


NARRATIVE REVIEW



Machines that save lives in the intensive care unit: the ultrasonography machine

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Abstract

This article highlights the ultrasonography machine as a machine that saves lives in the intensive care unit. We review its utility in the limited resource intensive care unit and some elements of machine design that are relevant to both the constrained operating environment and the well-resourced intensive care unit. As the ultrasonography machine can only save lives, if is operated by a competent intensivist; we discuss the challenges of training the frontline clinician to become competent in critical care ultrasonography followed by a review of research that supports its use.

Keywords: Ultrasonography, Machine design, EDEC, UPUM

Introduction

The machines that save lives in the intensive care unit (ICU) require that the intensivist be knowledgeable in their use. This is particularly the case with critical care ultrasonography (CCUS); where the machine, when used by a competent operator, guides diagnosis and management of the critically ill patient. To save lives, this operator is tasked with obtaining and interpreting high quality ultrasonography images and immediately applying the results in a systematic and effective manner at point of care. The machine alone is a passive device that can only save lives when used by a capable operator. This article will review the three prerequisites for saving lives: a well-designed machine adapted to the situation that is combined with an adequately trained human operator who is able to use the results in a clinically effective manner at point of care (Fig. 1). We will also review whether there

is an evidence-base to support the contention that the ultrasonography machine, thus deployed, may save lives.

CCUS in case of constraints: the under-resourced ICU

We posit that CCUS may save many lives in the under-resourced ICU, where computerized tomography (CT), magnetic resonance imaging (MRI), or even chest radiographs are not readily available. As imaging is a key component to critical care practice, CCUS can serve as a highly effective and low-cost modality in the hands of the skilled operator.

The constraints (human and material resource limitations) encountered in low and middle-income countries should not be viewed as a singular issue. They impact the care of most critically ill patients around the globe. If we consider the case of sepsis (which is a major indication for CCUS), 85% of the 41 million incident cases and 85% of the 8 million related deaths occurred in countries with low or middle social development index in 2017 [1]. Similar human and material constraints impacted high-resource countries during the coronavirus disease 2019 (COVID-19) pandemic with the massive surge of critically-ill patients [2]. These constraints are also important when caring for the critically ill outside classical ICU

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walls (e.g., in emergency units, during transportation, or in humanitarian medicine). These shared constraints represent an opportunity through the concept of frugal innovation [3]. The frugal solution is designed to answer the need without concession on quality. The end-user needs, and the operational environment are at the heart of this innovation process, with a bottom-up approach. These patient-centred solutions are very meaningful for CCUS, which is primarily a clinically driven approach. They may create a robust continuum between the era of clinical examination and that of complementary examination. In addition to being adapted to a constrained environment, they may also be particularly effective and cost competitive in less constrained situations, in accordance with the concept of reverse innovation (i.e., some insights from low-income countries might offer transferable lessons for wealthier contexts).

The ideal frugal CCUS machine should be centered on robustness, core capabilities and functionality, focused on essential with high value and quality to produce high-end

Take-home message

A well-designed ultrasonography machine can save lives in the intensive care unit; if it is operated by an intensivist who is competent in image acquisition, image interpretation, and application of the results to establish diagnosis and to guide management at point of care.

solutions from a medical perspective, by understanding in depth the clinical need, operational environment, and associated constraints (Table 1). The goal is refined to its maximum to precisely meet needs, without concession on quality, and without superfluous addition [4]. In anticipation of the development of robust artificial intelligence (AI) capability, the frugal CCUS machine should have the potential to be upgraded in the future, as the rapid development of AI for image interpretation [5] may allow the building of reliable decision tools that could be remotely available worldwide with the ongoing constellation of

