Point-of-care echocardiography – A road to future or a step backwards

Manan Vaishnav^{1,2} and John Sedgwick^{1,3}

¹The Prince Charles Hospital, Brisbane, Queensland, Australia

²The Gold Coast University Hospital, Southport, Queensland, Australia

³The University of Queensland, St Lucia, Queensland, Australia

Abstract

Echocardiography (Echo) has a myriad of clinical applications. Traditionally, it was performed and interpreted by cardiologist but the scope of its applications has lead physicians of other specialities to learn this useful skill. One of the newer and expanding scope of echocardiography is point-of-care (POC) echocardiography. In this review article, we aim to discuss the clinical applications of POC echo, common protocols and its limitations. Despite its widespread use, there is paucity of data describing its clinical efficacy and there is lack of guidelines regarding credentialing and quality control of POC echo.

Keywords: critical care echo, echocardiography in emergency, handheld echocardiography, point-of-care echocardiography.

Introduction

Point-of-care testing implies a diagnostic test which can be performed at the patient's bedside. The impetus on point-of-care testing has grown over the past few years as it is convenient for the patient and provides early diagnostic information to guide clinical decision making. Tests such as lipid profile, blood glucose and glycosylated haemoglobin, urine pregnancy and drug screen test, blood gas analysis and coagulation profile are examples of non-imaging point-of-care tests commonly used in clinical practice. Point-of-care imaging with ultrasound has become increasingly popular due to its portability, versatility and the lack of radiation exposure. Ultrasonography is utilised for diagnostic purposes in emergency department for undifferentiated clinical presentations such as abdominal pain or chest pain. It is also an extremely useful tool for invasive procedures like central venous access, thoracentesis or abdominal paracentesis.

Although a detailed clinical history and examination is the mainstay of initial evaluation, it is complemented by early diagnostic investigation especially if clinical signs are subtle and/or life-threatening conditions are suspected.

Echocardiography

Echocardiography (Echo) is a medical imaging diagnostic procedure that displays moving images of the heart using ultrasound waves. Since the advent of M-mode echocardiography in 1953 pioneered by Inge Edler and Hellmuth Hertz, the

technology has evolved into the most versatile imaging modality in cardiology. Two-dimensional (2D) and three-dimensional (3D) imaging, colour Doppler, spectral Doppler, tissue Doppler, strain and contrast-enhanced echocardiography have become the standard components of echocardiography. Echo is useful in assessment of ventricular systolic and diastolic function, chamber size, wall thickness, valves, atrial size and function, nature of pericardium and proximal vessels. It provides a timely comprehensive assessment of the cardiac structure and function without the hazards associated with ionising radiation. The advancements in miniaturisation of this technology have resulted in easy portability while providing high-quality image resolution.

Point-of-care echocardiography

Point-of-care echocardiography has gained significant impetus due to its broad range of diagnostic applications, compactness and safety. The first generation mobile echocardiography machine was the size of a laptop. The second generation equipment was handheld or pocket-sized weighing 2–3 kg. The third generation devices are of an extremely light weight of less than half kilogram. Recently, there have been mobile application based systems wherein an ultrasound transducer is connected to a smartphone and acts as a display screen for image acquisitions. Most of these devices have 2D echocardiography and colour Doppler capability. Leading vendors like General Electric (GE), Phillips, Siemens, Konica, Fujifilm etc. have devices that are commercially available.¹ These devices vary in their image quality and specifications. Hence, the data based on one device

Correspondence to email: drmanan2005@gmail.com
doi: 10.1002/ajum.12128

cannot be extrapolated to other handheld devices. There can be significant interobserver variability among users due to differences in image quality and user interface.

