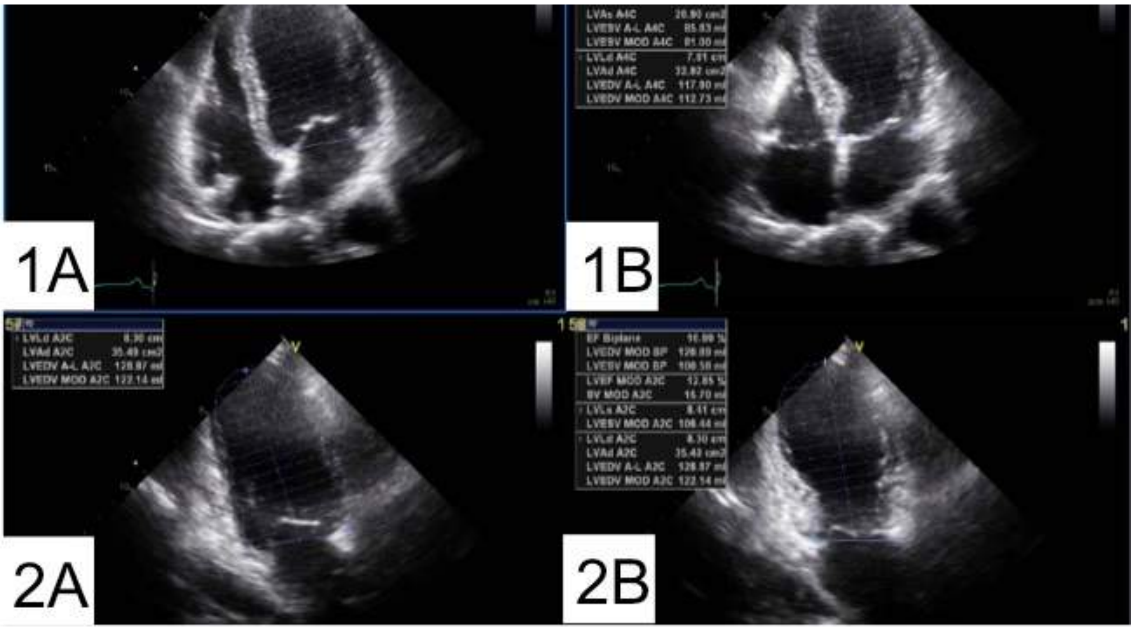

Figure 3. LV EF by Simpson method. This figure shows a calculation of the LV EF by Simpson method. The 4 chamber and 2 chamber frames at end systole and end diastole are used. The sofware applications of modern ultrasound machines automatically calculate the LV EF by using Simpson methods, once the ultrasonographer traces the endocardial border. In this example, it concerned a patient suffering from apical ballooning. Only the basal segments were contractile. Panels 1A and 1B are 4 chamber views at respectively end-diastole and end-systole. Panels 2A and 2B show the analogous 2 chamber views.

Since the ventricular endocardium is traced from base to apex, there is less possibility to under- or overestimate the ventricular function due to regional hypokinesia. The method is generally described as Simpson's method. Simpson's method is based on the summation of the smaller volumes in order to obtain the overall left ventricular volume. The length of the LV is divided into 20 parallel discs, from base to apex, with a diameter of each disc determined in two apical views (two-chamber and four-chamber) ***(Figure 3)***.

Left ventricular endocardium is traced in end-diastole and end-systole in both views. These parameters are used to calculate both left ventricular end-diastolic and end-systolic volumes as well as the LVEF. The crucial element in the echocardiographic evaluation of LVEF using Simpson's method is accurate identification of the ventricular endocardium. Poor image quality and failure to identify papillary muscles will produce significant errors.

- Noteworthy, in case of suboptimal image quality, the use of echocardiographic contrast (air bubbles) may improve the endocardial definition
- Some of the more recent ultrasound devices may also have an automatic endocardial border detection

3D Volumetry

This method renders a 3D image and estimates EF, based on the use of a dedicated 3D probe. The imaging is in itself not difficult, since a single volume acquisition suffices to calculate EF. Automated border detection of the endocardium in Real Time 3D echo seems promising, but remains yet to be validated (20). The question remains if this high-end ultrasonography equipment will be within the practical scope of an emergency/ICU department. For the time being, this method requires tedious post processing techniques and cannot be recommended; hence it falls outside the scope of this article.

Eyeballing

If one is familiar with cardiac ultrasound, one can estimate the left ventricular function by just viewing movie-loops of the ventricular motion. Some articles state that a focused training in the 'eyeballing technique' can result in acceptable accuracy in estimating LVEF (21) .

Mitral Annulus Post Systolic Excursion (MAPSE)

A quick method to estimate LVEF is to measure systolic movement of the mitral annulus ring. Using M Mode in apical four-chamber view, one can visualise this movement with ease. Technical considerations and pitfalls are however obvious.

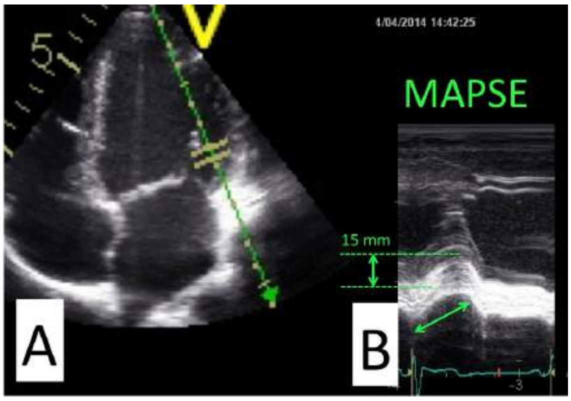

Figure 4. Mitral Annulus Post Systolic Excursion (MAPSE). Panel A shows the acquisition of MAPSE from the mitral valve insertion on the left ventricular free wall. Panel B shows M Mode registration with clear systolic movement of the mitral annulus plane. MAPSE is estimated at 15 mm.

One has to align the M Mode perpendicular to the annulus movement, in order not to underestimate the systolic excursions. Since one only measures MAPSE in one or two positions of the atrio-ventricular plane, it extrapolates LVEF function based on sparse data. However, MAPSE can be easily obtained in patients with poor imaging quality and in dorsal decubitus. Intra- and inter-observer variability is around 5 %, which is acceptable (22). Furthermore it is an independent predictor of 28-day mortality (23). Some key-points to remember ***(Figure 4)***:

- MAPSE of > 10 mm correlates with an EF > 55%
- MAPSE of < 8 mm relates to a reduced ejection fraction
- This leaves an "indeterminate" grey zone between 8-10 mm, where no statement regarding LV function can be made

2.3. Contractility or dP/dt

This is an underutilized indicator of LV function. Mitral regurgitation dP/dt is afterload independent but is influenced by preload. It is a measurement of contractility of the LV in the isovolumetric contraction phase (24,25).

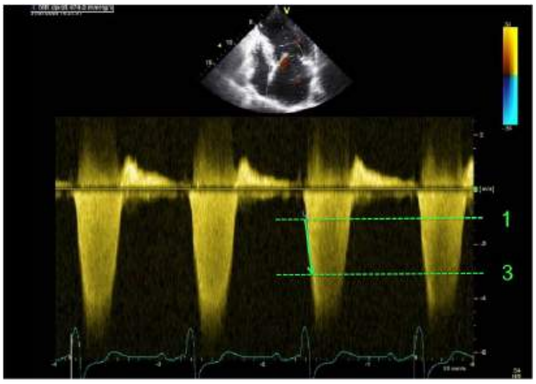

Figure 5. Contractility dP/dT. The panel shows a mitral valve regurgitation signal by continuous wave (CW) Doppler. Change in velocity is measured, by definition, between 1 and 3 m/sec. The dP/dT is 474 msec, and implying severely diminished LV function.

This technique requires a measurable mitral regurgitation on the Continuous Wave signal, obtained from a four-chamber view. It necessitates alignment of the regurgitated jet with the ultrasound beam. Most echocardiographic ultrasound machines will provide reference lines at 1 and 3 m/sec and will calculate and display dP/dt automatically ***(Figure 5)***.

- The normal dP/dt is > 1200 mmHg/sec
- dP/dt between 800 to 1200 mmHg/sec suggests mild LV dysfunction
- dP/dt < 800 mmHg/sec severe LV contractile dysfunction

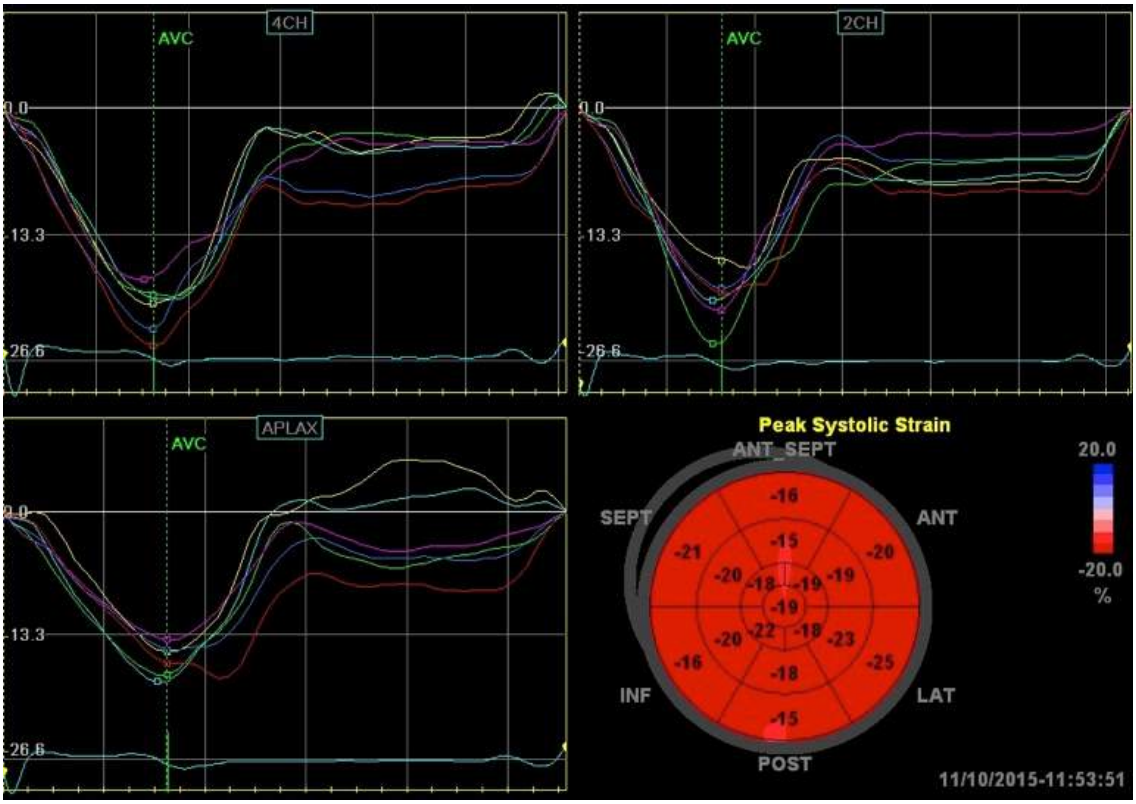

Figure 6. Speckle Tracking Longitudinal Strain (STE). This figure shows STE of a patient with preserved LV EF and normal global longitudinal strain.

2.4. Speckle Tracking Echocardiography (STE)

Two-dimensional speckle tracking echocardiography (STE) is a relatively novel and sensitive method for assessing ventricular function by measuring the myocardial deformation (strain). STE has been demonstrated to be able to unmask myocardial dysfunction before it can be detected with conventional echocardiography. Contrary to Doppler Strain imaging, STE is an angle independent technique. This independence of alignment is a potential advantage when echocardiographic imaging has to be performed in suboptimal conditions, as is often the case in patients in the ICU.

A recent study demonstrated that STE is a feasible technology for assessing the left ventricular deformation in septic patients in the ICU. Furthermore, a greater portion of the patients in this study were identified as having systolic dysfunction of both the RV and LV when assessed by STE as compared with conventional echocardiography (26).

Another study has shown that the combination of global longitudinal strain (GLS) and the APACHE II score have additive value in the prediction of ICU and hospital mortality in septic shock patients admitted to the ICU (27). STE may help in early identification of high-risk patients in the ICU. STE is a promising field in cardiac ultrasound that will be developed further over the next years and standardization of this technique is currently under revision (28) ***(Figure 6)***.

3. Cardiac preload and Diastolic Function

Even in the optimal setting of the echo laboratory, assessment of the loading conditions and diastolic function is often challenging.