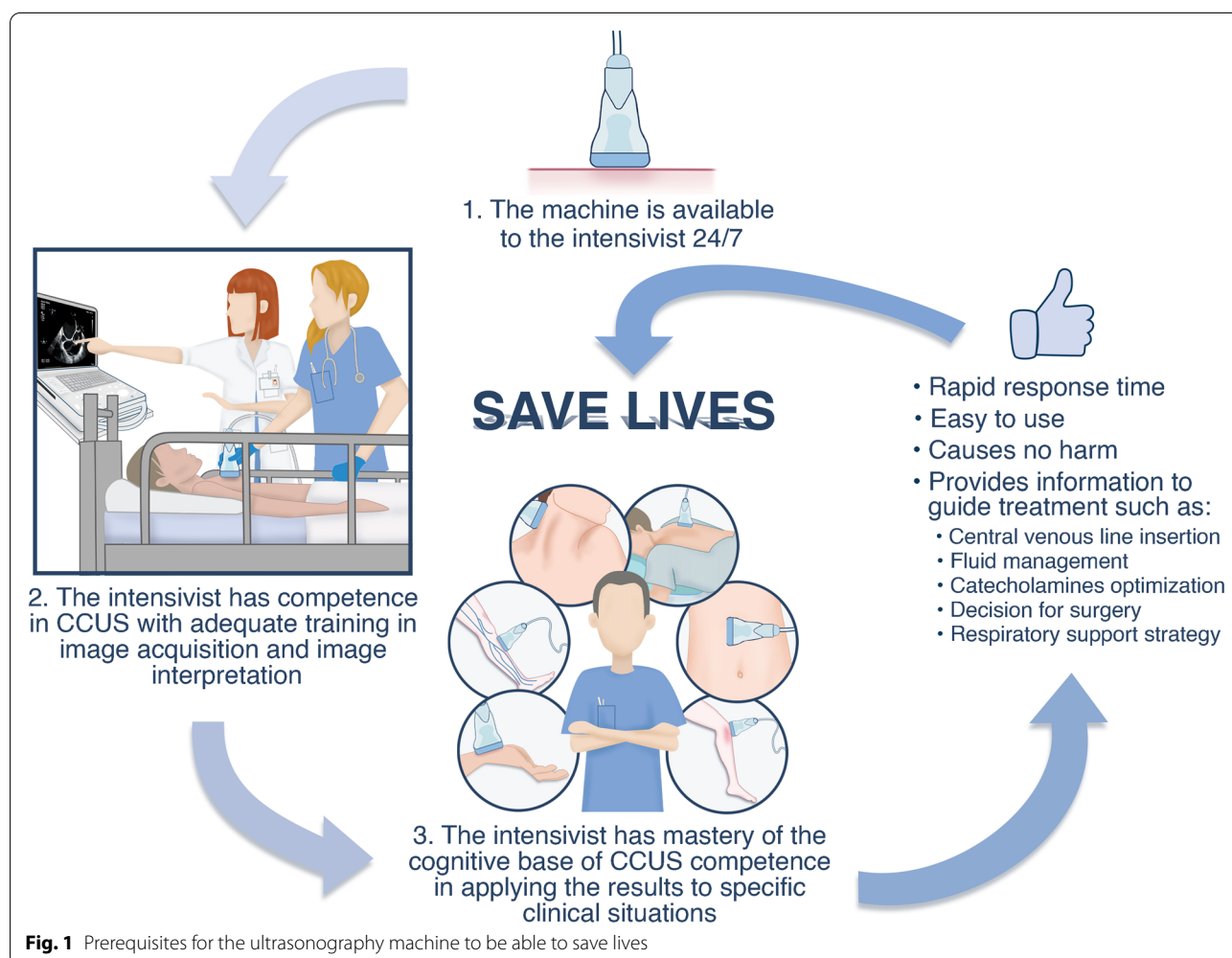


Table 1 Recommended design elements for the ultrasonography machine used in the under-resourced ICU

1. Machine capability is selected based upon the clinical needs of the ICU team (e.g., 2D, M-mode, Doppler, lung imaging, catheter placement), while discarding superfluous or redundant options
2. Robustness is an essential characteristic, with a design that is compatible with shocks, extreme temperatures, dust, unstable power sources and electric blackout
3. The device should be easy to use, highly functional, rugged, adaptable, and easy to clean
4. The maintenance should be as easy as possible, and feasible at least in part by the end-user, especially for crucial elements like the battery or the probe
5. The machine should have adequate memory for storage of images, and have internet connectivity to permit telemedicine connection, storage of images, and remote training capability
6. The machine should have the processing capability for potential artificial intelligence applications

ICU intensive care unit, 2-D two dimensional

satellites for broadband global internet connectivity. While independent of machine design per se, training in image acquisition/interpretation and appropriate application of the results is required for the machine to be used to save lives. Recent advances in learning and communication technologies (e.g., online courses, simulation and telemedicine) should be combined to deliver training easily and broadly, with the aim of reproducing bedside teaching [6]. Some available ultraportable ultrasonography (UPUM) devices can already connect clinicians around the globe in real time by turning a smartphone or tablet device into an integrated tele-ultrasound solution, combining two-way audio-visual calls with live ultrasound streaming. This will allow setting an international network of experts in CCUS to assist the worldwide collection and adequate live interpretation of the images. This will also globalize research in CCUS to help develop more consistent international recommendations.