In the 1990s, emergency physicians started using echocardiography for assessing penetrating cardiac trauma injuries.² Since then, the indications for bedside echocardiography have expanded across various clinical settings especially emergency medicine and critical care. In certain acute undifferentiated clinical presentations, limited echocardiography to answer a specific question can be quite useful and alter clinical management. In a study by Cardim *et al.*³ involving 190 patients in two tertiary hospitals referred for outpatient cardiology consultations, use of handheld echocardiography lead to the diagnosis in 74% patients with around 19% patients being discharged from the clinic and only 33% needing comprehensive echocardiographic assessment. The accuracy of handheld devices with an experienced operator has also been validated. In a study by Prinz and Voigt, 349 patients underwent handheld echocardiography using Vscan, GE Vingmed Ultrasound AS device. There was no significant difference in the quality of endocardial visibility grades, regional wall motion scores, ejection fraction assessment, left ventricular measurements, intraventricular septal and posterior wall thickness compared to comprehensive echocardiography.⁴

POC Echo is an echocardiographic study conducted by a physician at the patient's bedside. It can be categorised into focussed Echo and limited Echo.⁵ Focussed echo is defined as examination of the cardiovascular system done by a physician in adjunction to the clinical examination to answer a particular question or narrow the list of differential diagnoses. It is generally done with a predefined protocol. Limited Echo is a dedicated cardiac echo done by a professional with the training to acquire images from all acoustic windows to identify the pathology. They should have the knowledge to identify incidental findings. They should be able to have the skills to apply quantitative techniques like estimation of ejection fraction or assessing Doppler flow velocities and gradients. They should also be able to define pertinent positive and negative findings.⁵

Clinical applications

Undifferentiated shock

A common presentation in the emergency department or intensive care unit is a patient with circulatory collapse of undetermined origin. Initial history and clinical assessment are useful but often do not guide definitive management in such unwell patients. Point-of-care echocardiography is critical to rapidly assess left ventricular function, volume status and exclude a pericardial effusion complicated by cardiac tamponade.² The findings help guide clinical decision making, for example, if evidence of severe left ventricular dysfunction seen on echocardiography, the predominant treatment would be inotropic support. On the other hand, if the left ventricular function is preserved, aggressive fluid resuscitation can be provided.

Volume status can be assessed by examining the inferior vena cava and its collapsibility on echocardiography. This technique is useful in hypovolaemic shock. Presence of pericardial effusion with evidence of diastolic right ventricular collapse supports a diagnosis of tamponade. However, in one study, 34% who did not have clinical evidence of tamponade had diastolic right ventricular collapse,² which highlights the assertion that imaging findings suggesting cardiac tamponade should be interpreted along with the patient's clinical status. Hypotension in a patient following cardiothoracic surgery is a common clinical scenario where volume status assessment and exclusion of cardiac tamponade are extremely crucial.

Right ventricular dysfunction and leftward septal bowing are common echocardiographic finding in haemodynamically significant pulmonary embolus causing circulatory collapse.⁶

Evidence of a hyperdynamic ventricle on point-of-care echocardiography in septic patients has 94% specificity in a study of 103 emergency department presentations with undifferentiated shock.⁷ It also has to be kept in mind that sepsis can also cause diffuse myocardial suppression.

Trauma

POC echocardiography plays a pivotal role in penetrating chest trauma by ruling out pericardial tamponade early. This plays a significant role in decreasing mortality in these patients. The focussed ultrasound assessment with sonograms in trauma (FAST) also includes looking for haemothorax and intraperitoneal fluid in trauma patients. Blunt chest trauma needs POC assessment for aortic dissection, cardiac contusion and acute valvular regurgitations.²

Chest pain syndromes

Acute coronary syndrome

Myocardial infarction is the most common life-threatening emergency presentation. The diagnosis of an acute ST-elevation myocardial infarction (STEMI) is done with electrocardiography. Primary percutaneous revascularisation or thrombolysis is the mainstay of immediate management of a STEMI. In patients with non-ST-elevation myocardial infarction (NSTEMI) or unstable angina, point-of-care echocardiography can be helpful in risk stratification of these patients. In a study of 466 patients, Fleischmann *et al.* found at early echocardiography in patients with NSTEMI or unstable angina could predict outcomes such as heart failure, arrhythmias, recurrent myocardial ischaemia. Assessment of regional wall motion abnormality had an incremental role in predicting these outcomes in a multivariate analysis⁸ but it requires high level of training and expertise to interpret.

Point-of-care echocardiography is also useful in patients who deteriorate suddenly following an acute coronary syndrome due to mechanical complication of the myocardial infarction-like acute left ventricular free wall rupture, ischaemic

ventricular septal defect and acute mitral regurgitation due to rupture of chordae.