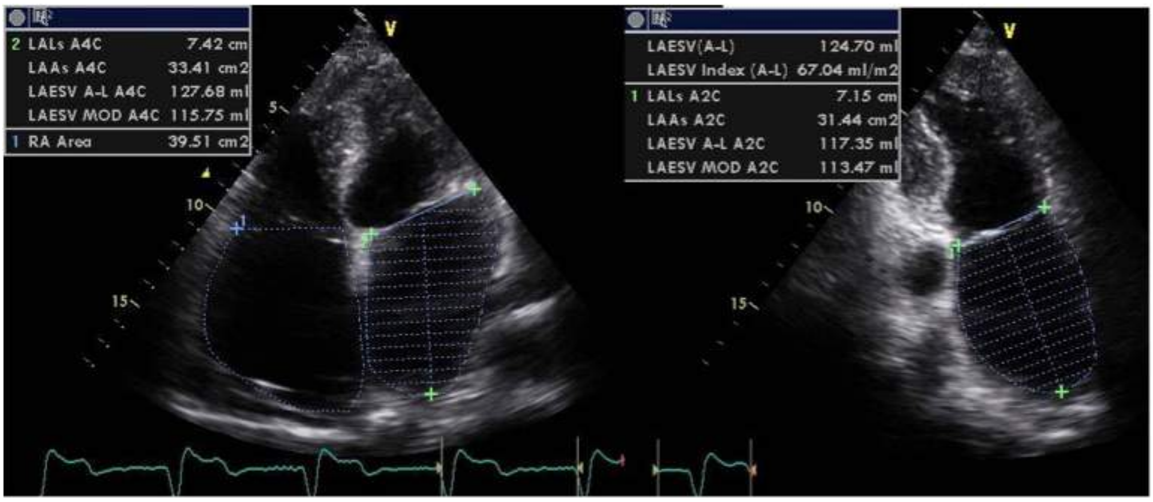

Figure 7. Quantification of the LA volume . This figure demonstrates the measurement of the LA volume. A frame at start of the diastole in the 2 chamber and 4 chamber view is used. The automated software of the ultrasound machine calculates the LA volume indexed to BSA.

Bedside echo Doppler evaluation in the ICU is often more difficult due to suboptimal image quality: patients are in supine position in the ICU, whereas the patients in the ultrasound laboratory lay on their left side, when echocardiography studies are performed.

As a consequence, these measurements in the ICU often have to be obtained from suboptimal acoustic windows. Imperfect alignment with the ultrasound beam is a major limitation for the use of echo Doppler, especially for quantitative assessment. Despite these limitations, adequate evaluation of the diastolic function is an essential part of the echocardiographic assessment. Moreover, the evaluation of the loading condition is often the main reason for ordering a cardiac ultrasound study in patients, hospitalized in the ICU.

Over the last decades, several parameters have been proposed to assess the diastolic function. The goal of this paper is not to review all these methods, but to describe a comprehensive approach for the evaluation of the diastolic function, feasible to be used in the ICU. Assessment of the diastolic function is not based on a single measurement. The diastolic "mitral inflow" patterns, but also quantification of the left atrium and the systolic function have to be taken into account. In most echocardiography training programs a stepwise approach is proposed:

Step 1: assessment of the systolic function

Paradoxically, assessment of the systolic function as described in the previous sections is the first step in the evaluation of the diastolic function. In heart disease, the diastolic function is affected before decrease in LV EF appears. Thus, an impaired systolic function excludes a normal diastolic function. Interpreting systolic function is the first step in the ESC/EACVI (European society of cardiology/ European Association of Cardiovascular Imaging) algorithm for diastolic assessment (29).

Step 2: assessment of the left atrium

Quantification of the left atrium (LA) is the next step in the work up. LA dilation is the consequence of longstanding LA pressure and/or volume overload. Thus, LA enlargement does not necessarily mean LA pressure is definitely increased, but it indicates a likelihood of elevated LA pressure (LAP). Due to this property, LA volume is sometimes called the HbA$_1$c of diastology. LA dilation is *considered incompatible* with preserved diastolic function. Quantification of LA volume according body surface area (LA_{vol}/BSA) (30):

- $LA_{vol}/BSA < 29$ ml/m2: normal
- LA_{vol}/BSA: 29 - 33 ml /m2: mild
- LA_{vol}/BSA: 33 -39 ml/m2: moderate
- $LA_{vol}/BSA > 39$ ml/m2: severe

The European Association of Echocardiography and the American Society of Echocardiography guidelines use the threshold value of LA_{vol}/BSA of 34 ml/m2 in combination with Doppler measurements in algorithms to estimate the LAP (31) (**Figure 7**).

Step 3: evaluation of the diastolic flow patterns

The mitral inflow Doppler velocity pattern

This measurement is the keystone of the diastolic flow patterns. At the end of the systole, the aortic valve closes. The left ventricle starts to relax and left ventricular pressure decreases. Once the left ventricular pressure falls below the LAP, the mitral valve opens and the diastolic filling of the LV begins. The interval between closing of aortic valve and opening of the mitral valve is called the isovolumetric relaxation time (IVRT). Mitral inflow pattern consists of an early rapid filling E (early) wave, with a peak and deceleration (down) slope (DT). Due to the rapid filling of the LV cavity, the left ventricular pressure increases and filling velocity decreases. At the end of the diastole, atrial contraction occurs, resulting in the A (atrial) peak (32).

Abnormal diastolic flow patterns

1/ Impaired relaxation*:* With aging and heart disease, there is a decrease in diastolic relaxation as well as elastic recoil. This results in a slower LV pressure decline. Subsequently, it takes more time before the LV pressure becomes equal to the LAP. Thus, the IVRT is prolonged. Because of the decreased relaxation of the LV, the filling occurs at lower velocities (E peak decreases) en the filling-time prolongs, with subsequent increase in DT. Mitral E velocity is decreased and A velocity is increased. This results in an E/A ratio <1.
The impaired diastolic filling pattern typically occurs in case of hypertrophic cardiomyopathy and can be summarized as follows (32):

- Decreased E velocity
- Increased A velocity
- E/A ratio <1
- Prolonged DT (> 160 msec)
- Prolonged IVRT (> 90 msec)

2/ Restrictive filling pattern (decreased compliance): The increase in LAP results in a faster opening of the mitral valve, with subsequent shortening of the IVRT. The high LAP results in an increased initial trans-mitral gradient (higher E peak). Due to noncompliance of the LV, the early diastolic filling results in a fast raise of pressure in the LV with early equalization of LV and LA pressure, which results in a shortened DT. The atrial contraction results in a small A wave with a shortened duration, as the increase in LV pressure increases more rapidly as consequence of the noncompliant state of the LV. Thus, in a restrictive filling pattern, the mitral inflow velocities can be summarized as follows (32):

- Increased E velocity
- Decreased A velocity
- E/A ratio > 2
- Shortened DT (< 160 msec)
- Shortened IVRT (< 70 msec)

3/ Pseudonormalized pattern: This pattern is a transition from impaired to restrictive filling pattern. As the name indicates, it resembles a normal filling pattern, with normal E/A ratio and DT. This filling pattern is the result increased LA pressure superimposed on a relaxation abnormality.

E/e' ratio

Tissue Doppler Imaging (TDI) is able to measure the longitudinal mitral annular velocity. The e' is the early diastolic peak velocity obtained by TDI. It has been demonstrated that e' is relatively load-independent. Meanwhile E is dependent of loading conditions as well as ventricular relaxation (33). Thus, dividing E/e' reflects better the loading conditions of the LV (***Figure 8***).

$$E/e' \approx \frac{\text{LAP x rel}\cancel{\text{axation}}}{\text{rel}\cancel{\text{axation}}} \approx \text{LAP}$$

Figure 8. Equation to calculate left atrial pressure form E/e’

E/e' is considered as the single best parameter to estimate the LAP. As mentioned earlier, in order to evaluate the filling pattern, it is wise never to rely on one single measurement. Nonetheless E/e' is very useful to discriminate the normal diastolic filling pattern from a pseudonormalized filling. In the latter e' is decreased. Keypoints to remember are (31):

- E/e' < 8 reflects normal LA pressure
- E/e’ > 15 implies increased LA pressure

Unfortunately, there is a large grey area in between these two values. For ICU purposes it is interesting to note that E/e’ correlates well with pulmonary artery occlusion pressure (PAOP ≈ LAP). The following formula has been suggested by Nagueh *et al.* (34):

- $PAOP = 1.24 * (E/e') + 1.9$ mmHg

The M Mode acquisition of the mitral annulus post systolic excursion, or MAPSE, is in essence a less accurate measurement of tissue displacement. Studies have shown that BNP levels correlate inversely to MAPSE and even better than E/e’(35).

Step 4: Integration of the information of the previous step

By putting the information, obtained in the previous steps together, the diastolic dysfunction can be graded into 4 classes:

- Diastolic dysfunction grade I: impaired relaxation
- Diastolic dysfunction grade II: pseudonormalized pattern
- Diastolic dysfunction grade III: reversible restrictive pattern
- Diastolic dysfunction grade IV: irreversible restrictive pattern

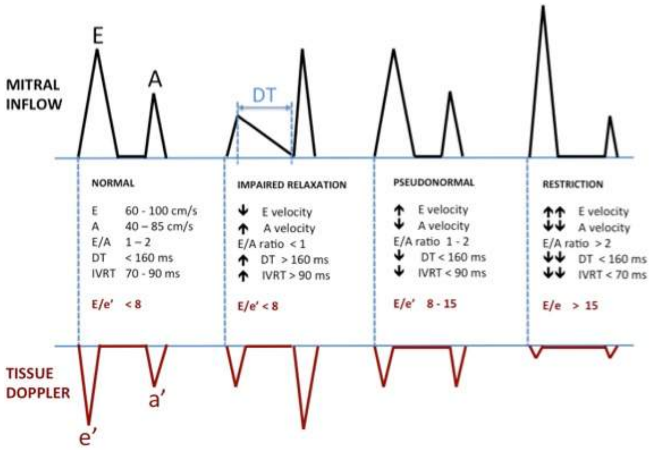

Figure 9. Diastolic Filling Patterns. Theoretical appearance of Mitral Inflow signal and Tissue Doppler Imaging in the 4 different states of diastolic function: normal, impaired relaxation, pseudonormalized flow pattern and restriction.

The differentiation between diastolic dysfunction grade III and IV is difficult to make in ICU patients, as this requires cooperation of the patient while performing echo Doppler measurements with or without Valsalva Manoeuvre (***Figure 9 and Figure 10***).

The EAE algorithm to estimate the filling pressure in patients with preserved LV EF starts with E/e' (31) (***Figure 11***):

- E/e' < 8: normal LAP
- E/e' 9-14: LA_{vol}/BSA is used to further discriminate:
  - $LA_{vol}/BSA < 34$ ml/m2: normal LAP
  - $LA_{vol}/BSA > 34$ ml/m2: elevated LAP
- E/e' > 15: elevated LAP

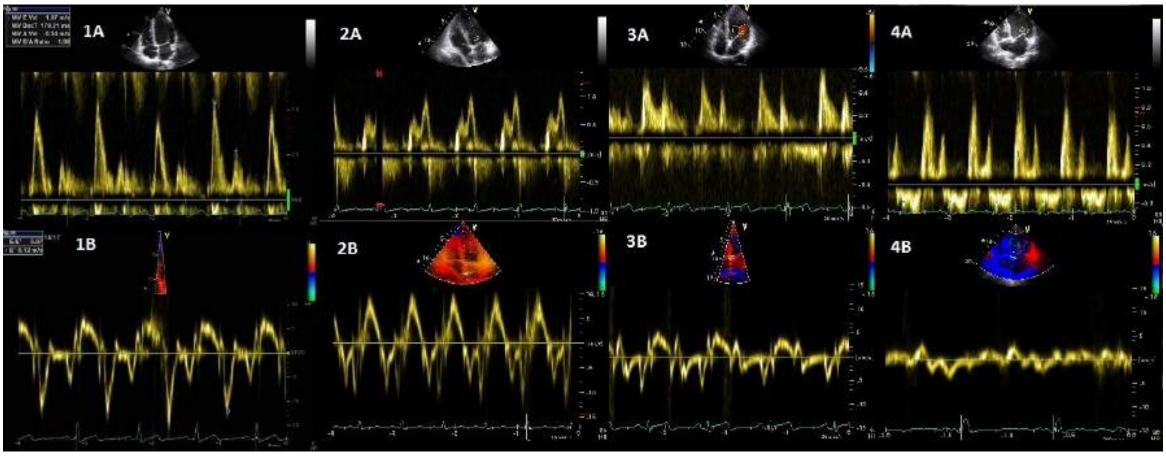

Figure 10. Diastolic function in real-life.
Panel 1A and 1B show respectively the mitral inflow velocity and e' in a 23-years-old man with normal left atrial pressure (LAP). E/A = 1.5, e' = 12 cm/s and E/e' = 8.67. Panel 2A and 2B show respectively the mitral inflow velocity and e' in a patient with delayed relaxation (diastolic dysfunction grade 1) in a 68-years-old female suffering from hypertensive left ventricular hypertrophy. E/A =0.53, e' = 9 cm/s and E/e' = 7.8. Panel 3A and 3B show respectively the mitral inflow velocity and e' in a patient with pseudo normalized mitral inflow pattern (diastolic dysfunction grade 2). E/A =1.34, e' = 4.5 cm/s and E/e' = 13.3. Remark the contribution of the e' to allow discrimination between normal and pseudo normal inflow velocities. Panel 4A and 4B show respectively the mitral inflow velocity and e' in a patient with restrictive inflow pattern due to cardiac amyloidosis. E= 110 cm/s, E/A = 2.2 , e' = 3.3 cm/s and E/e' = 33.