Is there evidence that CCUS has utility in the resource constrained environment? Shaddock et al. performed a systematic review of the use of portable ultrasound devices in the limited resource environment using standard Cochrane Guidelines for Systematic Reviews and Meta-analyses from 2010 through 2021 [7]. They identified 23 articles that fulfilled criteria for review with the conclusion that, although overall methodological quality of the studies was low with high risk of bias, portable ultrasound machines have a wide range of uses in rural and remote, low-resource settings. Patient outcomes were improved with useful clinical information gained through early diagnosis of emergency conditions and screening studies.

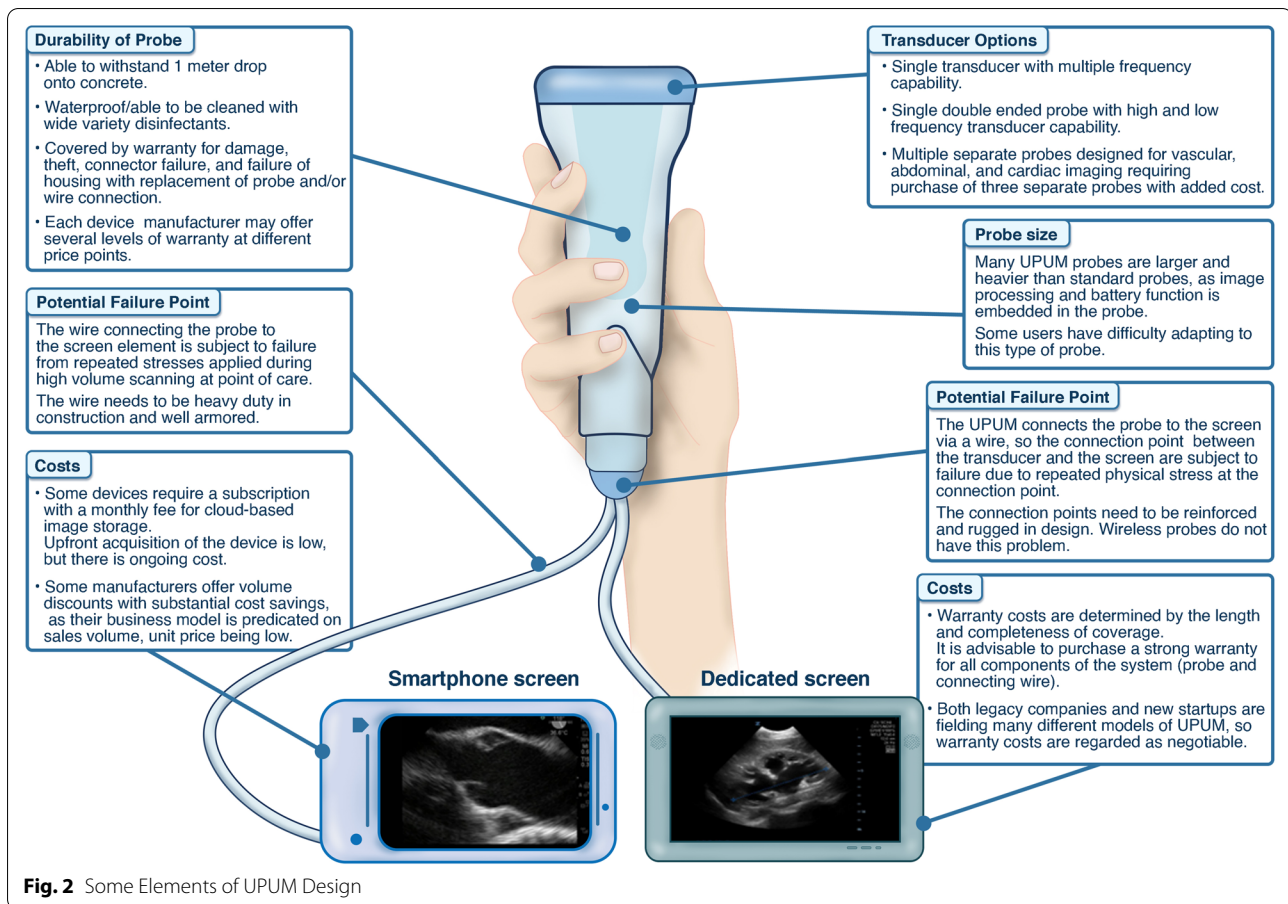
An example of the utility of CCUS for diagnosing adult respiratory distress syndrome (ARDS) is in the Kigali definition of ARDS [8]. The Berlin definition of ARDS is a standard metric in the well-resourced ICU, but it has limited application in the under-resourced ICU where chest radiography may not be readily available. In the Kigali definition of ARDS, lung ultrasonography replaces chest radiography as the imaging modality of choice.