Aortic dissection

Use of point-of-care echocardiography is limited in diagnosis of acute aortic dissection. Transthoracic echocardiography (TTE) provides a limited view of the thoracic aorta and hence transoesophageal echocardiogram (TEE) is a more sensitive and specific tool. An obvious dissection flap can be often seen on TTE but it cannot be relied upon to exclude the diagnosis. Transthoracic and transoesophageal echocardiography play an important role in assessment of pericardial effusion and aortic regurgitation associated with acute aortic dissection. Point-of-care TEE for suspected aortic dissection is useful in patients with renal failure who cannot have iodinated contrast or gadolinium-based contrast. As sedating the patient for a TEE is time consuming and has its own risks, most emergency physicians would consider computerised tomography (CT) of the aorta in patients with strong clinical suspicion of aortic dissection. Apart from diagnosis of an aortic dissection, a CT aortogram provides accurate information on the extent of the dissection and aids surgical management.²

Pulmonary embolism

Point-of-care echocardiography does have a role in diagnosis and management of pulmonary embolism (PE). Haemodynamically significant PE can cause right ventricular dilation, strain and dysfunction. The sensitivity of RV dilation in detecting PE was 90% with a specificity of 26% when the point-of-care echocardiogram was done by 69 emergency physicians⁹ (Table 1). Also, RV strain diagnosed by emergency physicians on point-of-care (POC) also with history of cardiovascular disease was the independent risk predictor of in-hospital adverse events¹⁰ (Table 1). It can also lead to deviation of the interventricular septum leftwards due to pressure overload. McConnell sign which shows severe right ventricular (RV) free wall dysfunction with preserved apical function is a classic finding. Other parameters including RV/LV ratio, RV size, RV fractional area change, IVC collapsibility can be assessed on echocardiography to prognosticate PE.¹¹ These findings may not be present in small subsegmental PE with no associated RV strain. In haemodynamically stable patients with PE, the sensitivity and specificity of echocardiography to diagnose PE was around 55% and 69% respectively in a study by Mansencal *et al.*¹² (Table 1). No large randomised trials have been done to assess use of echocardiography to guide thrombolysis in pulmonary embolism. There have been case reports on point-of-care TEE which led to the diagnosis of pulmonary embolism in a patient with pulseless electrical activity arrest (PEA).

Undifferentiated dyspnoea

Point-of-care ultrasound to assess for left ventricular dysfunction, interstitial oedema and pleural effusion along with IVC

collapsibility can diagnose decompensated heart failure earlier and lead to appropriate management.¹³ In a study by Sriram *et al.*¹⁴ showed moderate sensitivity and specificity of lung ultrasound especially looking for B lines in patients who presented with exacerbation of chronic obstructive lung disease. There was a randomised study by Laursen *et al.*¹⁵ where they randomised patients presenting to emergency department with dyspnoea, chest pain or cough. It was noted that POC Echo was superior to conventional tests to reach correct presumptive diagnosis and early institution of treatment at 4 h of admission in emergency (Table 1).

Cardiac arrest

Cardiac arrest rhythms are classified into shockable or non-shockable rhythms. The advanced cardiac life support (ACLS) algorithms have achieved great deal of success in managing patients with shockable rhythms. The non-shockable rhythms or PEA need to be managed by treating the cause. The most common reversible causes of PEA are hypoxia, severe hypovolaemia, pulmonary embolism, cardiac tamponade and tension pneumothorax.¹⁶ POC echocardiogram can provide significant diagnostic and prognostic information in these scenarios. Presence of collapsed left and right ventricle with low end-diastolic volume on TTE is a sign of severe hypovolaemia. Evidence of a large pericardial effusion with diastolic RV collapse and systolic right atrial collapse along with clinical evidence of pulsus paradoxus and Kussmaul's sign is diagnostic of cardiac tamponade. Loss of 'slipping' sign of the parietal and visceral pleura in the 4–5 intercostal space at the midclavicular line can diagnose pneumothorax in a supine patient. A dilated right ventricle with evidence of RV dysfunction in patients with PEA can be suggestive of a massive pulmonary embolism with right heart strain.¹⁷ The lack of cardiac activity in a patient with PEA has high positive predictive value for death as seen in some studies. This enables decision making regarding ongoing resuscitation measures.¹⁸ POC transthoracic echocardiogram can be technically difficult during cardiopulmonary resuscitation. TEE can be a useful and more accurate tool especially in patients who have been intubated. However, it should not interrupt cardiopulmonary resuscitation. The midesophageal view would enable the physician to examine the cardiac chambers, ascending aorta and look for pericardial effusion. On a 180 degree rotation in the same view, the descending thoracic aorta can be examined looking for aortic dissection. This has limitations of cost, need for further training, need for gastric decompression and interference of image quality from prosthetic material like endotracheal tube. It is associated with pharyngeal or laryngeal tear, hematoma and oesophageal perforation.¹⁷