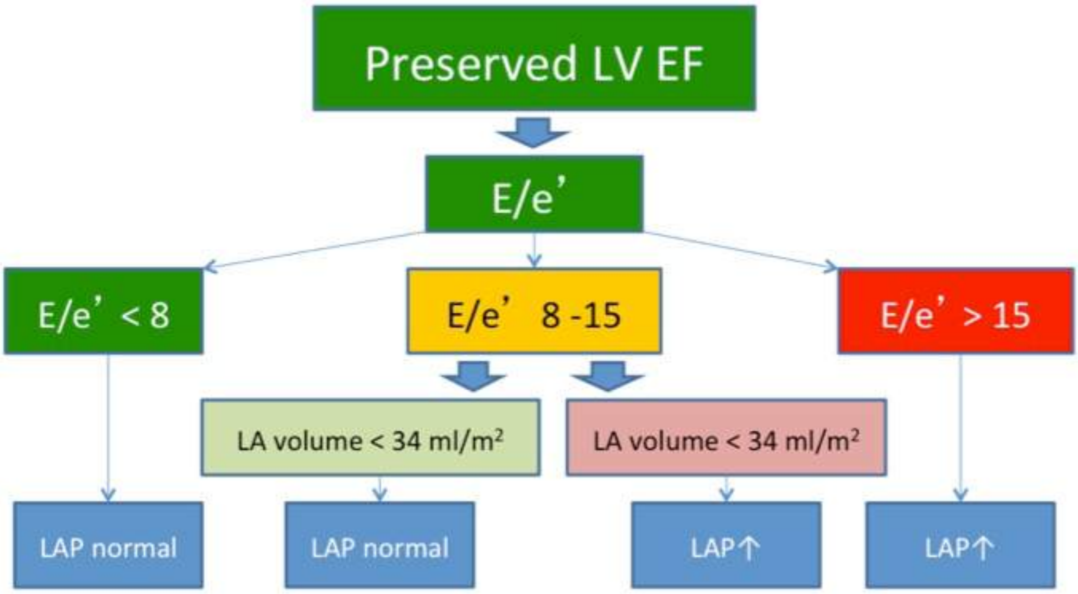

Figure 11. Preserved LV EF. Proposed simplified flowchart for assessment of loading conditions and/or filling pressures.

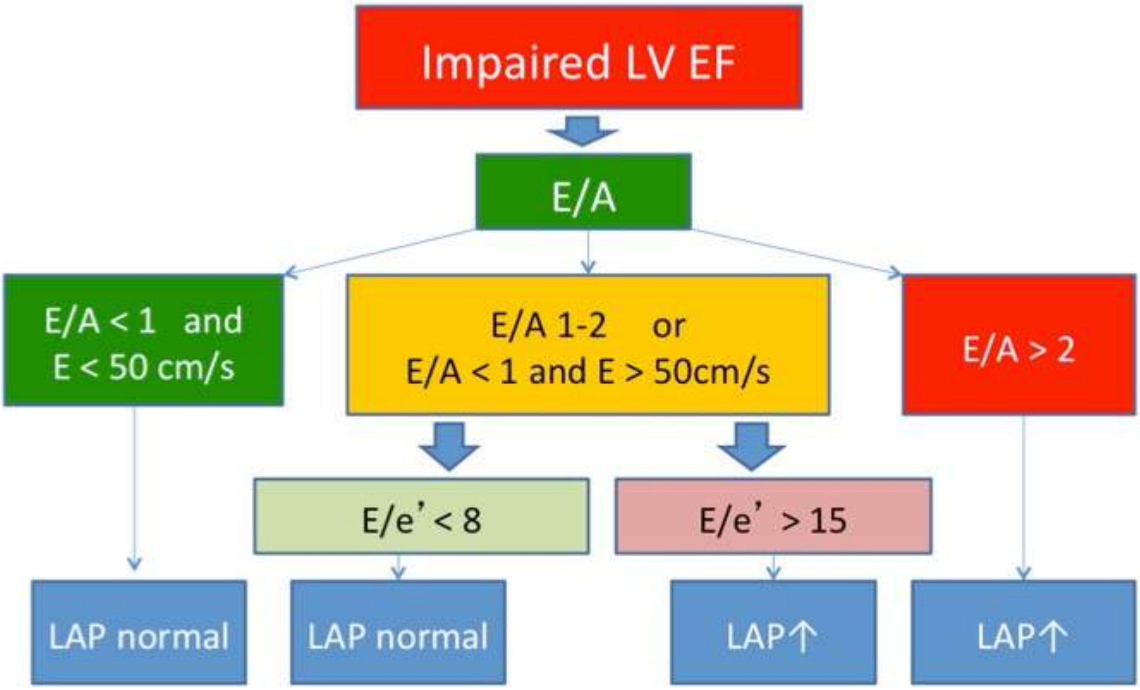

Figure 12. Impaired LV EF. Proposed simplified flowchart for assessment of loading conditions and/or filling pressures.

In patients with decreased LV EF the algorithm, the mitral inflow pattern is the first step in the evaluation (***Figure 12***):

- E/A < 1 and E < 50 cm/s: normal LAP
- E/A > 2 and DT < 150 cm: elevated LAP
- E/A 1 - 2 *or* E/A <1 and E > 50 cm/s use E/e' to make further discrimination:
  - E/e' < 8: normal LAP
  - E/e' > 15: elevated LAP

Thus, LV systolic function, LA volume, mitral inflow velocities and E/e' are the most important factors to determine the grade LV diastolic function. The Pulmonary Vein Velocity Patterns and colour flow mapping (CFM) transmitral flow propagation also provide additional information. Their acquisition and interpretation are outside the scope of this article, since they require more profound expertise.

4. Right ventricular assessment

4.1. Right ventricle

Assessment of right heart structure and function is a basic part of cardiac ultrasound evaluation. It is an essential addition to left heart parameters and has long been neglected. Due to its geometry, the right ventricular (RV) function is more difficult to quantify. Since its cavity is not circular 2D Simpson is not feasible. Short axis linear measurements in M Mode do not correlate well with RV function.

3D echocardiography has been demonstrated to be able to accurately measure the RV EF. As mentioned afore, this requires sophisticated modern cardiac ultrasound machines.

The goal of this paper is to provide a comprehensive and relatively easy to perform bedside evaluation of the RV function. The combination of 4 measurements, as described below, allows a basic assessment of the RV function and RV pressures.

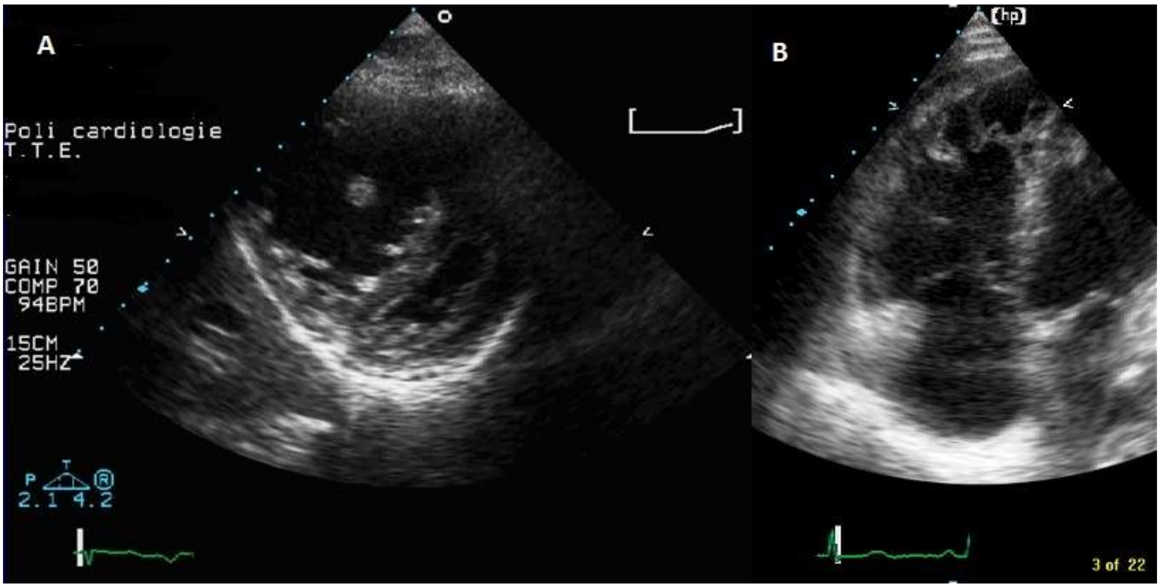

Figure 13. RV overload. These images were made in a 55-years-old woman suffering from severe pulmonary hypertension, due to chronic pulmonary embolism. Panel A shows an image obtained from the parasternal short axis view and panel B an image from the 4 chamber window. Remark the dilated RV, that oversizes the LV dimensions, with rightward ventricular septal shift (***D Shape*** of LV).

In patients with severely increased RV pressure or volume overload, examination of the global RV shape may be helpful (***Figure 13***).

- In normal conditions, the LV dimensions are larger than the RV dimensions with a rightward ventricular septal shift
- If the RV "oversizes" the LV with leftward ventricular septal shift, there is major volume or pressure overload (**D-shaping** of left ventricle)
    - In case of pressure overload, the leftward ventricular shift is most prominent at end-systole
    - In case of volume overload this shift is most pronounced at end-diastole

4.2. TAPSE: Tricuspid annular plane systolic excursion

TAPSE measures the distance of the systolic excursion of the RV annular segment along its longitudinal plane (36). This measurement is obtained from an apical 4-chamber view. Thus, TAPSE represents longitudinal function of the right ventricle. The limitation of this method is the assumption that the displacement of the basal segment is representative for the entire RV. Nonetheless, the European and American Society of cardiology recommend TAPSE in the routine use for assessment of the RV function. In their consensus document, the advantages and limitations were summarized (29): "Advantages: TAPSE is simple, less dependent on optimal image quality, and reproducible, and it does not require sophisticated equipment or prolonged image analysis.

Disadvantages: TAPSE assumes that the displacement of a single segment represents the function of a complex 3D structure. Furthermore, it is angle dependent, and there are no large-scale validation studies. Finally, TAPSE may be load dependent."

- TAPSE > 16 mm is considered indicative for normal RV function
- TAPSE < 16 mm implies impaired RV function

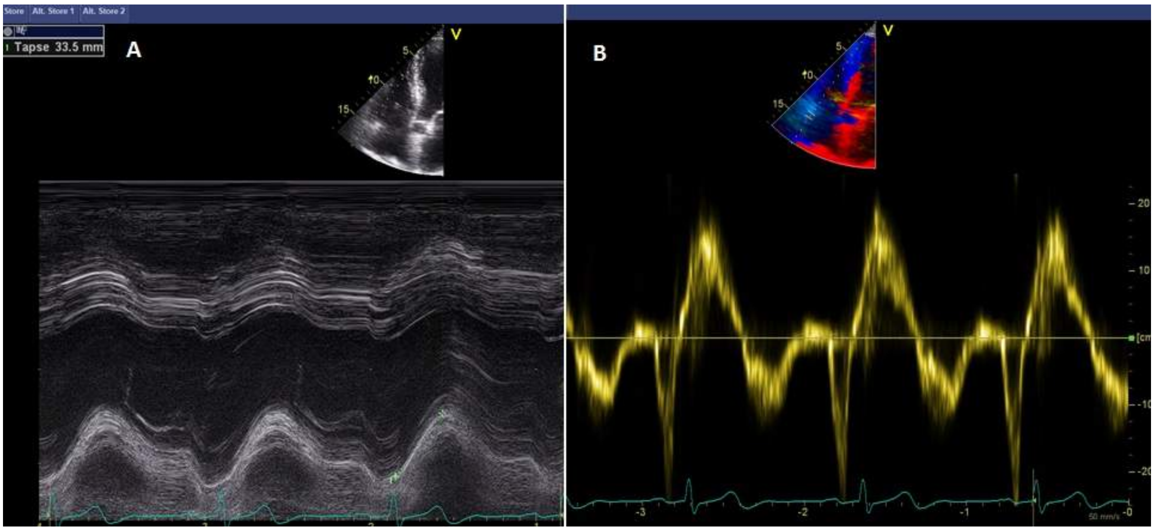

Figure 14. Tricuspid annular plane systolic excursion (TAPSE) and systolic excursion velocity
Panel A and B were measured in a patient with normal right ventricular function. Panel A shows TAPSE (Tricuspid annular plane systolic excursion). This measurement is performed from the 4 chamber window. It measures the distance of systolic excursion of the RV annular segment along its longitudinal plane. Panel B shows a Doppler Tissue Imaging measurement of the RV S' or systolic excursion velocity.

