# Point-of-care cardiac ultrasound techniques in the physical examination: better at the bedside

Bruce J Kimura[1,2]

[1]Department of Cardiology, Scripps Mercy Hospital, San Diego, California, USA
[2]Department of Graduate Medical Education, Scripps Mercy Hospital, San Diego, California, USA

**Correspondence to**
Dr Bruce J Kimura, Scripps Mercy Hospital, 4077 Fifth Avenue, San Diego, CA 92103, USA; kimura.bruce@scrippshealth.org

Received 3 January 2017
Accepted 2 February 2017
Published Online First 26 April 2017

**To cite:** Kimura BJ. *Heart* 2017;**103**:987–994.

## ABSTRACT

The development of hand-carried, battery-powered ultrasound devices has created a new practice in ultrasound diagnostic imaging, called 'point-of-care' ultrasound (POCUS). Capitalising on device portability, POCUS is marked by brief and limited ultrasound imaging performed by the physician at the bedside to increase diagnostic accuracy and expediency. The natural evolution of POCUS techniques in general medicine, particularly with pocket-sized devices, may be in the development of a basic ultrasound examination similar to the use of the binaural stethoscope. This paper will specifically review how POCUS improves the limited sensitivity of the current practice of traditional cardiac physical examination by both cardiologists and non-cardiologists. Signs of left ventricular systolic dysfunction, left atrial enlargement, lung congestion and elevated central venous pressures are often missed by physical techniques but can be easily detected by POCUS and have prognostic and treatment implications. Creating a general set of repetitive imaging skills for these entities for application on all patients during routine examination will standardise and reduce heterogeneity in cardiac bedside ultrasound applications, simplify teaching curricula, enhance learning and recollection, and unify competency thresholds and practice. The addition of POCUS to standard physical examination techniques in cardiovascular medicine will result in an ultrasound-augmented cardiac physical examination that reaffirms the value of bedside diagnosis.

## INTRODUCTION

The patient's bedside has been the epicentre of medical care for centuries. It is from this site, the 'point of care,' that the physician obtains the patient's history and performs physical examination, anchoring initial diagnostic impressions and setting a pathway for subsequent triage, testing, treatment and referral. In today's acutely ill patient, limited applications of ultrasound at the point of care are easily performed and have higher sensitivities for the same pathological processes sought by physical techniques.[1 2] The detection of disease by taking a quick look for ultrasound 'signs' that augment traditional physical methods bridges the use of ultrasound to the venerable practice of physical examination[3] (table 1). The following paper will specifically review the use of point-of-care ultrasound (POCUS) to improve the cardiac physical examination.

## VALUE OF ULTRASOUND AT THE 'POINT OF CARE'

Miniaturisation and simplification of devices that perform ultrasound imaging has resulted in the development of a novel methodology and non-traditional user groups.[4] The economic, quality and medico-legal implications of using ultrasound as a part of the physical examination or as a limited diagnostic test have resulted in controversy and affect the inclusion and dissemination of POCUS in medicine (table 1).

Despite the ongoing ambiguities of POCUS privileging and reimbursement, there is little debate over the value of improving a physician's own physical examination. Perhaps more than any other organ system, physical examination of the heart is routinely performed regardless of the patient's chief complaint, as it provides the status of the cardiovascular system under the current physiological stressors. Finding signs representing common abnormalities that have prognostic value or treatment implications should be the goal of bedside examination by any method and result, time permitting, in confirmation by more comprehensive evaluation. Published studies of the diagnostic accuracies of traditional physical examination versus POCUS examination demonstrate higher sensitivity of POCUS, whether compared as absolute accuracies (table 2) or when measured as incremental improvement in accuracy by the same observer on the same patient (table 3). The diminishing sensitivity of cardiac physical examination has caused much concern over recent years and has many potential explanations including a reduction in training and skills of the current generation of physicians, the increased number of patient care environments where physical examination techniques cannot be adequately practiced and reduced prevalence of physical findings in contemporary patient populations and disease presentations. Few studies have evaluated a truly 'blended' examination as often performed in clinical practice, where the incremental effect of adding a limited ultrasound examination to traditional bedside evaluation addresses the specific biases of user confidence in their own accuracies, particularly when attempting to reconcile discordant bedside data.