Cardiopulmonary mechanical support

With the increasing use of mechanical support devices, the use of POC echocardiography has increased significantly. Impella

CP[®] is an axial flow temporary mechanical assist device used in patients with high risk coronary revascularisation procedures or cardiogenic shock. It is inserted through the femoral artery and placed in the left ventricle 3.5 cm below the aortic valve and pointing away from the mitral valve apparatus. This distal end is placed above the aortic valve; hence, it facilitates withdrawal of blood from the left ventricle and ejection into the aorta. This mechanism vents the left ventricle and achieves blood flows of 2.5–3.5 L/min. POC echocardiography can be used to assess the exact placement of the Impella CP[®] into the left ventricle and gain optimal function. If the outflow area of the Impella CP[®] is placed below the aortic valve, it can lead to haemolysis and device failure due to its inability to vent the left ventricle.¹⁹ It can also be to assess correct positioning of inflow and outflow cannula in veno-venous extracorporeal membranous oxygenation (ECMO).²⁰ Point-of-care TTE and TOE can be useful in optimisation of left ventricular assist device (LVAD) function. Perioperative assessment of degree of aortic regurgitation, exclusion of left ventricular thrombus, presence of prosthetic valve or mitral stenosis, assessment of right ventricular function, degree of tricuspid regurgitation and postoperative pericardial effusion play a crucial role in managing LVAD.²⁰

Outreach outpatient clinic

In countries with geographical or logistic barriers to health-care provision, POC echocardiography can be a useful tool for assessment of patients in outreach clinics. Although clinical history and examination are key in guiding investigation and management, they have their own limitations. In a systematic review by Thomas *et al.*, it was noted that POC echocardiography can diagnose more than moderate mitral and aortic stenosis with a sensitivity of 92–100% and 63–100%, respectively, compared to around 33–88% and 71–100% on auscultation by an experienced physician. It can accurately detect left ventricular dysfunction in approximately 92% of the cases and right ventricular dysfunction in approximately 72% of the cases. This enables triage of patients who need comprehensive echocardiography and improve cost-effectiveness.²¹

Medical education

Several medical schools have incorporated POC echocardiography as a part of their student curriculum. It can be used in early years of medical schooling for visual correlation while introduction of anatomy. POC echocardiography, when introduced early can lead to improved image acquisition but the interpretation can be suboptimal due to paucity in understanding in concepts of cardiac pathophysiology.²² On the other hand, the image interpretation is much better by final-year medical students.²³ Although no randomised control trials have been performed to assess the benefits of introducing POC ultrasound in

primary medical curriculum, there has been increased demand among students and educators in doing so. Most of the studies in this area got medical students to competently acquire images on standard ultrasound machines before introduction of hand-held devices.²⁴

Our literature search showed a few studies conducted on common clinical applications of POC echo. The following table shows a summary of these studies.

Clinical application	Study	Prospective/retrospective	Number of patients	Outcomes
Pulmonary embolism	Taylor <i>et al.</i> ⁹	Retrospective	411	98% specificity for POC echo vs. comprehensive study
	Mansencal <i>et al.</i> ¹²	Prospective	76	87% sensitivity and 69% specificity of POC echo and venous Doppler comparing it to CTPA
	Taylor <i>et al.</i> ¹⁰	Retrospective	161	Right ventricular strain and cardiopulmonary disease are key predictors of adverse events
Acute coronary syndrome	Kontos <i>et al.</i> ²⁵	Prospective	260	91% sensitivity for POC echo vs. 40% in ECG 75% specificity in POC echo vs. 94% ECG
	Sabia <i>et al.</i> ²⁶	Prospective	180	Significantly higher detection rate of myocardial infarction compared to ECG
Cardiac arrest	Blaivas <i>et al.</i> ¹⁸	Prospective	169	Cardiac standstill on echo had 100% positive predictive value of death and 58% negative predictive value
Pericardial effusion	Mandavia <i>et al.</i> ²⁷	Prospective	515	96% sensitivity and 98% specificity to detect pericardial effusion on POC echo