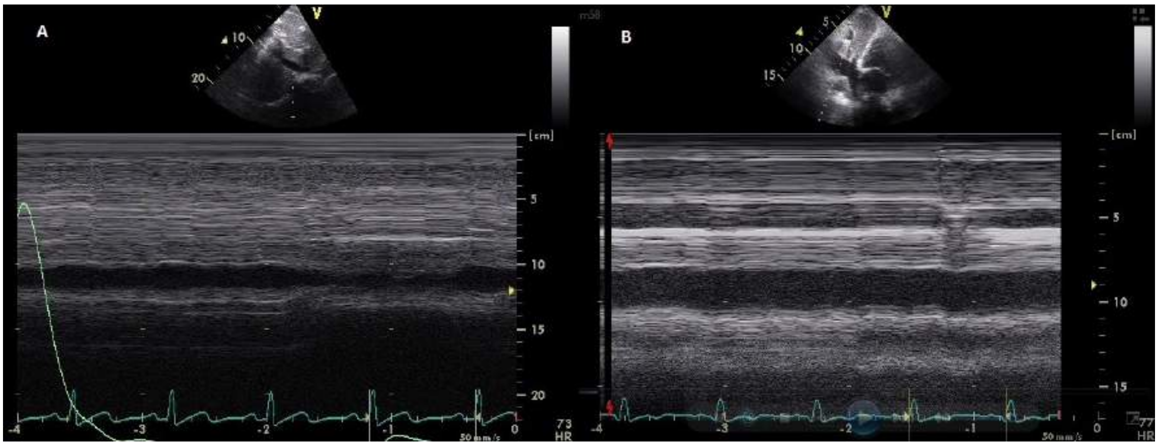

Figure 15. Collapse of inferior vena cava (IVC). Panel A: IVC diameter < 2.1 cm that collapses > 50% with a sniff: normal right atrial (RA) pressure of 3 mm Hg (range, 0-5 mm Hg). Panel B: IVC diameter > 2.1 cm that collapses < 50% with a sniff suggests high RA pressure of 15 mm Hg (range, 10-20 mm Hg). (See Text for explanation)

4.3. Tissue Doppler Imaging: RV S' or systolic excursion velocity

According to the earlier mentioned consensus document (29), Pulsed TDI can be used to measure the longitudinal velocity of excursion RV S'. It is easy to measure, reliable and reproducible. This Doppler measurement however is prone to errors due to suboptimal alignment of the annulus with the Doppler cursor. Lindqvist *et al.* (37) validated this method in a population based study. S' velocity has been demonstrated to correlate well with other measures of global RV systolic function (***Figure 14***).

- RV S′ velocity > 15 cm/s at the annulus (RV free wall) is considered normal, with lower velocities at the mid and apical segments

- RV S' velocity < 10 cm/s indicates RV systolic dysfunction

4.4. *Inferior (Vena Cava) IVC dimensions*

The IVC and its inspiratory collapse can be measured in the subcostal window. IVC diameter should be measured just proximal to the entrance of hepatic veins (***Figure 15***). The European Association of Echocardiography recommends quantification as follows (29):

- IVC diameter < 2.1 cm that collapses >50% with a sniff, suggests normal RA pressure of 3 mm Hg (range, 0-5 mm Hg)
- IVC diameter > 2.1 cm that collapses < 50% with a sniff, suggests high RA pressure of 15 mm Hg (range, 10-20 mm Hg)
- In scenarios in which IVC diameter and collapse do not fit this paradigm, an intermediate value of 8 mm Hg (range, 5-10 mm Hg) may be used

However, there are constraints to the use of IVC and its collapse in patients on the ICU:

- The IVC is commonly dilated and may not collapse in patients on ventilators
- IVC may be dilated in the presence of normal pressure in normal young athletes

4.5. *Systolic Pulmonary Artery Pressure (SPAP) and Right Ventricular Systolic Pressure (RVSP)*

Assuming absence of relevant right ventricular obstruction, Tricuspid Regurgitation (TR) velocity reliably permits estimation of RVSP with the addition of Right Atrial (RA) pressure, using an RA pressure estimated from IVC dimension and its collapsibility. In order to estimate pressure gradients out of maximal velocity, one needs to use a simplified Bernouilli equation (13):

- $\Delta P = 4V^2$

An estimated TR velocity of 3 m/sec will thus correspond to a gradient of 36 mmHg. In order to estimate RVSP we need to add an RA pressure. This can be estimated using the IVC protocol from the previous section. As SPAP is also stroke volume dependant and may increase with age, SPAP may not always indicate increased pulmonary vascular resistance (PVR) (***Figure 16***).

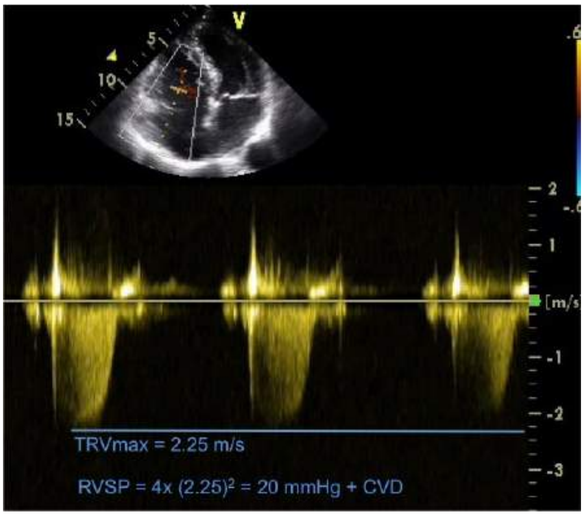

Figure 16. Tricuspid regurgitation signal.
This figure shows a Tricuspid Regurgitation velocity measurement from the 4 chamber view. The peak velocity equals 2.3 m/s. According to the simplified Bernoulli equation, the systolic pressure gradient between RV and RA = $4\,\Delta V^2 = 4 \times (2.6)^2$ = 21.2 mm Hg. Panel A from figure 15 was obtained the same patient. Right atrial pressure (RAP) was determined to be 3 mm Hg. Right ventricle systolic pressure (RVSP) is calculated using the simplified Bernouilli equation: pressure = 4 x velocity (in meters/second) squared. Thus, RVSP = RAP + TR gradient = 3 + 21.2 mm Hg = 24.2 mm Hg.

5. Fluid responsiveness

The primary question that fluid responsiveness monitoring seeks is to answer whether the patients' CO will increase after volume expansion (38). The cardiac ultrasound quantification methods to measure stroke volume, described in an earlier section, may contribute to answer this difficult question. Most of these methods evaluate the changes in stroke volume after fluid challenging by administration of a bolus of fluid. Alternatively, they use the passive leg raise method to increase venous return to the right atrium. In the medical community, measurement of changes in IVC dimensions after administration of an i.v. bolus of fluid is of particular interest, because of its technical simplicity.

It should be noted that the echocardiographic methods to predict fluid responsiveness are promising, but nowadays there is lack of robust validation of these methods among the different subpopulations of patients in the ICU. Further research is needed , before practical guidelines for the daily use can be made.

5.1. Left ventricular outflow tract (LVOT) Velocity Time Integral (VTI) variation with volume loading

In critically ill patients, the variation of CO and VTI after the administration of 50 ml crystalloid solution over 10 seconds can accurately predict fluid responsiveness (39). The utility of this method of fluid challenging to determine fluid responsiveness was also demonstrated in mechanically ventilated children in the postoperative period (40,41) (Figure 17).

- An increase in VTI > 15% after administration of 50 ml crystalloid solution over 10 seconds predicts fluid responsiveness (39).

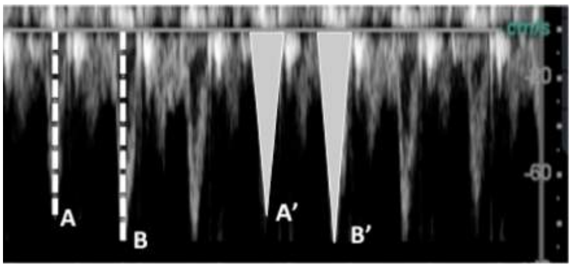

Figure 17. Flow variation on left ventricular outflow tract. Pulsed wave analysis at the level of the left ventricle outflow tract (LVOT). Fluid responsiveness is indicated by large variations (> 10 – 15%) between expiratory (A) and inspiratory (B) values of peak velocity (cm/sec) or velocity time integral (A' and B' respectively).

5.2. Left ventricular outflow tract (LVOT) Velocity Time Integral (VTI) increase with Passive Leg Raise (PLR)

Passive leg elevation (PLR to 45°) results in increased venous return to the right atrium. Using the NICOM (Non-Invasive Cardiac Output Monitor; Cheetah Medical, Tel Aviv, Israel), recent studies found PLR to be a promising tool for the evaluation of fluid responsiveness (42,43). Echocardiographic assessment of changes in stroke volume due to PLR have also been demonstrated to be useful predictors for fluid responsiveness (44). However, it is questionable if this method is sufficiently validated among the different subgroups of ICU patients, in order to make general recommendations for its use. We were also unable to find a consensus threshold for the change in stroke volume, allowing discriminating the responders from the non-responders (in general a 5 to 10% increase is used).

5.3. Left Ventricular end diastolic area (LVEDA)

This a controversial method to determine fluid responsiveness. At the level of the papillary muscles in the parasternal short axis window, the area of the left ventricle at end diastole is measured by tracing the endocardial border (45)(Figure 18).

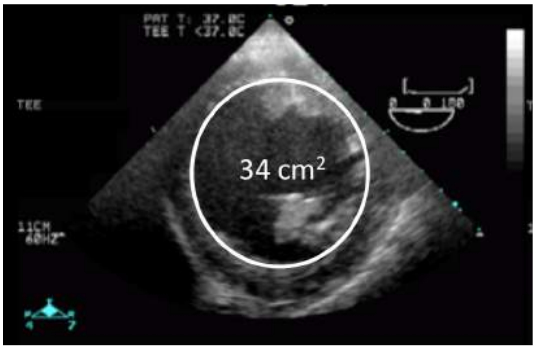

Figure 18. Left ventricular end diastolic area. Large left ventricular end diastolic area obtained with transesophageal echocardiography in a patient with dilated cardiomyopathy. Note that the papillary muscles are included within the surface area.

It has been advocated that:

- An LVEDA of less than 10 cm^2 or a LVEDA index (LVEDA / BSA) of less than 5.5 cm^2/m^2 indicates significant

hypovolaemia (normal range of LVEDAI is between 8 to 12 cm^2/m^2)
- An LVEDA of more than 20 cm^2 suggests volume overload

It should be mentioned that severe concentric hypertrophy can reduce LVEDA even without any hypovolaemia. Furthermore, there is lack of consenus on the use this method for the assessment of fluid responsiveness. Cannesson et al. stated that LVEDA should not be used to predict fluid responsiveness, as it is inaccurate and requires to much technical skills and training (38). Given these major criticism, its use cannot be promoted (46).

5.4. IVC collapsibility index

The IVC collapsibility index is expressed as the difference between the value of the maximum diameter and the minimum diameter, divided by the maximum of the two values. This is an index right atrial pressure (see previous section) and volume status (Figure 19).

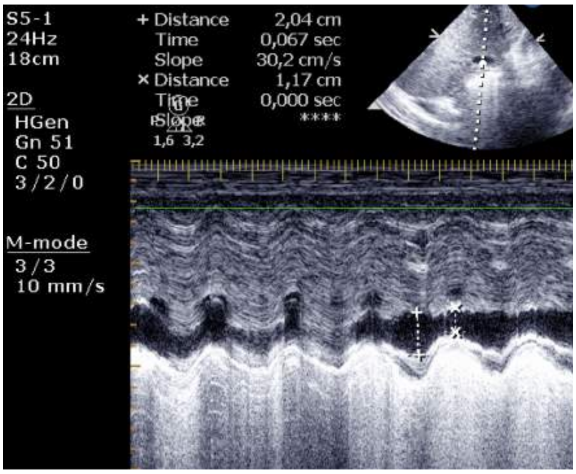

Figure 19. Fluid responsiveness. Inferior vena cava collapsibility index (IVCCI) of 50% in a patient with shock that was severely underfilled and fluid responsive.

Given the relative simplicity of the measurement technique and its noninvasive nature, the use of this parameters to predict fluid responsiveness seems very attractive. Its known that changes in both VCI and CVP are apparent during an infusion of a standardized fluid bolus.

Stawicki et al. demonstrated that the dynamic change in VCI as a measurement of responsiveness to fluid bolus is inversely related to changes seen in CVP in patients in the surgical ICU. They also found that an IV bolus tends to produce an early response in VCI, while the CVP response is more gradual (47). However, other studies showed that bedside ultrasonographic measurement of the inferior vena cava fails to predict fluid responsiveness in the first 6 hours after cardiac surgery (48) and hemodynamic response to early hemorrhage (49). Despite it promising potential, IVC collapsibility to bolus fluid challenging cannot be recommended as a predictor of fluid responsiveness. Further research is needed.

Conclusion

Hemodynamic assessment by echocardiography is an important if not vital tool in unstable critically ill patients admitted to the ICU. The technique enables fast and accurate bedside diagnosis, allowing focussed treatment. Cardiac ultrasound is feasible in almost all ICU patients and even suboptimal image quality will not impede the measurement of Doppler signals that can provide important clues for ICU physicians. Cardiac output, MAPSE, and TAPSE can be used in order to obtain an insight in systolic cardiac function within minutes. After a focused training ICU physicians can learn to "eyeball" ventricular function rapidly. Basic training allows to evaluate diastolic filling patterns and to guide fluid management. We suggest adding emergency and critical care cardiac ultrasound in the core curriculum of ICU physicians. The consensus document of the European Society of Cardiology on emergency echocardiography can serve as a guide; in order to identify the necessary standards one should meet to become a skilled critical care cardiac sonographer.