In addition to the capability of detecting disease at an earlier stage, inherent advantages exist in using ultrasound for bedside examination, particularly in modern acute care settings where ambient noise levels, frequent alarms and patient immobility can mask soft auscultatory findings or limit manoeuvring, accounting for some of the reduced sensitivities reported for physical findings in emergency settings.[5] Unlike the original validation studies of physical techniques that primarily involved only expert practitioners and patients with a single, symptomatic lesion, initial studies using ultrasound have noted incremental value for cardiac diagnosis

**Table 1** Comparison of traditional cardiac physical techniques, POCUS as a physical examination technique and POCUS as a limited echo diagnostic test

| | Traditional physical examination | POCUS as physical exam technique | POCUS as limited ultrasound examination |
|---|---|---|---|
| Use model | ▶ Applied after history<br>▶ Directed, expanded or truncated by physician<br>▶ Daily use during inpatient rounds and in outpatient visits | ▶ Applied during traditional physical examination<br>▶ Simplified, fundamental imaging protocol for all patients<br>▶ Daily use, as needed during inpatient rounds, and for outpatient visits | ▶ Applied as a diagnostic test after history and physical<br>▶ Multiple distinct imaging protocols and indications<br>▶ Once during initial patient evaluation |
| Indication | ▶ In forming diagnoses<br>▶ As follow-up of abnormalities noted previously<br>▶ Screening | ▶ In forming diagnoses<br>▶ To evaluate physical findings, as needed<br>▶ In follow-up, during or after treatment<br>▶ Screening | ▶ In confirming or excluding diagnostic considerations<br>▶ Documentation of medical necessity needed |
| Patients | All | All | Smaller minority with indications |
| Devices | ▶ Binaural stethoscope<br>▶ Cost of $150<br>▶ No power necessary<br>▶ Individual ownership | ▶ Simplified devices, primarily 2D imaging<br>▶ Ideally pocket-sized, rapid boot time, low maintenance, simplified user presets<br>▶ Cost of $8000 (for pocket-size)<br>▶ Battery operated<br>▶ Individual or shared ownership | ▶ Fully featured, multiple modalities (eg, Doppler), variable use dependent on imaging protocol<br>▶ Usually cart based, network connected, ·Cost of $50 000–$150,000<br>▶ Electric power needed<br>▶ Institutional/group ownership typical |
| Accuracy considerations | ▶ Low sensitivity, moderate specificity for signs moderately associated with advanced disease<br>▶ No gold standard; prevalence of signs in disease states defined by expert use | ▶ Moderate sensitivity, moderate to high specificity for signs that are associated with abnormalities related to disease<br>▶ Early disease detected<br>▶ Findings confirmed by gold standard, advanced imaging techniques (echo, TEE, CT/MRI) | ▶ High-sensitivity and specificity imaging protocol for a predefined abnormality highly associated with disease<br>▶ Often non-specific and incomplete for incidental findings<br>▶ Can be gold standard for primary finding; incidental findings need confirmation by advanced imaging (echo, TEE, CT/MRI) |
| Potential liability | For 'signs' sought. | For ultrasound 'signs' sought | For all recorded findings, primary and incidental |
| Additional reimbursement | $0 (a required part of clinical evaluation) | $0 (as a part of physical examination) | $25–$100* |
| Documentation of results | As part of patient encounter (consultation, progress note) | Results reported as part of physical examination within encounter | Images recorded, formal report generated as a medical test |
| Education | Medical school and residency | Medical school and residency | Subspecialty training |
| Competency | ▶ Non-formalised<br>▶ By observation in practice | User determined, based on personal improvement of bedside accuracy | Competency standards exist for formal testing interpretation |
| Considerations and limitations | ▶ Difficult to master , hearing dependent<br>▶ Difficult in the certain patient groups (eg, obese, COPD, postop or immovable)<br>▶ Practice often confounded by time constraints or ambient noise<br>▶ Examination sensitivity and breadth falls over time<br>▶ Few prognostic or outcome data | ▶ Brief, fundamental examination can be learnt in months<br>▶ Technically limited in certain patient groups but less so than physical examination and unaffected by noise<br>▶ Technique requires repetitive practice to maintain skills<br>▶ Detection of predetermined signs should generate referral for complete study<br>▶ Emerging prognostic and outcome data | ▶ Imaging protocol driven, test remains standard<br>▶ Image quality may fall with lack of practice<br>▶ Few standardised imaging protocols available<br>▶ Least technically limited of the three<br>▶ Likely to generate the most echo referrals to delineate both primary and incidental abnormalities found<br>▶ Prognostic and outcome data limited to specific clinical indications |