Continued

Clinical application	Study	Prospective/retrospective	Number of patients	Outcomes
Hypotension	Moore <i>et al.</i> ²⁸	Prospective	51	Good correlation in LVEF assessment between emergency physicians and cardiologists
	Volpicelli <i>et al.</i> ²⁹	Prospective	108	Good concordance with ultrasound-based diagnosis and the final diagnosis ($k=0.710$, $P < 0.001$)
Assessment of Left ventricular function	Randazzo <i>et al.</i> ³⁰	Prospective	115	86% agreement in estimated EF with POC echo between emergency physician and cardiologist
Dyspnoea	Laursen <i>et al.</i> ¹⁵	Prospective, randomised	320	POC ultrasound superior to conventional tests in accurate emergency department within 4 h of admission

Protocols for image acquisition

There have been a few imaging protocols developed for focussed echo in emergency situations. The FAST protocol is used to assess patients with blunt trauma. It includes subcostal view, longitudinal views of the left and right upper quadrant and transverse and longitudinal suprapubic view.³¹ This is a focussed examination of the heart to rule out haemopericardium; hence, these patients should have a comprehensive echo whether there is a clinical suspicion of severe valvular lesion or coronary dissection secondary to the trauma.

The RUSHed protocol includes parasternal long axis, apical four chamber, subcostal (inferior vena cava), longitudinal right and left upper quadrant, suprapubic and pulmonary views.¹³ This protocol is particularly useful in undifferentiated shock and hypotension. It enables detecting pathologies such as cardiac tamponade, pneumothorax, haemothorax, massive pulmonary emboli with evidence of right heart strain, cardiogenic shock and aortic dissection.

The FATE protocol for developed by Prof Eric Sloth and it is a more detailed examination of the cardiac structure and function. The FATE assessment includes performing a subcostal

view followed by apical 4 chamber, parasternal long axis and parasternal short axis views. The extended FATE views acquire images of the inferior vena cava, apical two chamber, three chamber and five chamber view and parasternal short axis views at the mitral and aortic valve level.³² It enables diagnosis of pathologies like severe left ventricular dysfunction, cardiac tamponade, pulmonary embolism, aortic dissection, severe valvular lesions, myocardial ischaemia and hypovolaemia.

Limitations

POC Echo has advantages of cost and time efficacy but has certain limitations which need to be addressed before it becomes a standard of care. Predefined standards for training in echocardiography image acquisitions and interpretation should be determined before implementation of POC echo in a health organisation to maintain quality control and accountability. There should be standardised documentation for POC echo and appropriate image viewing programs for handheld devices.³³ These images should be appropriately stored in archives so that they can be retrieved when needed.⁵

Standardised training programs should be set up providing credentials to care providers to perform POC echo for appropriate healthcare regulation. The billing structure for POC echo should be formalised as well. The recommendations from the American Society of echocardiography for focussed cardiac ultrasound are for a novice user to perform and interpret at least 20–30 studies if the scope of acquisition is limited to attain an acceptable level of skill.⁵ POC echocardiography is more likely to be performed under different conditions; hence, the accuracy and reliability are limited compared to high-end echocardiography. Some handheld devices have limitations in availability of spectral Doppler and strain analysis which decreases its diagnostic accuracy.³⁴

Conclusion

In summary, POC echocardiography has a broad range of clinical applications. There has been increasing number of devices introduced in the market which are more compact and portable with adequate image quality. It is a useful diagnostic tool along with history and physical examination. It does need standardisation and credentialing to maintain accountability and safe patient practice. More clinical trials need to be performed to show cost efficacy and optimal patient management with POC echocardiograph.