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Notes

CHAPTER 10

Point-of-care Gastrointestinal and Urinary Tract Sonography in daily evaluation of Gastrointestinal Dysfunction in Critically Ill Patients (GUTS Protocol)

Angel Augusto Perez-Calatayud, Raul Carillo-Esper, Eduard Daniel Anica-Malagon, Jesus Carlos Briones-Garduno, Emilio Arch-Tirado, Robert Wise, Manu L.N.G. Malbrain

Purpose. There is currently a lack of universally accepted criteria for gastrointestinal (GI) failure or dysfunction in critical care. Also, the clinical assessment of intestinal function is notoriously difficult and thus often goes unrecognized, contributing to poor outcomes. A recent grading system has been proposed to define acute gastrointestinal injury (AGI) in conjunction with other organ function scores (e.g., SOFA). Ultrasonography has become widely accepted as a diagnostic tool for GI problems and pathology. We propose a sonographic examination of the abdomen, using the GUTS protocol (gastrointestinal and urinary tract sonography) in critically ill patients as part of the point-of-care ultrasound evaluation in patients with AGI.

Methods. This article reviews possible applications of ultrasonography that may be relevant to monitor the GI function in critically ill patients.

Results. The GI ultrasound protocol (GUTS) focuses on four gastrointestinal endpoints: gastrointestinal diameter, mucosal thickness, peristalsis, and blood flow. Also, it is possible to examine the urinary tract and kidney function.

Conclusion. Real-time ultrasound with the GUTS protocol is a simple, inexpensive, bedside imaging technique that can provide anatomical and functional information of the GI tract. Further studies are needed to investigate the utility of GUTS with other parameters, such as GI biomarkers, AGI class, and clinical outcomes.

INTRODUCTION

There is currently a lack of universally accepted criteria for gastrointestinal (GI) failure or dysfunction in critical care. Furthermore, the clinical assessment of intestinal function is notoriously difficult and thus often goes unrecognized, contributing to poor outcomes. [1, 2] Several biomarkers for GI function have been proposed. Three such biomarkers include intestinal fatty acid binding protein (I-FABP), liver fatty acid binding protein (L-FABP), and plasma citrulline [3], however, clinical use is still unclear, and treatment strategies are currently based on experience rather than evidence. Delayed gastric emptying (GE) was reported in 50% to 80% of critically ill patients, especially those with diabetes. [3] The prevalence of abnormal small bowel motility in ICU patients is less well known. [3] The European Consensus Definition of acute gastrointestinal injury (AGI) suggests a graded severity score: [4]

1. AGI grade I represents a self-limiting condition with increased risk of developing GI dysfunction or failure;
2. AGI grade II (GI dysfunction) represents a condition requiring interventions to restore GI function;
3. AGI grade III (GI failure) represents a condition when GI function cannot be restored with interventions;
4. AGI grade IV represents a dramatically manifesting GI failure, which is immediately life threatening (e.g. abdominal compartment syndrome with organ dysfunction). [4]

Ultrasonography (US) is a widely accepted diagnostic tool for gastrointestinal disease. Bedside point-of-care US (POCUS) is increasingly used to facilitate accurate diagnosis, monitor fluid status, and guide emergency and critical care procedures. [5-7] Gastrointestinal function can be assessed with US, thus providing anatomical and functional information through evaluation of the lumen, wall and surrounding structures of the stomach and bowel. However, it may be best used in combination with the evaluation of functional processes such as peristalsis and blood flow, providing important information about food passage and perfusion. [8] Such an approach may lead to an improved practical management approach for adult ICU-patients with AGI through better visualization of bowel pathology and associated changes in real time ("live anatomy"). [8] We propose a sonography protocol as part of POCUS evaluation of the GI and urinary tract in critically ill patients with four main examination endpoints: diameter, mucosal thickness, peristalsis, and blood flow. The mnemonic GUTS (the Gastrointestinal and Urinary Tract Sonography protocol) is derived from this approach.

General Sonography of the Gastrointestinal Tract

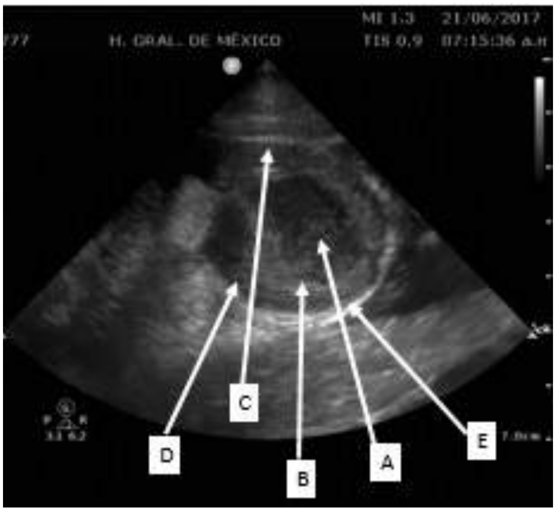

Figure 1. POCUS of the GI tract helps to identify 5 layers. A: a hyperechogenic inner layer – represents the border between the digestive fluid and mucosa; B: a hypoechogenic layer – a thin layer that represents mucosa, lamina propria, and lamina muscularis; C: a hyperechogenic layer – represents submucosa; D: a hypoechogenic layer – represents the muscular layer, the thickness of which depends on the segment of the digestive tract being examined ; E: an outer hyperechogenic layer – represents the border between the peridigestive fat and serous layer. [11]

For a complete examination, both low and high-resolution probes are needed with 5 or 7 MHz transducers. Abdominal compression should be performed using the US probe, in the same way as when performing palpation with the fingertips. [9] POCUS of the GI tract helps to identify five layers (Fig.1), visualized only when the intestinal walls are normal. [10, 11, 31, 38]

1) A hyperechogenic inner layer – represents the border between the digestive fluid and mucosa; [11]
2) A hypoechogenic layer – a thin layer that represents mucosa, lamina propria, and lamina muscularis; [11]
3) A hyperechogenic layer – represents submucosa; [11]
4) A hypoechogenic layer – represents the muscular layer, the thickness of which de-

pends on the segment of the digestive tract being examined; [11]
5) An outer hyperechogenic layer – represents the border between the peri-digestive fat and serous layer. [11]

Doppler Techniques

Doppler US is used to assess the signal from visceral vessels that supply the GI tract, and smaller vessels within the intestinal wall. This technique cannot assess capillary flow. Doppler US mode helps perform an analysis of superior and inferior mesenteric in-flow using pulsed Doppler scanning and provides several quantifiable parameters such as pulsatility index (5.3 ± 2.7), resistance index (1.1 ± 0.1), systolic (8.4mm ± 3.5) and diastolic (3.2mm ± 0.7) velocities, and blood flow volume (305 mL/min ± 168). [12-14] For optimal assessment of GI vessels it is suggested to position the probe over the sample area at a distance of 2–3cm distal to the origin of the vessel (performed in a longitudinal plane as it runs parallel to the aorta), and in a proximal direction to any side branches. [14-16] The probe should be tilted to an angle of <60° and a high pass filter of 100 – 200 kHz used to eliminate low frequencies related to vessel wall movement. [17, 18]

GASTRIC ULTRASOUND

Dysfunctional gastric emptying in critically ill patients can contribute to complications during procedures related to airway management and can result in unsuccessful enteral feeding, and an increased risk of aspiration. [19] Animal experiments have shown a link between the severity of pulmonary damage and the volume of gastric fluid aspirated. [20] A 6-hour fasting period (2 hours for clear fluid) has been recommended for patients undergoing elective surgery to reduce the risk of aspiration during anesthesia. [21] In the ICU, gastric emptying is frequently altered and influenced by several factors including age, diagnosis on admission [22], underlying disease processes [23], therapeutic interventions, medications [24,25], electrolyte and metabolic disturbances, and mechanical ventilation. [26]

The measure of the antral cross-sectional area (CSA) by US is feasible in most critically ill patients. Several studies suggest that the distal parts of the stomach (antrum and body) are evaluated better in a semi-sitting position. [27-32]

Procedure

Abdominal US should be performed with standard settings, and a curvilinear, low-frequency transducer (2–5 MHz) for the GUTS protocol. This provides the necessary penetration to identify relevant anatomical landmarks. [32] Normal gastric wall thickness is 4–6mm and has the distinct five layers as described above (Fig. 2). [11, 27-32, 38] This is often referred to as the "gut" signature. The three following sonogram windows are used to assess the gastric antrum.

1) Epigastric: Probe is placed sagittally over the epigastric area and rotated clockwise to visualize the gastric antrum, under the left hepatic lobe (LHL), superior mesenteric vein (SMV), and above the inferior vena cava (IVC) (Fig. 2a).
2) Subcostal: Probe is placed sagittally at 45 degrees at the left subcostal area, then rotated clockwise to visualize the gastric body, superior to IVC and SMV, and a transversal image of the LHL (Fig. 2b).
3) Trans-splenic: Probe is placed in the mid-axillary line and at the left subcostal margin to visualize the gastric fundus beside the splenic hilum (Fig. 2c).

The epigastric window remains the most validated position. It assesses the longitudinal (D1) and anteroposterior (D2) diameters of a single section of gastric antral CSA using the abdominal aorta and the left lobe of the liver as landmarks, to consistently maintain the same standardized scanning level (Fig. 1a, b). [33]

Koenig et al. [35] published a study to qualitatively assess the gastric contents of patients requiring urgent endotracheal intubation with a rapid (< 2 min) left upper-quadrant US examination helping to identify patients with a full stomach (mean gastric volume of 553 ± 290 mL). [35]

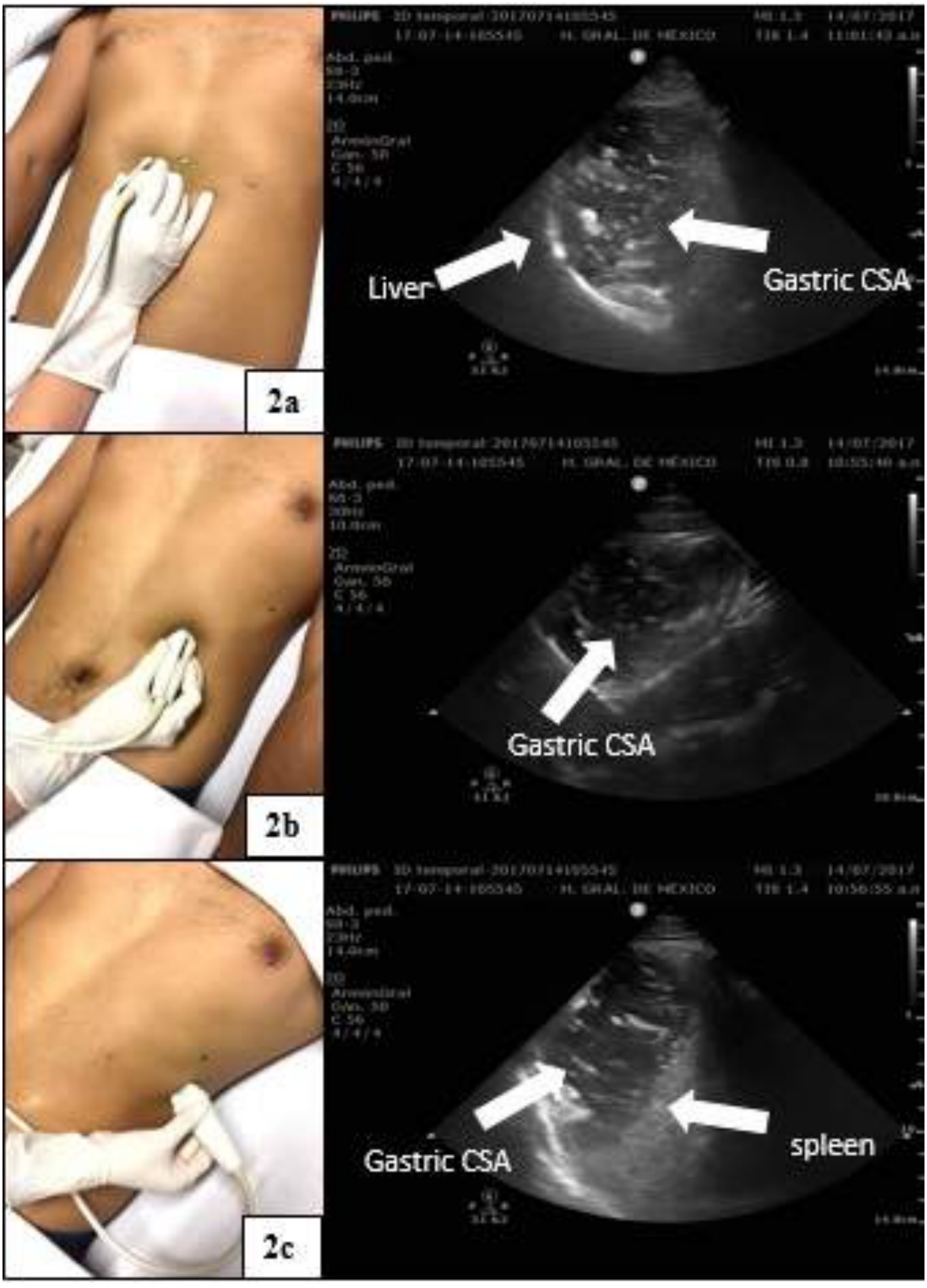

Figure 2. Gastric ultrasound windows of a healthy volunteer with a full meal: 2a Epigastric; 2b Subcostal; 2c Transsplenic.