The reality is that there is very limited evidence on the utility of CCUS in the resource constrained environment. One reason for this may be that the intensivist community who faces the difficult challenges of this type of ICU practice has neither the time nor support for well-designed research activity. Although not yet proven to improve outcomes such as mortality and morbidity of critical illness in the limited resource ICU, effective dissemination of frugal CCUS may allow wide implementation of multipurpose ultrasound-driven protocols to improve clinical outcomes.

Machine design for CCUS in the under-resourced ICU

CCUS may be used as the primary and only imaging modality in the under-resourced ICU, so cost, durability, and ease of use are key elements of machine design in this challenging practice environment. Large full-service ultrasonography machines used by consultative cardiology and radiology services are not suitable for the limited resource ICU due to their heavy weight, large footprint, cost, difficulty in obtaining repairs, and, in some operating environments, difficulty with securing the machine. Smaller mobile cart mounted machines present the same challenge of securing the device, obtaining service, and relatively high cost. In operating environments where there are space constraints (ambulance, air transport, outer space, remote evacuation), the same principles apply concerning machine design as in the resource limited ICU.

Recent generation UPUM are most suitable for use in the under-resourced ICU given their low cost, good image quality, and ease of use. The machine, being pocket-sized, is under the direct personal control of the intensivist; so the device is well secured. Current UPUM design consists of a probe that attaches to either a small, dedicated screen or to a smartphone. As smartphones are ubiquitous, the probe-smartphone setup is a good option: while dedicated screen systems are required where there



is no cellular signal. Most UPUM have internet connectivity allowing telemedicine function, cloud-based image storage, and remote training. Some machines have full Doppler capability, and some models are engineered to withstand a one-meter drop, as durability is a factor in the remote environment ICU practice. Some recent generation UPUM incorporate AI capability that includes automated image interpretation and provide guidance to the operator to achieve optimal image quality. The initial AI applications are focused on echocardiography but will likely be extended to general CCUS. There has been rapid evolution of UPUM design. Both the well-established manufacturers and several startups have fielded UPUM; and to complicate matters, machines are subjected to rapid software upgrades and are marketed with a variety of options. Figure 2 summarizes some design elements of the UPUM. The proliferation of device models is so rapid that it is not possible to present a comprehensive discussion of machine type or capability. Capable machines with a single probe design that can be used both for vascular and body imaging cost approximately 2000–4000€ while dedicated screen models that require a separate vascular and body probe cost 8000–12,000 €. Widespread

use of the UPUM in the under-resourced ICU may have major influence on provision of care and save lives, providing that the intensivist is well trained in its use.

The machine in the well-resourced ICU

A variety of ultrasonography machines are in use in the well-resourced ICU.

1. Large full-service machines: These machines have excellent image quality, large screens, advanced level capability such as 3-D and strain, and sophisticated controls. Being difficult to maneuver, they are not suitable for rapid high-volume point of care scanning in the busy ICU but are well designed for collective consultative use.
2. Small cart mounted systems. These highly maneuverable small footprint cart mounted machines with full Doppler capability became widely available in the early 2000's with two different design approaches. Clamshell units are designed as single purpose devices with relatively small screens, while laptop style units with larger screens may have dual use both as an ultrasonography machine and, in some mod-

els, as a computer. Recent generation machines have sealed flat control services that can be easily disinfected. Both types have acceptable image quality with a variety of probe options including transesophageal echocardiography capability (TEE) capability and are useful for shared use by the ICU team.

