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CLINICAL COMMENTARY

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Echocardiography in the intensive care unit: from evolution to revolution?

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From the "ECHO-in-ICU group"

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Abstract *Background:* Over recent decades, echocardiography has become a pivotal diagnostic tool for the assessment of patients with hemodynamic compromise in general intensive care units (ICUs). In addition to its imaging capability, echocardiography provides a detailed cardiovascular assessment, based on the combination of real-time two-dimensional evaluation of cardiac structure and function and hemodynamic information provided by Doppler measurement of blood flow velocity. However, despite its ease of use, portability and accuracy, the diffusion of echocardiography among ICUs has been limited by various factors. *Discussion:* We discuss here the main reasons for the slow acceptance by the critical care community of echocardiography as a first-line diagnostic tool for the evaluation of hemodynamically unstable patients. One of these reasons is probably the absence, in most countries, of a training program in echocardiography specifically dedicated to intensivists. We report recent French experience in the organization of specific echocardiographic certification aimed at intensivists and anesthesiologists. We strongly believe that a broader use of echocardiography would be beneficial in terms of diagnostic capability and patient management. Therefore, we would like to involve colleagues from other countries and the European Society of Intensive Care Medicine in defining the objectives of echocardiography training for intensivists and in organizing postgraduate courses and training programs aimed at developing the use of echocardiography in ICUs. This would allow the current "evolution" in mentalities to become a true "revolution" in our daily practice.

Keywords Echocardiography · Monitoring · Hemodynamic · Cardiac function · Educational program

Introduction

Echocardiography is currently the sole imaging modality at the bedside that provides real-time information on cardiac anatomy and function [1–3]. Doppler echocardiography allows detailed evaluation of hemodynamics to rapidly identify the mechanisms of circulatory failure [4, 5]. Modern management of critically ill patients

presenting with hemodynamic compromise is based on both early identification of the underlying cause and treatment [6]. Opinion leaders have recently re-emphasized that time saves lives [6], and the concept of early goal-directed therapy has now been widely recommended in international guidelines [7]. By accurately assessing hemodynamics within a few minutes, echocardiography appears ideally suited to the early hemodynamic evaluation of patients with persistent shock despite aggressive goal-directed therapy. In addition, continuous evolution in technologies and electronics and the emergence of transesophageal multiplanar probes have meant that adequate imaging quality, hence reliable information, is routinely obtained in virtually all ventilated patients. It has long been known that transesophageal echocardiography (TEE) leads to additional relevant changes in therapy [8, 9], even in patients monitored by right heart catheterization (RHC) [10, 11]. Surprisingly, despite all these advantages, echocardiography is still not yet available in most intensive care units (ICUs), and a recent European survey showed that only 20% of intensivists have certification in echocardiography [12].

This manuscript describes the recent evolution in the practice of echocardiography in the general ICU, analyzes potential reasons for the slow spread of this imaging technique in critical care medicine, reports French experience in the education and training of intensivists for the practice of echocardiography, and calls for a two-level international educational program. Readers should be aware that this manuscript presents an opinion from the viewpoint of two types of specialists, i. e. intensivists and anesthesiologists, in one country, France. It does not pretend to exhaustively discuss education in echocardiography around the world.

Practice of echocardiography in the ICU

In the environment of a general ICU, echocardiography was first performed by board-certified consultant cardiologists who were called to assist in the diagnosis of cardiovascular diseases. Echocardiography was limited to the examination of cardiac and great vessel anatomy and rapidly appeared as an accurate imaging modality for the identification of various acute conditions including cardiac tamponade [13], complications of myocardial infarction [14], spontaneous aortic dissections [15], and traumatic aortic injuries [16].