Kruisselbrink described "near perfect" intra- and inter-observer reliability (correlation coefficient > 0.8) with maximum bias within a 13% limit. [36] Bouvet found a significant positive relationship between antral CSA and aspirated gastric fluid volumes. [37] The cutoff value of antral CSA predicting the risk for aspiration was considered to be 340 ml with 91% sensitivity and 71% specificity. The author found an area under the receiver operating curve of 0.9. Gastric US can also identify other pathologies such as gastric tumors (carcinomas and rarely teratomas), hypertrophic pyloric stenosis, and even bezoar related to enteral nutrition.

SMALL AND LARGE BOWEL ULTRASOUND

For a complete bowel examination both low and high-resolution probes are needed, the latter using a frequency above 5 MHz for measuring bowel wall thickness. The scan starts by placing the probe over the right iliac fossa to identify the terminal ileum. The probe is moved cranially and caudally to scan overlapping sectors and applying sufficient pressure to identify the dorsal wall of the abdominal cavity. [38]

Bowel Wall Thickness

The most common finding is the wall thickness of normal small and large intestine being <2mm when distended. [39, 40] The exceptions to this are the duodenal bulb and rectum, which are less than 3 and 4mm, respectively. [39]

Bowel Diameter and Intraluminal Contents

The diameter of the bowel and its contents may vary according to site, fasting/feeding state, and bowel function. Normal bowel loops show a maximal diameter of 25mm for small bowel and 50mm for colon. [4] These values are used as cutoffs for intestinal bowel obstruction, other pathological conditions such as intestinal infectious and inflammatory diseases, and abnormalities that affect bowel peristalsis. [38] Intraluminal content of the gut appears as a thin hyperechoic line on a longitudinal section, representing the interface between the two mucosae that face each other when empty. [38] Gaseous content produces comet tail artifacts (as seen in lung ultrasound) that can hide the bowel wall distal to the probe. [39] In this case, only the most superficial wall can be properly studied. When evaluating intraluminal content, liquid content appears anechogenic. Both the superficial and distal walls can be visualised as well as the internal profile of the mucosa. [38] When liquids are mixed with a solid or gaseous component, they appear as a corpuscular mass, and the sonographic image will consist of spots of different sizes and echogenicity. When peristalsis is slow, it is possible to distinguish different layers in the intraluminal content. [38] Solid matter may be appreciated with a stone-like aspect or as a dark solid mass with posterior shadowing. This is usually observed in the colon. [38]

Bowel Wall Vascularity

Color or power Doppler sonography is used to estimate perfusion abnormalities and may show hyperemia. The spectral analysis of Doppler signals of arteries supplying the GI tract (truncus celiacus, superior and inferior mesenteric arteries) and the vessels draining the intestine, can be used to estimate bowel perfusion. Color Doppler can usually assess the perfusion in vessels 1mm in width, with blood flows up to 1mm/sec. Colour Doppler allows for the assessment of mural flow, the absence of which is a sign of ischemia. Unfortunately, this finding is only reported in 20–50% of the patients with a proven diagnosis of ischemic colitis. [42, 43]

Peristalsis

Assessment of bowel peristalsis is difficult and subjective but may provide useful information in several intestinal diseases. Increased small bowel peristalsis has been described in coeliac disease and acute mechanic bowel obstruction. This is in contrast to a dynamic ileus that is characterized by an absence of peristaltic movements. [44, 45] Dilated loops of bowel are essentially static, and the bowel contents do not move.

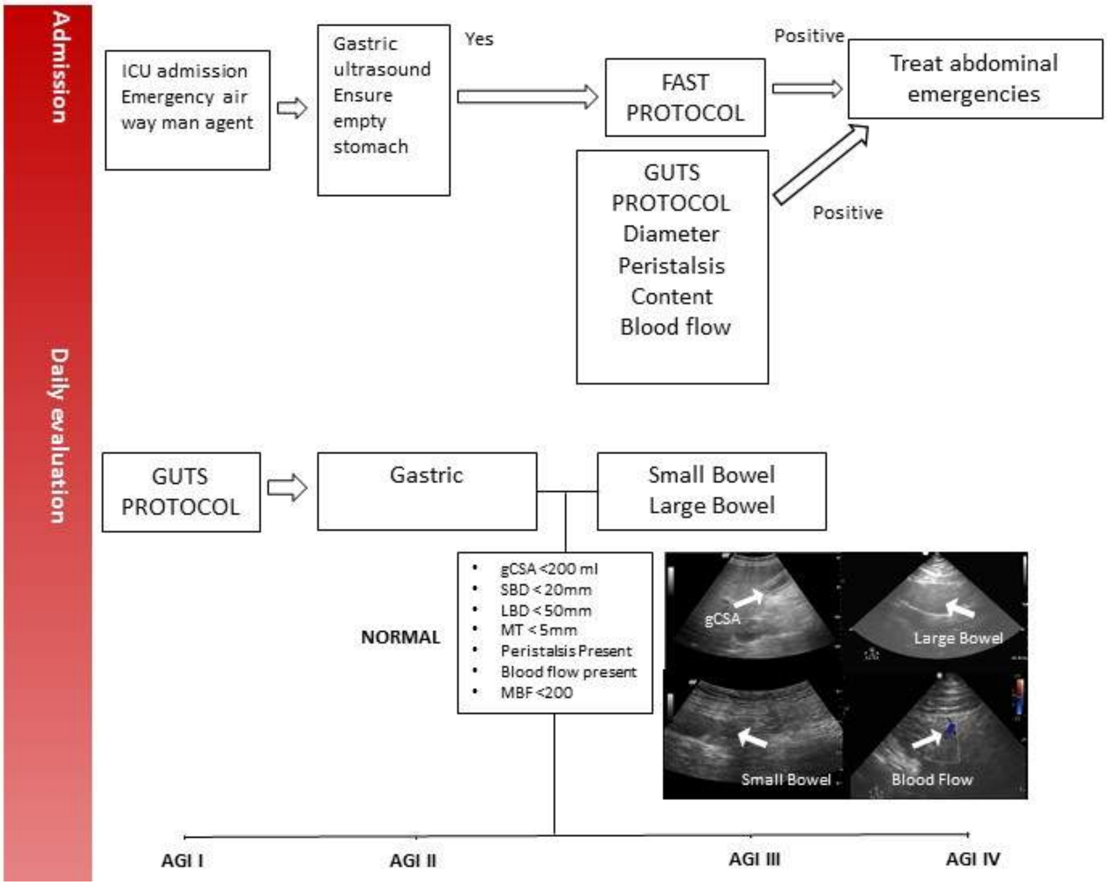

Figure 3. GUTS Protocol. Part 1. gCSA – gastric cross sectional area, SBD small bowel diameter, LBD large bowel diameter, MT- mucosal thickness, MBF Mesenteric blood flow, IAP - intrabdominal pressure, RI, resistive index, APP abdominal perfusion pressure.

Four different peristaltic movements are described:

1) Absent peristalsis; No peristaltic movement, which can be partial (obstruction, ileus) or complete **(ESM video1)**;
2) Present ineffective peristalsis; Peristaltic movement can be seen, but intestinal content does not move forward, but rather sways (pendulum-peristalsis) **(ESM video 2)**;
3) Present effective peristalsis; Peristaltic movement is propulsive, and bowel content is pushed forward **(ESM video 3)**;
4) Augmented peristalsis; It can be described as partial (obstruction, ileus) or total (bacterial overgrowth) **(ESM video 4)**. [46]

Noninvasive Gastrointestinal Monitoring

While controversy still exists about optimal gastric volume and further research is required to examine its use in the critically ill patient, some of the GI dysfunctions in critically ill patients that can be monitored with ultrasound are summarized in **Table 1.** For the experienced user, GI ultrasound allows identification of pathology in the intestinal tract: small or large bowel intussusception, inflammatory bowel disease, necrotizing enterocolitis, Meckel's diverticulum, appendicitis, diverticulitis or duplication cysts.

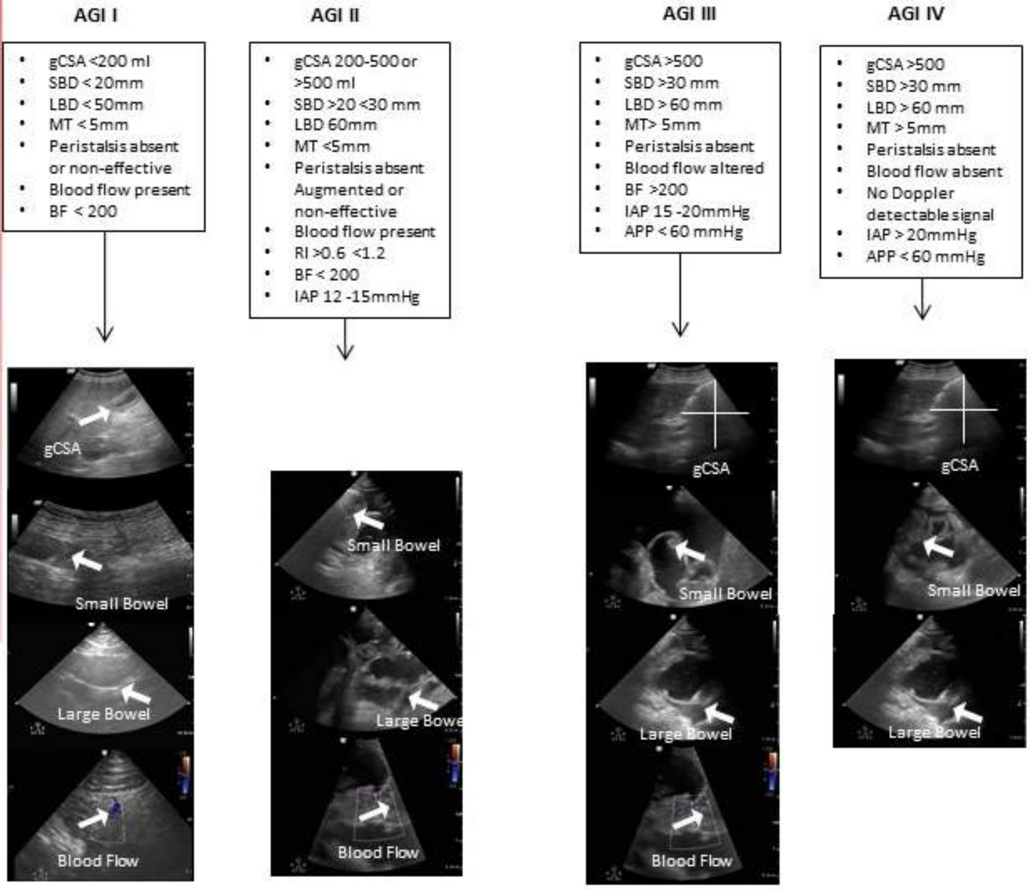

Figure 3. GUTS Protocol. Part 2. gCSA – gastric cross sectional area, SBD small bowel diameter, LBD large bowel diameter, MT- mucosal thickness, MBF Mesenteric blood flow, IAP - intrabdominal pressure, RI, resistive index, APP abdominal perfusion pressure.

GASTROINTESTINAL AND URINARY TRACT SONOGRAPHY PROTOCOL (GUTS) (Fig 3)

On admission, Focused Assessment with Sonography for Trauma (FAST) and GUTS protocol should be performed for the diagnosis of GI emergencies. After initial treatment and stabilization, application of daily GUTS protocol at the bedside can help clinicians assess the evolution of GI function. Normal findings were described previously. Classification of pathological findings are listed below.

AGI Grade I

According to the definition and clinical findings proposed by the ESICM Working Group on Abdominal Problems [4], patients with AGI grade I have gastric ultrasound findings showing an antral CSA with a predicted volume <300ml [37], and absent or ineffective (intestinal content sways) peristalsis. Blood flow is present at all times, with some hyperemia on Doppler ultrasound. Small bowel diameter is less than 20mm, and the diameter of the colon is less than 50mm. Mucosal thickness is normal and <5mm.
Other possible ultrasound findings are the presence of ascites in FAST, and renal Doppler flow

showing a resistive index of less than 0.7. Resistive index (RI) can be calculated as follows:

$$RI = \frac{\underline{\textit{(peak systolic flow – diastolic flow)}}}{\textit{Diastolic flow in the renal arteries}}$$

AGI Grade II

Gastric ultrasound shows an antral CSA of >300ml [37] or >500ml in gastroparesis, peristalsis is absent or ineffective, augmented peristalsis can be seen in the presence of bacterial overgrowth. Blood flow is present at all time, hyperemia can be present, small bowel diameter >20mm, but <30mm, and colonic diameter <60mm. Mucosal thickness is usually <5mm. Other ultrasound findings are the same as in AGI grade I.

AGI Grade III

Gastric ultrasound demonstrates an antral CSA of >300ml [37] or >500ml in gastroparesis, peristalsis is absent, intestinal content varies, and blood flow is absent or severely diminished**.** Small bowel diameter is >30mm, and colonic diameter is >60mm (toxic megacolon should be suspected when the diameter of the colon is more than 60-65mm). Mucosal thickness is classically >5mm. Other ultrasound findings are an RI>0.7 on renal Doppler and diaphragmatic excursions <1.5cm in spontaneous breathing ventilation (diaphragm excursion is abolished in controlled ventilation). Ascites may be present.

AGI Grade IV

Sonographic findings are the same as in AGI Grade III, with absent blood flow**.** Other ultrasound findings are a renal Doppler RI>1 indicating a severe compromise of renal blood flow, the presence of acute kidney failure (AKI), and diaphragmatic excursions <1.5cm in spontaneously breathing ventilation. Significant ascites may be present. The ESICM Working Group on Abdominal Problems included GI bleeding leading to hemorrhagic shock as a Grade IV AGI (ESM video 5 shows a massive GI bleed).