Conflict of interest

This is to declare that the authors conform with the journal's publication policy and all authors are in agreement of the contents in the article. There were no financial grant received for this article, and there was no conflict of interest among the authors.

References

- 1 Zoghbi WA. Echocardiography at the point of care: an ultra sound future. *J Am Soc Echocardiogr* 2011; 24(2): 132–4.

- 2 Arntfield RT, Millington SJ. Point of care cardiac ultrasound applications in the emergency department and intensive care unit—a review. *Curr Cardiol Rev* 2012; 8(2): 98–108.
- 3 Cardim N, Fernandez Golfín C, Ferreira D, Aubele A, Toste J, Cobos MA, *et al.* Usefulness of a new miniaturized echocardiographic system in outpatient cardiology consultations as an extension of physical examination. *J Am Soc Echocardiogr* 2011; 24(2): 117–24.
- 4 Prinz C, Voigt JU. Diagnostic accuracy of a hand-held ultrasound scanner in routine patients referred for echocardiography. *J Am Soc Echocardiogr* 2011; 24(2): 111–6.
- 5 Spencer KT, Kimura BJ, Korcarz CE, Pellikka PA, Rahko PS, Siegel RJ. Focused cardiac ultrasound: recommendations from the American Society of Echocardiography. *J Am Soc Echocardiogr* 2013; 26(6): 567–81.
- 6 Dudaryk R, Benitez Lopez J, Louro J. Diagnosis and thrombolytic management of massive intraoperative pulmonary embolism guided by point of care transthoracic echocardiography. *Case Rep Anesthesiol* 2018; 2018: 8709026.
- 7 Jones AE, Craddock PA, Tayal VS, Kline JA. Diagnostic accuracy of left ventricular function for identifying sepsis among emergency department patients with nontraumatic symptomatic undifferentiated hypotension. *Shock* 2005; 24(6): 513–7.
- 8 Fleischmann KE, Lee TH, Come PC, Goldman L, Cook EF, Caguioia E, *et al.* Echocardiographic prediction of complications in patients with chest pain. *Am J Cardiol* 1997; 79(3): 292–8.
- 9 Taylor RA, Moore CL. Accuracy of emergency physician-performed limited echocardiography for right ventricular strain. *Am J Emerg Med* 2014; 32(4): 371–4.
- 10 Taylor RA, Davis J, Liu R, Gupta V, Dziura J, Moore CL. Point-of-care focused cardiac ultrasound for prediction of pulmonary embolism adverse outcomes. *J Emerg Med* 2013; 45(3): 392–9.
- 11 Dahhan T, Siddiqui I, Tapson VF, Velazquez EJ, Sun S, Davenport CA, *et al.* Clinical and echocardiographic predictors of mortality in acute pulmonary embolism. *Cardiovasc Ultrasound* 2016; 14(1): 44.
- 12 Mansencal N, Vieillard-Baron A, Beauchet A, Farcot JC, El Hajjam M, Dufaitre G, *et al.* Triage patients with suspected pulmonary embolism in the emergency department using a portable ultrasound device. *Echocardiography* 2008; 25(5): 451–6.
- 13 Chenkin J, Atzema CL. Contemporary application of point-of-care echocardiography in the emergency department. *Can J Cardiol* 2018; 34(2): 109–16.
- 14 Sriram KB, Singh M. Lung ultrasound B-lines in exacerbations of chronic obstructive pulmonary disease. *Intern Med J* 2017; 47(3): 324–7.
- 15 Laursen CB, Sloth E, Lassen AT, Christensen R, Lambrechtsen J, Madsen PH, *et al.* Point-of-care ultrasonography in patients admitted with respiratory symptoms: a single-blind, randomised controlled trial. *Lancet Respir Med* 2014; 2(8): 638–46.
- 16 Hernandez C, Shuler K, Hannan H, Sonyika C, Likourezos A, Marshall J. C.A.U.S.E.: cardiac arrest ultra-sound exam—a better approach to managing patients in primary non-arrhythmic cardiac arrest. *Resuscitation* 2008; 76(2): 198–206.
- 17 Long B, Alerhand S, Maliel K, Koyfman A. Echocardiography in cardiac arrest: an emergency medicine review. *Am J Emerg Med* 2018; 36(3): 488–93.