In the ICU, noninvasive hemodynamic assessment was initially limited to the determination of stroke volume and cardiac output using two-dimensional echocardiography [17] combined with Doppler mode [18]. In fact, at that time, intensivists did not fully realize the potential of echocardiography. In the mid-1980s, a few intensivists proposed to extend the use of ultrasound to a more global and comprehensive assessment of hemodynamics. These pioneers suggested that RHC could be favorably supplanted by echocardiography for the hemodynamic evaluation of patients presenting with septic shock or acute respiratory distress syndrome [19, 20]. This supposed that intensivists were able to perform their own examinations, without calling the cardiologist, thus permitting 24-h availability of immediate echocardiography and repeat studies following therapeutic interventions. Recently, the same authors reported their 15-year experience with the routine use of echocardiography for guiding initial management of patients with acute circulatory failure, without the use of RHC [4, 21]. The clinical value of echocardiography in the ICU has been corroborated by other intensivists who have show the accuracy of TEE in the identification of leading mechanisms of circulatory failure as well as expeditious diagnosis of acute cardiovascular conditions [8–11, 22–24].

Although no study has yet demonstrated the positive impact of echocardiography on ICU prognosis, there is evidence to support its therapeutic impact [8, 9] and its value in predicting mortality [25]. In addition, clinical experience accumulated during daily practice contributes to the growing popularity of echocardiography in several ICUs [26].

Diffusion of echocardiography in ICUs

The use of echocardiography in ICUs spread fairly slowly until the end of the 1990s. Recent interest in echocardiography among intensivists can be explained by several factors: negative trials evaluating the impact of RHC on prognosis, accumulation of clinical evidence documenting the additional value of echocardiography compared with traditional invasive hemodynamic assessment, increasing number of publications on clinical applications of echocardiography, and design of specific courses dedicated to the education and training of intensivists.

Historically, the development of critical care medicine was strongly associated with the use of RHC from its introduction in 1970 [27]. Many therapeutic algorithms used by intensivists for the management of critically ill patients relied on pressure, flow, and metabolic measurements obtained by RHC. Since recent publications clearly show the lack of benefit with this invasive technique, RHC is no longer regarded as a cornerstone in the evaluation of hemodynamically unstable patients [28–33]. These concordant negative results undoubtedly led intensivists to use echocardiography as an alternative and less invasive approach, despite the fact that it is not suited to long-term continuous monitoring.

During the same period, TEE became the first-line diagnostic procedure officially recommended by several American scientific societies for the assessment of circulatory failure complicating the perioperative course or in specific situations occurring in ventilated ICU