Gastroparesis with high gastric residuals or reflux,
Paralysis of the lower GI tract
Visible blood in gastric content or stool.
Feeding intolerance is present if at least via enteral route.
Bowel dilatation
Bowel ischemia,
Bowel Obstruction
GI bleeding leading to hemorrhagic shock,
Ogilvie's syndrome,
Ascitis
Bowel Bacterial overgrowth
Toxic Megacolon
Intraabdominal perfusion
Ileum

Table 1. GI dysfunctions that could be monitored with ultrasound in critically ill patients

COMPLEMENTARY EVALUATION

Daily evaluation of the GI tract in critically ill patients should include a sonographic Doppler evaluation of renal, liver, splenic arteries and portal vein, as part of an intraabdominal perfusion examination.

Renal Doppler

The RI, pulse wave Doppler signal from segmental branches of the right renal artery, showed a slight but significant during intraabdominal hypertension. This suggests an increase of intrarenal pressure. [47] The RI reflects vascular resistances and increases in acute and chronic renal disease. This index is affected by IAH and may represent an early sign of renal impairment. [47] A recent meta-analysis suggested that RI may be a predictor of persistent AKI in critically ill patients with a pooled sensitivity and specificity of 0.83 (95% CI, 0.77-0.88) and 0.84 (95% CI, 0.79-0.88) and a positive and negative likelihood ratio of 4.9 (95% CI, 2.44-9.87) and 0.21 (95% CI, 0.11-0.41). [49] However, renal RI could increase for many other reasons. It has been proposed as an early marker of renal dysfunction in sepsis, cardiac surgery, IAH, the need to use vasopressors, and should be taken into consideration during interpretation. [47-50]

Bladder

The easiest way to scan the urinary bladder is by an external suprapubic abdominal approach with a convex 2.5–5MHz probe. Bladder volume can be calculated by scanning the bladder transversely and longitudinally and using the following ellipsoid formula:

$$Volume = height \times width \times depth \times 0.5236$$

However, the bladder is never totally spherical therefore operators should allow for some measurement error. When evaluating the urinary track as part of the GUTS protocol, the absence of bladder content could be an approach to the evaluation of oliguria for AKI related to IAP or ACS, and may also help identify any obstruction caused by urine catheter malfunction.

Liver and spleen

Ultrasound of the liver is divided in general US views, which includes anatomic views of the liver, gallbladder, and biliary tree. This is important but beyond the scope of this paper. However, Doppler analysis of hepatic and spleen circulation and portal vein should be performed for the assessment of intra-abdominal organ perfusion. The main findings of liver vessel Doppler US are described in portal hypertension and liver compartment syndrome following subcapsular hematoma. Unfortunately, there are no studies on Doppler US evaluation in patients with IAH. Cavaliere published a physiological study in sixteen healthy volunteers with an IAH simulation model where he found the inferior vena cava was compressed and deformed, the portal vein also had a decreased diameter, but blood velocity did not change significantly in the inferior vena cava, portal vein, right suprahepatic vein, or right external iliac vein. [50] He also reported a sensitivity of 65.6% and a specificity of 87.5% in the inferior vena cava section lower than $1cm^2/m^2$ to discriminate between the presence or absence of intra-abdominal hypertension. Finally, he found non-invasive ventilation did not affect vein sizes and velocities. Portal vein flow velocity has been reported to be from 14 to $16cm/sec^2$. Hepatic artery Doppler resistive index <0.78 and splenic artery resistive index <0.63 should be considered normal. [51] While there is neither evidence nor any published research on this issue, any increase in RI or portal vein flow velocity should be considered an alteration in perfusion seen primarily in patients with AGI grade IV.

DISCUSSION

The proposal for assessment of GI function with POCUS at the bedside could equip physicians with the ability to recognize abnormal pathology and physiology in critically ill patients with GI dysfunction. The four main features of the intestine should be accurately identified, namely: the gastrointestinal diameter (and intraluminal content), mucosal wall (thickness echo pattern, vascularity), peristalsis and motility, and blood flow. Gastrointestinal ultrasound is a noninvasive, inexpensive, widely available and repeatable tool that can be used at the bedside and can help to identify patients that may need more invasive (and more expensive) procedures. However, as with all POCUS techniques there is a learning curve, and the observed findings will need expert interpretation in order to explain common ICU complications, such as Clostridium difficile infection, bacterial peritonitis etc. [38] Incorporating GUTS into daily clinical evaluation of GI dysfunction will increase the accuracy of the technique in order to correlate the US findings with clinical severity of GI dysfunction. We believe that gastric content and volume assessment will become a new POCUS application and the standard of care. This could help to determine the risk for aspiration, a technique that is already widely used in anesthesia. [22, 23, 27-29, 33-37]

Perlas found the antral CSA grade correlates with gastric volume (gastric residual volume = 27.0 + 14.6 x right-lateral CSA – 1.28 x age). [31] Using this formula it is possible to non-invasively assess gastric volume at the bedside based on sonographic measurements of right lateral CSA. According to the author, this model predicts volumes from zero to 500mL and applies to nonpregnant adult patients with a body mass index (BMI) <40kg/m^2.[31] Both quantitative and qualitative gastric US can be used at the bedside. Others have found that the antral CSA has a positive correlation with gastric volume allowing a qualitative assessment of gastric volume with clinically acceptable accuracy. [34] Obtaining the antral CSA may be difficult in some critically ill patients, however, the technique is promising. Assessing gastric status could become a standard procedure in the critically ill, allowing safe emergency airway procedures and identifying patients at increased risk of gastric aspiration, or guiding appropriate medications when enteral feeding is not well tolerated. [34] The use of US to assess gastric contents by measuring antral CSA has already been studied in healthy volunteers. In the preoperative setting, it showed a very high degree of accuracy (98.5–100 %).

To date, the use of the GUTS protocol to diagnose and treat GI dysfunction in critically ill patients has not been shown to change the outcome. However, we believe that this intervention could make a significant contribution to GI care protocols **(fig 2)** and help clinicians with accurate daily clinical decisions. [46]

The GUTS protocol has limitations. Despite bedside availability, ease of use, repeatability, and noninvasiveness, there is a need for adequate training to use and interpret the ultrasound images correctly. The GUTS protocol cannot be considered to be disease specific. Therefore, it should always be interpreted in conjunction with clinical and laboratory data. Artifacts (interference of air-filled bowel) and patient constitution (obesity) contribute to limitations. Evaluating GI function by US is operator dependent and subject to interpretative errors.

CONCLUSIONS

This paper summarizes the potential utility of ultrasonography for monitoring GI function and dysfunction in the critical care settings and may lead to appropriate therapeutic interventions. Real-time ultrasound with the GUTS protocol is a simple, inexpensive and portable imaging technique that can provide anatomical and functional GI information. Future research is needed to assess the ability of the GUTS protocol to identify patients with GI dysfunction according to the grade of AGI as suggested by the ESICM working group.

Electronic Supplemental Material

ESM video 1; Absent peristalsis; we observe a small bowel loop with no peristaltic movement, secondary to ileus, essentially static, and the bowel contents do not move. We also observe ascites with dendrites. The large bowel has no peristaltic movement, and small bowel with same characteristics.

ESM video 1.mp4

ESM video 2; Present ineffective peristalsis; Peristaltic movement can be seen, but intestinal content does not move forward, but rather sways (pendulum-peristalsis)

ESM video 2.mp4

ESM video 3; Present effective peristalsis; Peristaltic movement is propulsive and bowel content is pushed forward.

ESM video 3 .mp4

ESM video 4; Augmented peristalsis; It can be described as total (bacterial overgrowth) in the video we observe the presence of ascites with dendrites and an augmented peristalsis of the small bowel. Partial augmented peristalsis (obstruction, ileus), we observe the presence of augmented peristalsis and a loop of small bowel with absent peristalsis secondary to intra-abdominal adherences.

ESM video 4.mp4

ESM video 5; The ESICM Working Group on Abdominal Problems included GI bleeding leading to hemorrhagic shock as a Grade IV AG, in this video we observe absent peristalsis with a propulsive intraluminal content corresponding to a massive GI bleeding.

ESM video 5 .mp4

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Notes

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CHAPTER 11

The state of critical care ultrasound training in Europe: A survey of trainers and a comparison of available accreditation programmes

Laura Galarza, Adrian Wong, Manu L.N.G. Malbrain

Background: Critical care ultrasound (CCUS) in Intensive Care Unit has been increasing exponentially for diagnostic and therapeutic purposes, however the lack of a uniform formal training structure and programme has posing the question of whether scans have been appropriately performed or reported, and whether there exists proper clinical governance to ensure a high standard of care.

Methods: An online survey was sent to the representatives of various national intensive care societies via the European Society of Intensive Care Medicine CoBaTrICE committee. A comparison between 5 worldwide accreditation programmes was also made.

Results: 27 from 42 countries replied our survey. 5 countries had a nationally accredited programme in ICM Echocardiography and 6 were developing it. 3 countries had a CCUS accredited program. Most had local programmes. Transthoracic echocardiography, lung and vascular ultrasound were considered essential. CCUS training programme should incorporate a combination of theoretical and practical teaching, but it is not clear which is the best format. Main barriers to delivering CCUS training included the lack of formally agreed competencies, lack of trainers and lack of time. There is also a lack of agreement between the five accreditation programmes.

Conclusions: There is a need for a well-structured and competent CCUS training program.

INTRODUCTION

There is currently a lack of universally accepted criteria for gastrointestinal (GI) failure or dysfunction in critical care. Furthermore, the clinical assessment **Introduction**
The use of ultrasound in critical care for diagnostic and therapeutic purposes has been increasing exponentially. Once the remit of radiologists and cardiologists, point-of-care ultrasound and focused echocardiography is becoming increasingly routine armament for all acute specialties including intensive care medicine, despite the lack of evidence that it improves patient mortality in the ICU setting.

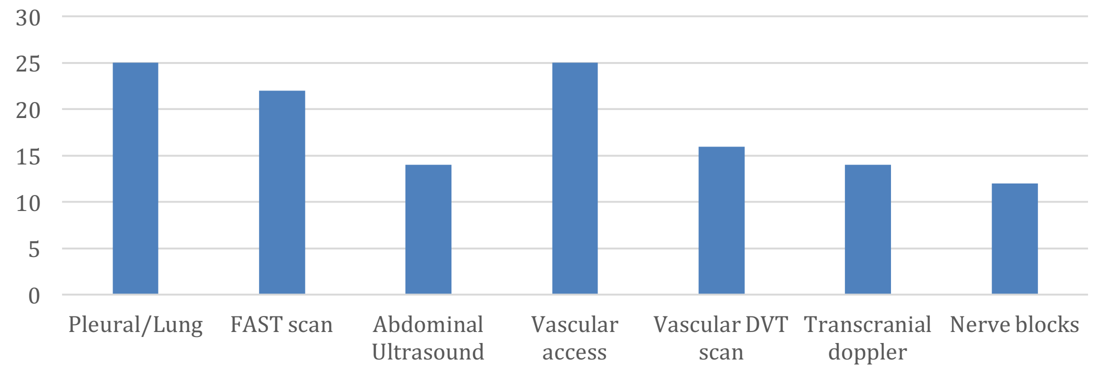


Figure 1. Modules that should be included in CCUS programme (Y axis indicates number of respondents).

As the list of diagnostic and therapeutic interventions is large, most critical care ultrasound (CCUS) programmes tend to be more focused examinations compared to that performed by radiologists. This approach has been adopted by most acute specialties including Emergency Medicine. The Royal College of Radiologists has published guidelines for non-radiologists wanting to train in ultrasound [1]. It recognises the increasing availability of ultrasound and acknowledges the role it plays in diagnosis and management of patients; clinicians now use ultrasound evaluation as an extension of the bedside clinical examination. Hence CCUS may become the modern stethoscope of the bedside critical care physician [2].

Although championed by enthusiasts, the use of CCUS has lagged behind that of other acute specialties. Two international expert statements have acknowledged the challenges of obtaining appropriate training in echocardiography and CCUS [3, 4], and further described the components of competence with specific goals of training and skill development. Despite this, the lack of a uniform formal training structure and programme is a recurring issue worldwide, posing the question of whether scans have been appropriately performed/reported, and whether there exists proper clinical governance to ensure a high standard of care.

The aim of our survey was to ascertain the current state of CCUS training in Europe. We also compared the available accreditation programmes worldwide and the perceived barriers for colleagues in accessing CCUS training.

Methodology

An online survey was sent to the representatives of various national intensive care societies via the European Society of Intensive Care Medicine CoBaTrICE Committee. Members of the committee play a role in Intensive Care Medicine (ICM) training and programme development at national level. The survey addressed several areas of interest including current state of training, modules included and accreditation process and also where they perceived barriers to training in CCUS. The survey was conducted over a 6-month period between February and July 2016, allowing for 2 rounds of reminders to be sent to the representatives. The results were analysed using Google Form.

Five widely publicised CCUS accreditation programmes were analysed. Comparisons were made with regard to modules, training format, duration and assessment.

Results

27 from 42 countries contacted replied giving a response rate of 64%. These included the larger Western European countries such as France, Spain, Italy, UK and Germany.