3. Hybrid machines. These combine the attributes of the small cart mounted machines with the large full-service machines with a small footprint, a large screen, a low center of gravity, a flat easy to sanitize control surface, image quality that approaches high end machines, sophisticated controls that were not available on the clamshell units, and TEE capability. Their reasonable cost, excellent image quality, ease of movement within the ICU, and large screen size indicate that they will replace previous generation cart mounted machines that are reaching the end of their service life.
4. The UPUM. Unlike the under-resourced ICU where the UPUM may be the only available machine, their main purpose is not to replace the larger machines; but rather to extend the reach of CCUS to every part of the hospital and for rapid use in emergency situations in the ICU. With their own UPUM in hand, the competent intensivist has immediate availability of a life-saving machine in the ICU on a truly 24/7 basis and is not reliant on a larger machine for all scanning function. Once the UPUM becomes widely available, it is conceivable that every intensivist who is competent in CCUS will acquire one either through ICU policy or through personal purchase.

The UPUM has great promise but also risk. Their cost and ease of use may result in their widespread use by intensivists who are not inadequately trained. This will bring risk to the patient, medico-legal risk to the operator, and discredit to the field. Effective training frontline intensivist is required for the ultrasonography machine to save lives.

Training and competence in CCUS

An ultrasonography machine only has utility when operated by a well-trained intensivist, so effective training in CCUS resulting in competence is essential to permit the machine to save lives. Given the importance of adequate training that results in competence, this section summarizes some key aspects of training and competence. The discussion is limited by space constraints of the manuscript and is designed to give the reader an overview of an important aspect of CCUS.

Competence in CCUS requires mastery of image acquisition and image interpretation. In addition, it requires mastery of the cognitive base of CCUS including how to

integrate the results of the examination into the clinical context. Training and assessment should equally emphasize these three components of competence. Critical care societies have established guidelines on CCUS training goals for basic and advanced levels [9, 10], yet there remains significant variability in content, duration and delivery mode of curricula [11, 12]. Given the heterogeneity of physicians seeking to learn CCUS, imposing a universal training format is challenging. The key goal is that training yield competence in all aspects of CCUS.

The cognitive base of CCUS may be acquired through textbooks, articles, internet material, and courses. Image acquisition can initially be taught on healthy models or simulators, as using simulators accelerates the learning curve for technical skills [13, 14]. This is followed by practice on ICU patients. [9]. Basic scanning technique may be achieved with hands on training at courses, but competency is achieved through longitudinal training [15]. Basic echocardiography should not become synonymous with substandard image quality; intensivists should strive to maintain high image quality standards with formative feedback and supervision [16]. The role of direct supervision (with concomitant benchmark reference views from an expert) cannot be overstated, but the optimal ratio of independent to supervised practice is yet to be defined and likely varies between individuals [16, 17]. Regular feedback is necessary to refine psychomotor skills and avoid acquisition mistakes [18]. As supervision remains a bottleneck to training [19, 20], intensivists may seek collaboration with other specialties such as cardiology, anesthesia, or radiology [21].

Assessment of competence in CCUS should be embedded in training, yet there is heterogeneity in how competency is assessed. Numerical requirements and training duration do not guarantee competency [21, 22]. Studies have reported a minimal number ranging between 25 and 50 to attest competency in basic echocardiography [23, 24]. For non-cardiac modalities, there are no definitive studies; recommended numbers are based on expert opinion [24, 25]. It is recommended that an expert supervisor appraises scans performed independently for quality, completeness, and interpretation accuracy [16]. Although attempts at international standardisations and certifications have been implemented, unaccredited practice remains common [26].

Maintenance of competence remains a concern, as skill retention after a short period of training is variable.[27, 28]. Systematic archiving and review of scans by experts is necessary to ensure continuing education and quality assurance [16, 18, 29].