*Dependent on number of examinations, patient location, professional versus technical fees.

2D, two dimensional; COPD, chronic obstructive pulmonary disease; POCUS, point-of-care ultrasound; postop, postoperative; TEE, transesophageal echocardiography.

by medical students,[6–9] residents,[10–13] non-cardiologists[14] and cardiologists,[15–18] often bolstered by the detection of multiple findings, some incidental and asymptomatic, in each patient. In bedside practice, skills with a stethoscope or ultrasound probe change over time, as they are variably acquired, honed or lost, as dictated by the physician and by the patients encountered. A recent study of well-trained medical residents who had stopped ultrasound imaging has found loss of proficiency after only 2 years.[19] Indeed similar to specific traditional physical examination techniques that are retained, maintenance of POCUS skills in practice may require frequent, repetitive use and simple, robust findings. Over time, the incremental value of adding less frequently employed ultrasound techniques to bedside examination, such as M-mode, colour and spectral Doppler, may differ between cardiologists and non-cardiologists largely due to prior echocardiography training and the prevalence of cardiac patients seen. The individual physician's realisation of personal improvement in aspects of his/her own bedside accuracies directly attributable to the use of ultrasound may be the strongest ethical argument for self-determined use of POCUS by non-cardiologists (figure 1) and will require self-directed maintenance of the appropriate skill set. However, regardless of individual variability in bedside skills, there exists an overall need to structure a fundamental POCUS examination using traditional, time-tested targets to coordinate standards for patient care and medical education in ultrasound.

## ACCURACY OF ULTRASOUND AND PHYSICAL TECHNIQUES FOR TRADITIONAL TARGETS OF BEDSIDE EXAMINATION

### Detection of LV systolic dysfunction

A reduction of LV systolic function, even when asymptomatic, has diagnostic, treatment and prognostic implications and has long been a target for bedside techniques. Few data exist in screening by non-cardiologists for the asymptomatic patient with LV dysfunction[20] or for the patient with incidental LV dysfunction who is admitted for another disease. When examined by cardiologists, the detection of an S3 was 68% sensitive