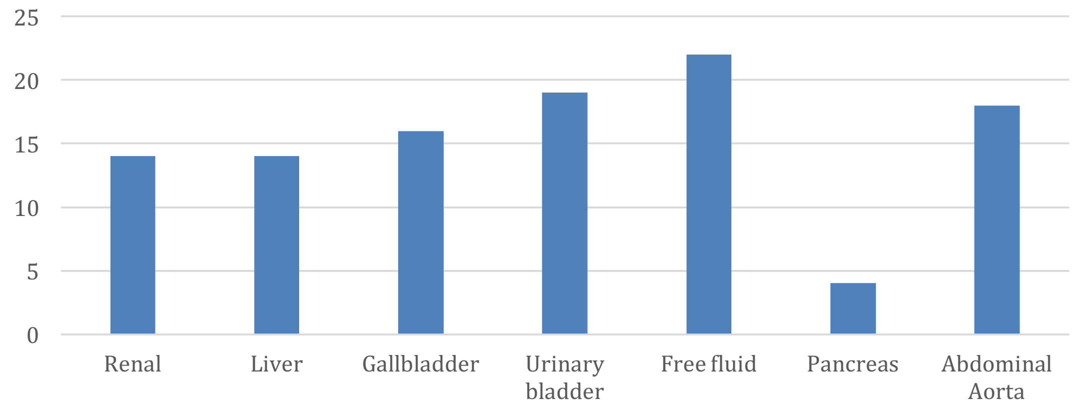


Figure 2. Submodules that should be included in the abdominal module of CCUS programme (Y axis indicates number of respondents).

Only 5 countries had a nationally accredited programme in ICM Echocardiography. These were the UK, Italy, Netherlands, Germany and Spain. A further 6 countries were in the process of developing one. The lack of formal accreditation programme did not mean that trainees were not exposed to echocardiography with a further 5 countries incorporating them into their ICM training programme. The majority of respondents (81%) had access to locally delivered transthoracic echocardiography (TTE) courses. 92.6% of respondents felt that TTE was an essential skill for Intensivists, only 40.7% thought that transoesophageal echocardiography (TOE) was.

Respondents agreed that a CCUS training programme should incorporate a combination of theoretical and practical teaching. A logbook should be kept. 74% of respondents felt that a formal assessment is required to ensure competencies. The main barriers to delivering CCUS training included the lack of formally agreed competencies, lack of trainers and lack of time. Resistance from specialities outside of ICM was also highlighted.

Five programmes were identified (Table 1):

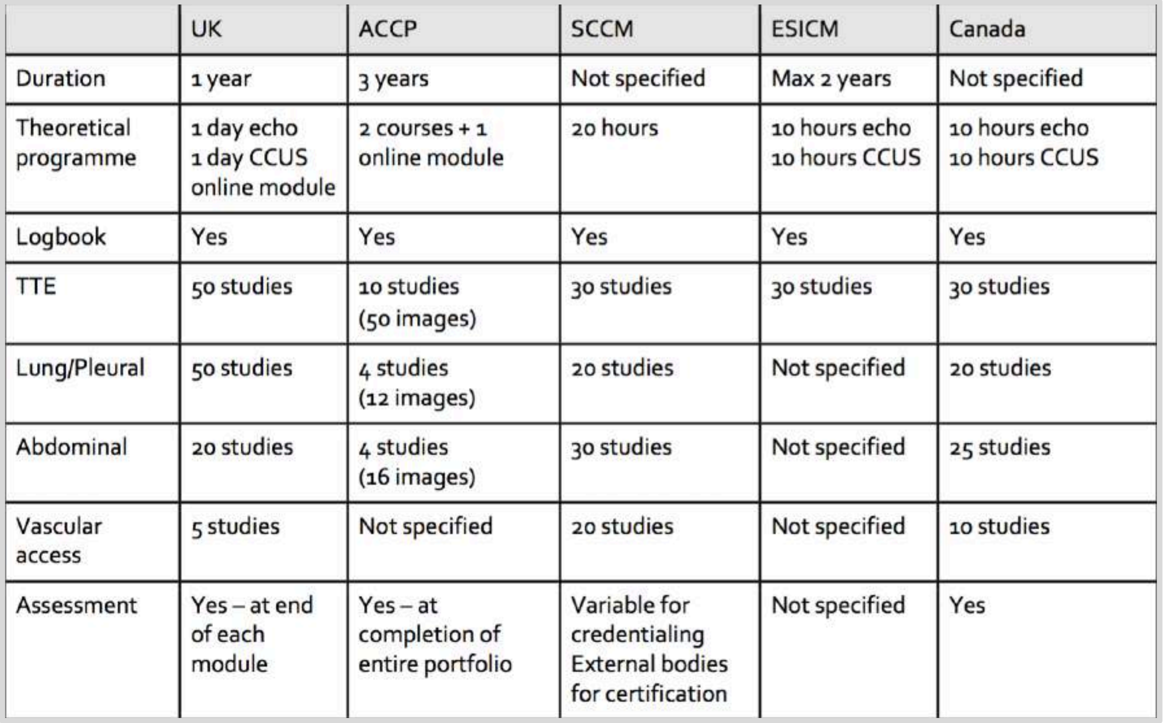
- American College of Chest Physician (ACCP) Critical Care Ultrasonography [5]
- Society of Critical Care Medicine programme (SCCM) [6, 7]
- Canadian Intensive Care Society programme [8]
- Core Ultrasound Skills in Intensive Care (CUSIC) and Focused Intensive Care Echocadiography (FICE) programme [9, 10]
- European Society of Intensive Care Medicine (ESICM) [3]

With regards to general CCUS only 3 countries had a national accreditation programme – United Kingdom, Spain and the Netherlands.

There was variation in which modules the respondents felt should be included in a CCUS training programme (Figure 1). Lung ultrasound and vascular ultrasound for obtaining access were considered essential. Transcranial Doppler and ultrasound-guided nerve blocks were deemed less important. Opinions regarding abdominal ultrasound training were divided in terms of its relevance to clinicians and what should be included in a training programme (Figure 2).

Discussion

There is little doubt that CCUS is a useful tool for Intensivists. Our survey has shown that there is considerable variation in access to CCUS training in the various national ICM training programmes and how training is delivered across Europe.



	UK	ACCP	SCCM	ESICM	Canada
Duration	1 year	3 years	Not specified	Max 2 years	Not specified
Theoretical programme	1 day echo 1 day CCUS online module	2 courses + 1 online module	20 hours	10 hours echo 10 hours CCUS	10 hours echo 10 hours CCUS
Logbook	Yes	Yes	Yes	Yes	Yes
TTE	50 studies	10 studies (50 images)	30 studies	30 studies	30 studies
Lung/Pleural	50 studies	4 studies (12 images)	20 studies	Not specified	20 studies
Abdominal	20 studies	4 studies (16 images)	30 studies	Not specified	25 studies
Vascular access	5 studies	Not specified	20 studies	Not specified	10 studies
Assessment	Yes – at end of each module	Yes – at completion of entire portfolio	Variable for credentialing External bodies for certification	Not specified	Yes

Table 1. Accreditation programmes in point-of-care ultrasound

Although critical care echocardiography is more established compared to general CCUS, only 5 countries had an established, formal accreditation programme for TTE. Despite this, it was considered an essential skill by over 90% of respondents. This is further evidenced by the fact that despite the lack of formal accreditation, exposure to TTE is incorporated into the training programmes of 46% of respondents with a further 17% currently developing programmes. Locally-organised TTE courses and training are available in the countries of 84% of respondents. Unsurprisingly, TOE is less well established being more invasive than TTE. The expertise required to deliver TOE training to the appropriate level and logistical considerations make this module more challenging to acquire compared to TTE.

General CCUS was less accessible and only 3 countries had formally adopted a national accreditation programme into their ICM training. Lung and vascular access ultrasound were the most well-established. More divisive is the abdominal which is probably the ultrasound modality most established outside radiology and cardiology. Indeed, the use of ultrasound in resuscitation such as the Focussed Abdominal ultrasound Scan in Trauma (FAST scan) is part of the skillset of most emergency physicians. Given the extensive list of intra-abdominal pathology that can be diagnosed on ultrasound, there was a lack of agreement as to what should be included into the list of competencies.

Our survey also highlighted the barriers to deliver a high quality-training programme for CCUS. The lack of trainers, time and agreed set of competencies have been particularly highlighted. For countries such as the UK with established accreditations for critical care echocardiography (FICE) and general CCUS (CUSIC), there remains the challenge of the lack of trainers which limits its incorporation into the national ICM training programme.

Opponents to the extended use of ultrasound outside of Radiology (or echocardiography outside of Cardiology) have raised concerns about the competencies of clinicians to perform and interpret such scans. Hence, the issue of training and accreditation is vital. Our survey has shown that there is considerable variation in the delivery of CCUS across Europe and indeed worldwide. The problem is further compounded by the absence of an agreed method on how best to train in CCUS. It is crucial that such competencies are agreed upon to ensure robust clinical governance.

We compared five accreditation programmes in point-of-care ultrasound specifically focused for the critical care setting. There were 3 from the Americas: the American College of Chest Physician CCUS, the Society of Critical Care Medicine programme and the Canadian Intensive Care Society programme. Two programmes were identified from Europe: the Core Ultrasound Skills in Intensive Care (CUSIC) programme from the UK and European Society of Intensive Care Medicine. There are other programmes available such as the WinFocus programme [11] which is not country-specific. Common themes across the programmes included the need for didactic teaching, direct supervision and maintenance of a logbook.

Delivery of didactic teaching varies between face-to-face courses and online teaching modules, and differ in their duration and structure. Although online teaching modules can improve accessibility to CCUS training, they do not address the issue of the shortage of trainers. Hands-on supervision early on in the learning curve is invaluable; without a critical mass of trainers, accessibility to CCUS will remain a challenge.

Within the different modules, the programmes again differ as to which competencies should be included. As an example, the abdominal module in the UK accreditation involves assessment of free fluid and urinary bladder scans. The Canadian programme includes renal ultrasound for the assessment of hydronephrosis and abdominal aortic scanning.

Other differences are the minimum number of scans and assessments between the programmes. These variations and lack of consensus need to be addressed to ensure that clinicians are competently trained. National bodies and large specialty organisations such as the Society of Critical Care Medicine and the European Intensive Care Society should play a role in this area.

Conclusion

Our survey provides a detailed analysis of the state of CCUS training in Europe. It highlights significant variation in the various programmes and the barriers to delivering training. When comparisons were made between prominent accreditation programmes, we noted significant variations in the delivery and expected competencies. Such issues need to be addressed before CCUS can be included in national ICM training programmes.

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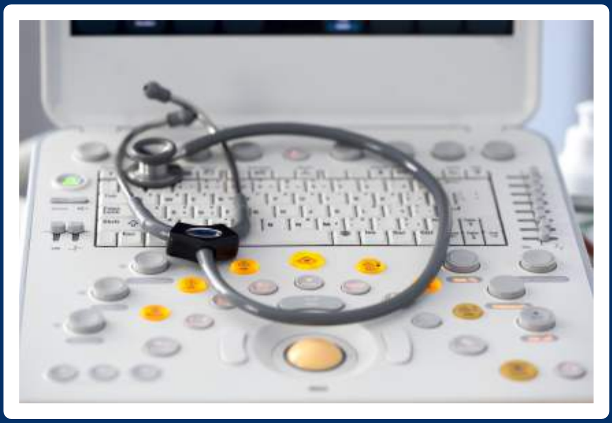
Notes

The iFAD started as local initiative form the pharmaceutical working group on fluids from the Ziekenhuis Netwerk Antwerpen (www.zna.be). Today iFAD is integrated within the not-for-profit charitable organization iMERiT, International Medical Education and Research Initiative, under Belgian law and as such the iFAD Organising Committee strongly recognizes and values a constructive partnership with all health care workers. The Executive Board of iMERiT as evolved to a majority of international members. The mission is to foster education and promote research on fluid management and monitoring in critically ill patients, by bringing together physicians, nurses, and others from a variety of clinical disciplines. The primary goal is to establish an international collaboration group with the final aim to improve and standardize care and outcome of critically ill patients with an emphasis on fluids, fluid management, monitoring and organ support. This can be achieved by collaborative research projects, surveys, guideline development, joint data registration and international exchange of health care workers and researchers.



This Comprehensive Book on Critical and Acute Care Ultrasound (CACU) summarizes the reviews published during the previous International Fluid Academy Days. The papers are published under the Open Access CC BY Licence 4.0.

Critical and Acute Care Ultrasound together with point of care ultrasound (POCUS) is becoming a holistic and translational discipline and is considered as the modern stethoscope for the critical care and emergency care physician.

Dr Roy Filly, Professor Emeritus of Radiology, and chief of the department of diagnostic sonography in Stanford predicted in 1988 that ultrasound would likely become the new stethoscope: “As we look at the proliferation of ultrasound instruments in the hands of untrained physicians, we can only come to the unfortunate realisation that diagnostic sonography truly is the next stethoscope: poorly utilized by many but understood by few”

This book is edited by Manu Malbrain, Internist-Intensivist, Director of the Intensive Care Department at the University Hospital in Brussels (UZB), Belgium, he is Professor at the Brussels Free University (VUB) and one of the chairmen of the iFAD meeting.