Table 2 Comparison of EDEC and NBE certification programs

	EDEC	NBE	Comment
Requirement to Take the Certification Examination	Formal enrollment in the EDEC certification program. This requires that the candidate be a specialist level intensivist	Active medical license No requirement to be formally enrolled in the NBE certification process No requirement to be specialist level intensivist	NBE has long standing policy of permitting any licensed physician to take any of the NBE echocardiography examinations
Examination Design	Part 1 MCQ Part 2 Cases Part 3 Hands on test of TEE skill on simulator	200 MCQ with mix of knowledge base items and case-based items No hands-on testing	NBE considers it the responsibility of the logbook supervisor to approve hands on image acquisition
Examination Schedule	Given at the annual ESICM meeting	Given each January in national system of North American computerized testing centers	All NBE examinations are given at computerized testing centers on a contracted basis
Examination Development	By ESICM EDEC committee members	By working committee organized by the NBE with representatives of Eight North American critical care societies	NBE considered it important to include all stake holding societies in the development of the examination
Psychometric Expertise	By in-house ESICM psychometricians	By psychometricians of the NBME	NBME is responsible for all of the major medical specialty examinations in USA
Overall Control of Certification Process	ESICM certification committee	NBE Certification Committee with six voting members	EDEC process controlled by single society; NBE by multiple societies
Logbook Image Set Requirement	100 TTE studies 35 TEE studies	150 TTE studies 50 TEE studies (proposed)	NBE TTE requirement is identical to cardiology requirement TEE is likely to be an add on certification in near future in USA
Logbook Supervision	Local mentor and remote supervisor	Local supervisor	Requirements to be a supervisor are similar between EDEC and NBE
Required Level of Training	Specialist level intensivist	Starting in 2025: certification in critical care medicine; before 2025: demonstration of substantial provision of critical care services	The 2025 rule was established to "grandfather" non-specialist clinicians who practice critical care

EDEC European Diploma of Echocardiography, NBE National Board of Echocardiography, TEE transesophageal echocardiography, MCQ multiple choice questions, ESICM European Society of Intensive Care Medicine, NBME National Board of Medical Examiners, TTE transthoracic echocardiography

Training in ACCE: a useful model?

In 2014, the European Society of Intensive Care Medicine (ESICM) issued an expert statement for training in advanced critical care echocardiography (ACCE) [29]. The working group proposed that competence in ACCE, given its complexity, required a formal certification process that was laid out in detail in the Statement. This framework was used to develop the European Diploma of Echocardiography (EDEC) [30]. The EDEC program, developed and administered by an ESICM working group, has been in operation since 2016. The stake-holding critical care societies in North America have developed a similar Certification program through the National Board of Echocardiography (NBE) that has been in operation since 2018 [31, 32]. While the two certification processes have an identical goal, which is to assure competence in ACCE, they differ in some respects in their processes (Table 2) Competence in basic level echocardiography is required to enter the EDEC certification

process, as it is part of the initial training of any intensivist. The NBE regards that competence in ACCE per se includes competence in basic level critical care echocardiography so has established no specific requirement for competence in basic level echocardiography. Currently, competence in both transthoracic and transesophageal echocardiography (TEE) is mandatory for the EDEC certification. The NBE will likely be adding TEE to their certification. It is unknown whether ACCE has added advantage over the use of CCUS (which includes basic level echocardiography) in terms of effect of patient centered outcomes; this will require further study.

The success of these two formal certification programs raises the question as to whether this model that assures competence might be applied to other parts of CCUS. This is a controversial proposal. The professional societies involved in writing the ESICM competence statement in 2014 recommended that there be no formal certification for CCUS. The justification for this position

was that CCUS training should be embedded into critical care training. If this is the case, requiring a specific certification for CCUS implies that other routine procedures such as airway management, or bronchoscopy etc., would also require a certification process thus opening a Pandora's Box i.e., this could lead to the requirement of certification for all types of standard ICU procedures. The complexity and cost of developing a certification process for CCUS would also be prohibitive.

The success of the ACCE certification processes suggests that this recommendation be reconsidered. A standard curriculum for CCUS and standardized testing sequence including image acquisition and interpretation would ensure that trainees had an adequate skill level. The resulting certification would confirm that the intensivist was competent in CCUS. This would duplicate the situation that now exists with ACCE certification i.e., if an intensivist is certified by EDEC or NBE in ACCE, this assures that they have a high level of competence. Because CCUS training is at present so variable in quality, a formal certification process would bring assurance that the intensivist that claimed competence CCUS was truly competent. The development mechanics of a CCUS certification process would be relatively straightforward given the experience with the ACCE programs. A major challenge would be in establishing an internationally accepted and uniform definition of competence similar to what has been established for ACCE. The idea that all intensivists are receiving adequate training in CCUS is an admirable goal, but at present is only aspirational. The ultrasonography machine will only save lives if operated by a competent user. The present reality is that the competence of the user can only be assured by a formal certification process of similar quality to the ACCE certifications.