- 18 Blaivas M, Fox JC. Outcome in cardiac arrest patients found to have cardiac standstill on the bedside emergency department echocardiogram. *Acad Emerg Med* 2001; 8(6): 616–21.
- 19 Fiza B, Tang M, Maile M. Management of cardiopulmonary assist devices in critically ill patients using point-of-care transthoracic echocardiography: a case series. *Crit Ultrasound J* 2017; 9(1): 24.
- 20 Stainback RF, Estep JD, Agler DA, Birks EJ, Bremer M, Hung J, *et al.* Echocardiography in the Management of Patients with Left Ventricular Assist Devices: recommendations from the American Society of Echocardiography. *J Am Soc Echocardiogr* 2015; 28(8): 853–909.
- 21 Thomas F, Flint N, Setareh-Shenas S, Rader F, Kobal SL, Siegel RJ. Accuracy and efficacy of hand-held echocardiography in diagnosing valve disease: a systematic review. *Am J Med* 2018; 131: 1155–60.
- 22 Nelson BP, Hojsak J, Dei Rossi E, Karani R, Narula J. Seeing is believing: evaluating a point-of-care ultrasound curriculum for 1st-year medical students. *Teach Learn Med* 2017; 29(1): 85–92.
- 23 Kraft P, Fleischer A, Wiedmann S, Rucker V, Mackenrodt D, Morbach C, *et al.* Feasibility and diagnostic accuracy of point-of-care handheld echocardiography in acute ischemic stroke patients – a pilot study. *BMC Neurol* 2017; 17(1): 159.
- 24 Johri AM, Durbin J, Newbigging J, Tanzola R, Chow R, De S, *et al.* Cardiac point-of-care ultrasound: state-of-the-art in medical school education. *J Am Soc Echocardiogr* 2018; 31(7): 749–60.
- 25 Kontos MC, Arrowood JA, Paulsen WH, Nixon JV. Early echocardiography can predict cardiac events in emergency department patients with chest pain. *Ann Emerg Med* 1998; 31(5): 550–7.
- 26 Sabia P, Afrookteh A, Touchstone DA, Keller MW, Esquivel L, Kaul S. Value of regional wall motion abnormality in the emergency room diagnosis of acute myocardial infarction. A prospective study using two-dimensional echocardiography. *Circulation* 1991; 3(Suppl): I85–92.
- 27 Mandavia DP, Hoffner RJ, Mahaney K, Henderson SO. Bedside echocardiography by emergency physicians. *Ann Emerg Med* 2001; 38(4): 377–82.
- 28 Moore CL, Rose GA, Tayal VS, Sullivan DM, Arrowood JA, Kline JA. Determination of left ventricular function by emergency physician echocardiography of hypotensive patients. *Acad Emerg Med* 2002; 9(3): 186–93.
- 29 Volpicelli G, Lamorte A, Tullio M, Cardinale L, Giraudo M, Stefanone V, *et al.* Point-of-care multiorgan ultrasonography for the evaluation of undifferentiated hypotension in the emergency department. *Intensive Care Med* 2013; 39(7): 1290–8.
- 30 Randazzo MR, Snoey ER, Levitt MA, Binder K. Accuracy of emergency physician assessment of left ventricular ejection fraction and central venous pressure using echocardiography. *Acad Emerg Med* 2003; 10(9): 973–7.
- 31 Scalea TM, Rodriguez A, Chiu WC, Brenneman FD, Fallon WF Jr, Kato K, *et al.* Focused Assessment with Sonography for Trauma (FAST): results from an international consensus conference. *J Trauma* 1999; 46(3): 466–72.
- 32 Jensen MB, Sloth E, Larsen KM, Schmidt MB. Transthoracic echocardiography for cardiopulmonary monitoring in intensive care. *Eur J Anaesthesiol* 2004; 21(9): 700–7.
- 33 Platz E, Solomon SD. Point-of-care echocardiography in the accountable care organization era. *Circ Cardiovasc Imaging* 2012; 5(5): 676–82.
- 34 Andersen GN, Haugen BO, Graven T, Salvesen O, Mjølstad OC, Dalen H. Feasibility and reliability of point-of-care pocket-sized echocardiography. *Eur J Echocardiogr* 2011; 12(9): 665–70.