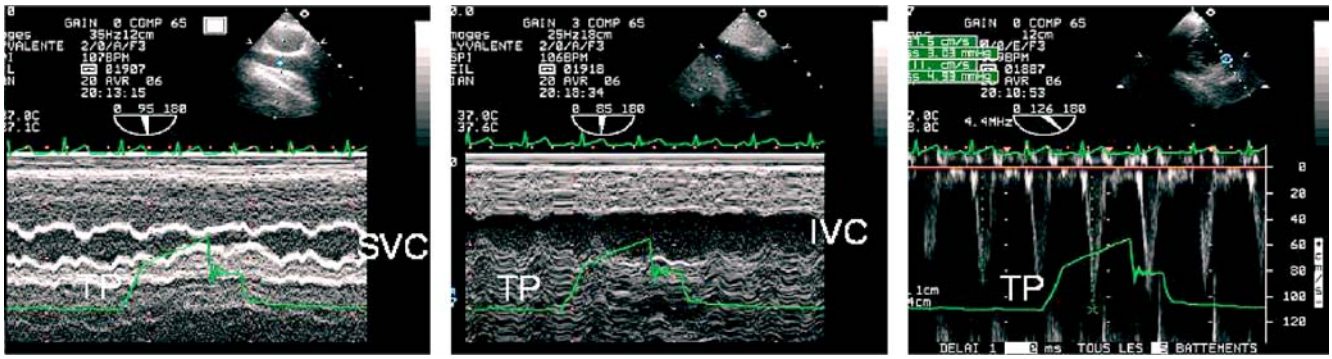

Fig. 1 Main echocardiographic parameters obtained in the same ventilated patient examined using TEE for septic shock. All parameters suggest the need for blood-volume expansion to increase left ventricular stroke volume, and hence cardiac output (fluid responsiveness). *Left panel:* In this TEE long-axis view of the superior vena cava (*SVC*), M-mode reveals a cyclic collapse of SVC at each inspiration. *Middle panel:* M-mode depicts cyclically a marked increase in inferior vena cava (*IVC*) diameter related to tidal ventilation. *Right panel:* The aortic pulsed-wave Doppler velocity profile recorded at the level of the left ventricular outflow tract clearly shows marked variations in the velocity–time integral of the Doppler velocity profile (reflecting stroke volume) during the respiratory cycle. Note that maximal Doppler velocities are observed during inspiration, while minimal velocities occur during expiration. *TP*, Tracheal pressure

patients [34, 35]. In addition, clinical studies showed the value of echocardiography in the diagnostic work-up and therapeutic management of various acute conditions, such as acute respiratory failure [36–38] and severe blunt chest trauma [39].

Finally, the concept of "functional hemodynamic" assessment indirectly accelerated the emergence of echocardiography as an unparalleled approach to the comprehensive evaluation of hemodynamics in ventilated patients with circulatory failure. Several echocardiographic parameters have been shown to accurately predict fluid responsiveness in ventilated ICU patients with septic shock (Fig. 1). Most of these indices use exaggerated heart–lung interactions produced by positive-pressure ventilation in the presence of relevant hypovolemia [40–45]. These simple yet robust indices of fluid responsiveness allowed intensivists to use echocardiography efficiently for day-to-day decisions, regarding fluid loading, for example.

So, although scientific publications in the field of echocardiography dedicated to the assessment of patients sustaining circulatory failure remained scarce until the end of the 1980s, the number of publications in peer-reviewed journals increased exponentially in the 1990s, in parallel with intensivists' growing interest in the technique (Fig. 2).

However, most intensivists are usually unfamiliar with echocardiography. Indeed, educational and training programs in echocardiography, when they exist, are not usually suitable for intensivists, but rather for sonographers and cardiologists. Indeed, board certification is designed to quantify valve diseases, evaluate valvular prostheses, assess the severity of a cardiomyopathy or congenital heart disease, or to identify a cardiac abnormality and confirm its causal relationship with the clinical scenario. In contrast, intensivists need to have a comprehensive approach to heart–lung interactions in ventilated patients and to learn how to perform a complete hemodynamic assessment in hypotensive patients and how to expeditiously identify gross cardiovascular diseases requiring prompt surgical correction (e. g., aortic dissection, cardiac tamponade, ruptured papillary muscles).

Scientific societies in the USA [46], the UK [47] and France [48] have published official guidelines to define the minimal training required to reliably practice transthoracic and transesophageal echocardiography. In these guidelines, a limited role for perioperative transesophageal echocardiography by anesthesiologists is described, but the evaluation of ICU patients by intensivists is unfortunately not discussed [46–48]. A position paper of the American Society of Echocardiography (ASE) and of the American College of Cardiology (ACC), published in 1999, even clearly discouraged "echocardiographic laboratory extenders" (e. g., anesthesiologists, emergency medicine physicians) from performing and interpreting echocardiograms themselves if they do not have a validated, at least 6-month training period in a laboratory with 300 cardiac echocardiographic and Doppler studies [49]. These two societies did not support the concept that a level 1-trained physician (3 months of training and 150 studies) should act, except if a sonographer is unavailable in the case of a life-threatening condition [49].