Research studies: does CCUS really save lives?

While the individual intensivist can recall dramatic findings that, if unrecognized, would have led to death of the patient (e.g., pericardial tamponade, tension pneumothorax etc.); the thoughtful intensivist will ask the question: Is there research that addresses this question, or must we rely on personal experience and intuitive judgment to support the utility of CCUS?

In 2017, ICM published a research agenda on CCUS which proposed ten studies/trials that should be performed to further support its utility [33]. Five years later, research on CCUS has not moved much forward, despite this call to arms. We see two reasons for this. First, physicians who use CCUS naturally consider that it saves lives. Lacking clinical equipoise, the ICU team that has fully incorporated CCUS into bedside practice would not be inclined to participate in a prospective randomized

controlled trial where they were barred from using CCUS. The second reason is that three requirements are needed to demonstrate that CCUS saves lives (Fig. 1); an adequate ultrasonography machine available 24/7; adequately trained physicians able to accurately perform and interpret CCUS studies, both already discussed; and a standard effective protocol for using the result to guide treatment of the patient. While machines are now widely available, the other two requirements may be more difficult to achieve. Just as when studying hemodynamic monitoring methods, when studying CCUS, it is necessary that the data obtained are accurate and relevant enough to influence therapeutic decision-making and that changes in management based on the system-guided protocol could alter the outcome [34]

Studies on CCUS in different locations (ICU, emergency departments, operating rooms) show that current research studies aiming to demonstrate that CCUS may save lives are very heterogeneous in their design, quality, population, objectives, and conclusions. Some studies have suggested neutral effect [36, 37] and others even that ultrasonography machine could worsen prognosis [37, 38]. We recently reported a systematic review and literature appraisal on methodology of conducting and reporting critical care echocardiography studies [39]. In the 256 research studies found, we showed that design and reporting were globally poor in the fields of LV systolic and diastolic function, RV function, fluid management and advanced echo techniques. For instance, ventilator settings, i.e., PEEP, plateau pressure and tidal volume, were only reported in 32%, 19% and 28% of cases respectively, while they are crucial to adequately interpret the exam, and so to accordingly adapt management. This led to the recommendation that there be adequate methodology to conduct and report critical care echocardiography research studies (Ref. [40] and, by implication to CCUS research.

However, there is some reasonable direct or indirect data which could suggest that CCUS may actually save lives. In considering the influence of ultrasonography on outcomes, its effect may be differentiated between its utility for guidance of procedures and its effect on establishing diagnosis and therapy of critical illness. Ultrasonography has utility in the ICU for guidance of a wide variety of procedures (e.g., central line insertion, thoracentesis, paracentesis, ECMO cannula insertion etc.) compared to blind insertion technique. Many studies have reported that ultrasound-guided techniques for central venous catheter placement increases success and decreases side effects, which could improve the outcome. A recent prospective multicenter and observational study performed in 354 pediatric critically ill patients found that vascular ultrasonography, compared to the landmark

technique, was associated with an increase in the first-attempt success rate, a reduced number of puncture attempt, and as a consequence fewer complications [45]. It is intuitively obvious that the safety of device insertion would be augmented with ultrasonography control than without, so we posit that ultrasonography guidance of needle and device insertion is now “industry standard” in the ICU where ultrasonography is available.