Educational program and training for the use of echocardiography by intensivists in France: "evolution" in mentalities

In France, echocardiographic training and certification for cardiologists initially consisted and still consists of

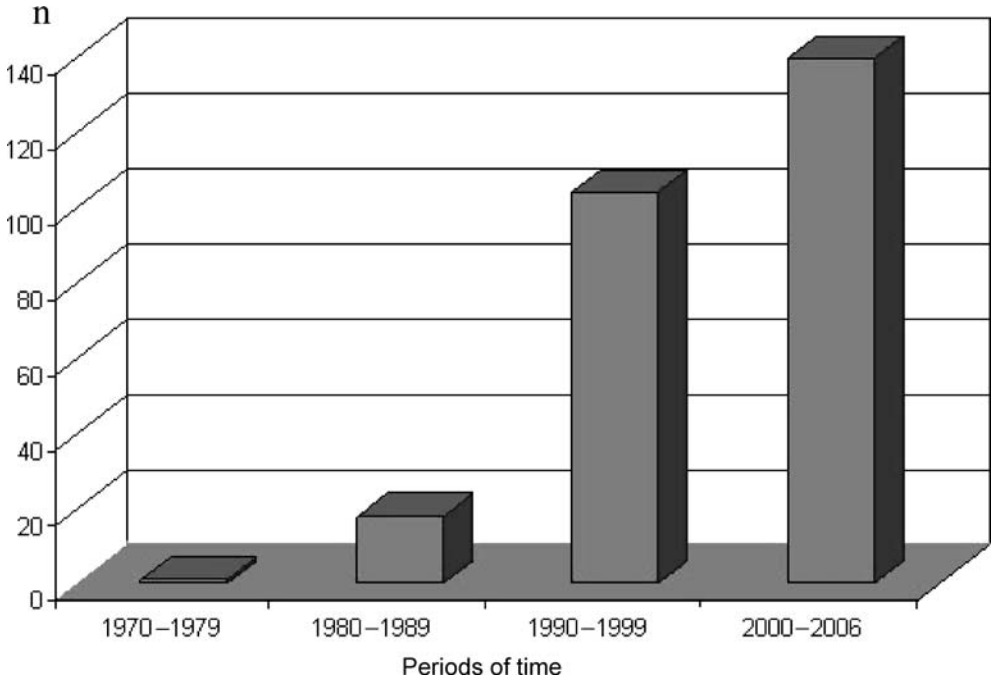

Fig. 2 Search in PubMed (www.ncbi.nlm.nih.gov/PubMed) for published manuscripts in peer-reviewed journals related to the use of echocardiography in ICU settings during four consecutive periods. The following keywords were used for the Medline search: "Critical Care" [MeSH] AND "Echocardiography" [MeSH], and "Intensive Care" [MeSH] AND "Echocardiography" [MeSH]. *n*, number

2-year certification combining courses and training with hands-on practice [48]. In 2004, an ad hoc cardiologist board and representatives of intensivists involved in the "ECHO-in-ICU group" jointly decided on substantial modifications of the national certification in echocardiography, by organizing a specific educational and training program specifically dedicated to intensivists and focused on the practice of echocardiography in the ICU. Intensivists and anesthesiologists are now allowed to apply for the 2-year certification program, with the full agreement of the French Societies of cardiology (SFC), intensive care medicine (SRLF) and anesthesiology and intensive care medicine (SFAR). During the first year of this program, intensivists, anesthesiologists and cardiologists attend common courses and obtain their first-year certification with the validation of an examination. All physicians also need to complete a training program in an echocardiography laboratory which consists of (at least) 120 transthoracic procedures under the supervision of a board-certified cardiologist. During the second year, in addition to a limited common course with cardiologists, intensivists and anesthesiologists have a specific course of about 20 h (content in Table 1), leading to a separate examination, evaluating various issues related to echocardiography in the ICU. They also follow a specific training with hands-on practice in ICUs or in cardiac surgery operating rooms. At least 120 examinations including 50 TEEs must be performed under the supervision of a board-certified intensivist. The "ECHO-in-ICU group" includes board-certified intensivists and anesthesiologists who are in

Table 1 Specific educational program for intensivists and anesthesiologists during the second year of certification in echocardiography