Regarding the possibility that CCUS may alter patient outcomes due to its influence on diagnosis and management, in a prospective observational controlled study performed in 165 patients, a protocolized use of an UPUM at the bedside improved the proportion of adequate diagnosis, the time to initial treatment and potentially the outcome [41]. In a randomized multicenter trial performed in 367 patients on chronic hemodialysis, pre-dialysis lung US (LUS) evaluating level of lung congestion to titrate ultrafiltration led to a risk reduction for recurrent episodes of decompensated heart failure and cardiovascular events after a follow-up of 1-year and half [42]. How similar results could be observed in critically ill patients who require renal replacement therapy after hemodynamic stabilization remains to be evaluated. In 123 patients admitted for heart failure, randomization in a LUS arm follow-up where physicians were encouraged to modify diuretic therapy in accordance with the number of B-lines, led patients to receive more diuretics, to have less urgent visits, hospitalization for worsening heart failure, and death (composite outcome) during the 180 days of follow-up after discharge [43]. A similar approach could be evaluated in the future during ICU stay. The respective benefits, harms, and diagnostic accuracy of point of care ultrasonography in patients with acute dyspnea were evaluated in a meta-analysis [44]. In 59 patients at high risk of weaning induced pulmonary edema, echocardiography when performed immediately before and after spontaneous breathing trial helped to optimize treatment, mostly by promoting negative fluid balance, to improve successful weaning [46]. An analysis of the MIMIC-III database in 6361 patients admitted in the ICU for sepsis found that 51% received a formal transthoracic echocardiography (TTE) done by a sonographer and interpreted by a cardiologist [47]. It was associated with a more positive fluid-balance on day 1 and more infusion of dobutamine. Mortality at day-28 was significantly reduced and patients with echo were more quickly weaned off vasopressors. From the Nationwide Inpatient Sample, an increase in the use of echocardiography between 2001 and 2011 was reported and was associated with prognosis improvement in patients admitted for heart failure, sepsis, and acute myocardial infarction [48]. In 90 pediatric patients with septic shock, patients randomized in serial echocardiography-guided

therapy had a shorter shock reversal time, a lower fluid balance, a higher rate of dobutamine infusion which was initiated earlier, and a lower mortality due to unresolved shock [49]. In a randomized controlled trial including 550 patients with shock, the use of a single-use TEE probe to more continuously monitor hemodynamics showed that time to resolution of signs of hypoperfusion, duration of organ support, length of stay and in-ICU mortality did not differ, while a shorter time to resolution of hemodynamic instability was reported during the first 72 h [50]. Finally, a randomized controlled trial in 86 patients admitted for septic shock, comparing an early goal-directed therapy with a CCE goal-directed therapy, recently showed that the cumulative fluid infusion volume and fluid balance at 12 and 24 h was lower in the CCE group, and the 6 h lactate clearance rate was improved [51].

There is no well-designed large prospective randomized controlled study that convincingly demonstrates the CCUS alters mortality or morbidity of critical illness. Available literature is only suggestive of a positive effect, and it is possible that this will remain the reality for the frontline intensivist who uses CCUS in everyday practice.

Given the difficulty of finding ICU teams who have clinical equipoise about CCUS, the need to ascertain that the ultrasonography imaging is accurate, the challenge of determining that the interpretation of the image is correct, and the difficulty in standardizing any therapy that would be predetermined by the results (complicated by the heterogeneity of the patient population and variability of other aspects of clinical management) makes it difficult to envision that there will ever be evidence-based proof that CCUS, like the other imaging modalities in widespread use in the ICU, alters outcome of critical illness. Imaging is a key element of critical care practice, as it is used to establish diagnosis. A basic principle of modern medical practice is that knowledge of an accurate diagnosis improves patient care, as it may lead to effective therapy. As CCUS, like CT scan, MRI, and chest radiography, are imaging modalities, their utility is to identify a diagnosis. They are not therapeutic, as only the clinician decides upon therapy based upon the perceived diagnosis. Instead of focusing on whether a specific imaging modality in of itself improves outcome, future research activity might be better focused on how to train intensivists to perform CCUS and integrate its findings into frontline ICU function.

Conclusion

Ultrasonography, CT, MRI, and standard radiography have a shared utility in the ICU, as they aid the intensivist in reaching a diagnosis. The clinician uses this

information to establish management strategy. CCUS has the unique advantage that the imaging modality is in the hands of the frontline intensivist at point of care for immediate, repeated, serial, and goal directed use. Consultative ultrasonography services and advanced imaging modalities will always have important applications in the ICU, but the widespread availability of high-quality cart mounted machines and UPUM make the ultrasonography machine uniquely positioned to save lives. This applies both in the well-resourced and limited resource ICU where the UPUM has major application as the primary imaging modality. Competence in image acquisition, image interpretation, and the cognitive base allows the intensivist to use the ultrasonography machine to save lives. This can only be achieved through adequate training.

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