1. Heart–lung interactions
2. Why and how to measure cardiac output using echocardiography?
3. Echocardiographic assessment of fluid requirement: "static parameters"
4. Echocardiographic assessment of fluid requirement: "dynamic parameters"
5. Cardiovascular diseases in the ICU; myocardial infarction and its complications, aortic injuries, cardiac tamponade
6. Hemodynamic evaluation using echocardiography in ARDS
7. Hemodynamic evaluation using echocardiography in sepsis
8. Echocardiographic diagnosis of a cardiogenic pulmonary edema
9. Patent foramen ovale and intrapulmonary shunts
10. Echocardiography in pulmonary embolism. Diagnostic and prognostic impact
11. Perioperative evaluation of mitral valve repair
12. Perioperative hemodynamic management
13. Specific patterns of shock after cardiac surgery
14. Respective indications of TTE and TEE; tolerance and pitfalls of TEE
15. Case presentations

ICU, intensive care unit; *ARDS*, acute respiratory distress syndrome; *TTE*, transthoracic echocardiography; *TEE*, transesophageal echocardiography

charge of defining and updating the educational program, running courses specifically dedicated to intensivists, organizing the second-year exam, and selecting yearly qualified training centers for the practice program. To be accredited as a training center, the ICUs need a dedicated high-quality ultrasound machine available 24 h a day, with a multiplanar transesophageal probe and a board-certified intensivist or anesthesiologist on the medical staff.

After the first 2 years, about 200 physicians from all French regions were certified. The "ECHO-in-ICU group" has accredited 72 (16%) of the 459 medical and surgical ICUs in France. This represents 54 (39%) of the 139 French university ICUs.

Future directions: towards a "revolution" in mentalities?

By training more and more physicians in the practice of echocardiography in the ICU, we hope that most units will have their own experienced and trained operator. These newly certified echocardiographers will then be in charge of supervising the training of other intensivists. In the future, tailored practice sessions can be organized, focusing on echocardiographic evaluation of hemodynamics, with special emphasis on the use of TEE in mechanically ventilated patients [50]. We anticipate that this goal will be reached in the near future, when enough adequately trained intensivists will be in charge of accredited training centers.

From an international point of view, there is a pressing need to organize an educational program in echocardiography for intensivists who cannot be trained in their own country. The consistent popularity of postgraduate courses organized at national and international conferences is a strong indicator of the need for such an educational program in the community of intensivists. To achieve this challenging goal, close collaboration between national societies is mandatory, since some of them, e. g. the German Society of Anesthesiology and Intensive Care Medicine, have already developed their own certification [51]. This will allow better definition of training objectives.

Ideally, a two-level educational program would be desirable [52]. The second level, as already implemented in France, would be an extensive educational program focused on the evaluation of hemodynamic failure and specifically dedicated to intensivists who plan to use echocardiography as a first-line modality for the assessment of critically ill ventilated patients. But, in part because many intensivists will not have the time, inclination or opportunity to take this optimal program, a first level is required. It would consist of a limited course based on transthoracic echocardiography in the ICU for all intensivists. Briefly, it could teach why, when, and how to record some very simple echocardiographic parameters, such as the inferior vena cava diameter, the size of the right ventricle, the contractility of the left ventricle, and the presence of fluid in the pericardium, to quickly guide therapy at any time of the day. Previous studies have reported the feasibility and clinical utility of such an approach in critically ill patients [53, 54]. This specific first-level training could be incorporated into the requirements for fellowship training in critical care medicine and as a part of the certification required to become an intensivist.

Finally, the focus of this position paper is echocardiography, but ultrasound can also be used to visualize the pleura, lungs, and great vessels. This argues also for the training of intensivists to use ultrasonography for detection of pleural effusion, thoracocentesis, and central line placement. There is now a need to discuss whether such training should be incorporated into first-level sonography certification.

In conclusion, we strongly believe that all physicians in charge of critically ill patients should be trained in echocardiography. Far from being competitive or conflicting, the use of echocardiography by intensivists and cardiologists is complementary. Accordingly, there is an urgent need for specific training in echocardiography for all intensivists. International cooperation is warranted to provide teachers for colleagues who have no access to echocardiography training programs in their own country, and to decide what to teach and how. This is in our patients' interests. It is time to change our practice and to move on from the current "evolution" to a true "revolution" in mentalities!

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