**Table 2** Cardiac bedside examination—traditional versus POCUS findings

| Entity | Physical finding (SN, SP) | POCUS finding (SN, SP) | Notes |
|---|---|---|---|
| LV systolic dysfunction | S3 (11%–51%, 85%–98%),[2] (13%, 98%) in ED.[5] Displaced apical impulse (5%–66%, 93%–99%),[2] 15% incidence in symptomatic HFrEF cohort[22] | Subjective estimation of contraction and/or EPSS >1 cm (69%–94%, 88%–94%)[6–10 12–18 24 25] | US criteria vary between studies; both easily learnt and are reproducible by non-cardiologists. Prevalence of physical findings in LVSD is <20%, and even lower in asymptomatic LVSD |
| Elevated LA filling pressures | S4 (35%–71%, 50%–70%)[2] | LAE (53%–75%, 72%–94%)[9 24 29 30] | LAE is prognostic and not found by physical examination. US learnt after brief training |
| Pulmonary oedema or interstitial disease | Rales (19%–64%, 82%–94%),[2] (62%, 68%) in ED[5] | B-lines (85%–98%, 83%–93%)[5 33 39] | B-lines are ultrasound artefacts and potentially vary between devices. US easily learnt by novices. Prevalence of 13% in HFrEF cohort[22] |
| Pleural effusion | Dullness to percussion (73%–89%, 81%–91%)[2 37] | Fluid in thorax (64%–90%, 72%–95%)[5 38] | Studies of physical findings used CXR as gold standard, whereas US used CT. Significant increase in SN with US, especially for small effusions |
| Right ventricular enlargement or pulmonary hypertension | Sustained left parasternal lift (71%, 80%)[2] | RV/LV>1 (55%, 69%)[42] | Non-specific finding of RVE is seen in RVMI, submassive pulmonary embolism, chronic or pulmonale. Expert US practice needed to use spectral Doppler |
| Elevated central venous pressures | JVP (47%–92%, 93%–96%)[2] (37%, 87%) in ED,[5] 22% incidence in HFrEF cohort[22] | IVC plethora (73%, 85%)[44] | POCUS advantageous in the supine ICU patient. POCUS data include non-experts. JVP by US correlates with physical estimates, but underestimates catheter-confirmed pressure |
| Valve regurgitation | Murmur for mild-or-worse: MR (56%–75%, 89%–93%) or AI (54%–87%, 75%–98%)[2] | Colour Doppler (82%, 93%) for mild severity[51] | Colour Doppler jet area limitations apply. Expert practice likely necessary to quantify severity |
| Severe aortic stenosis | Late peaking murmur (83%–90%, 72%–88%)[2] | Restricted cusp mobility (85%, 89%)[50] | Expert auscultation coupled with POCUS may be the best screening method |

CXR, chest radiography; ED, emergency department; EPSS, E point septal separation; HFrEF, heart failure with reduced ejection fraction; ICU, intensive care unit; IVC, inferior vena cava; JVP, jugular venous pulsations; LA, left atrium; LAE, left atrial enlargement; LV, left ventricle; LVSD, left ventricular systolic dysfunction; MR, mitral regurgitation; POCUS, point-of-care ultrasound; RVE, right ventricular enlargement; RVMI, right ventricular myocardial infarction; SN, sensitivity; SP, specificity; US, ultrasound.

**Table 3** Ten studies (> 2 users) comparing effect of POCUS after cardiac physical examination on overall diagnostic accuracy by user expertise

| Study | Users (n) | Patients | Results | Notes |
|---|---|---|---|---|
| Decara 2005[7] | 10 students instructed during 4-week course | 12 standardised outpatient models | After US use, diagnostic scores improved for detection of primary and all cardiac findings | Medical school teaching course |
| Panoulas 2013[8] | 5 students and 3 junior doctors with 2-hour tutorial including colour Doppler for cardiac abnormalities | 122 cardiology patients in emergency department or inpatient ward | US after physical examination improved accuracy from 49% to 75%. For LVSD, physical (26% SN, 85% SP) improved (to 74% SN, 94% SP) with US | Diagnostic US images obtained by trainees in 89% of patients. US had incremental benefit to the history, physical examination and ECG |
| Stokke 2014[9] | 21 students with 4 hours of training in focused cardiac US with Colour Doppler | 72 selected inpatients referred for echo | US after physical examination improved detection of significant valve disease from 40% to 64%. LV systolic dysfunction (90% SN, 57% SP), LAE (53% SN, 94% SP) reported | Auscultation used for murmurs only, no comparative assessment of gallops made for LV systolic dysfunction or LAE |
| Kimura 2002[10] | 10 IM residents with 2-hour training in single 2D view screen for LVSD | 12 selected outpatient models (5 with asymptomatic EF <50%) | After US use, improvement in 10/13 residents' accuracy for LVSD | Residents obtained fair/good quality studies in 82% of 156 examinations |
| Brennan 2007[11] | 4 IM residents with 4-hour training, 20 studies in IVC assessment | 40 consecutive patients undergoing right heart catheterisation | Compared with visual JVP assessment alone, US IVC improved accuracy for RAP >10 mm Hg from 60% to 71%. SN improved from 14% to 82% with US, SP similar for both techniques | Residents failed to recognise JVP in 37% versus unable to assess IVC in 10% |
| Galderisi 2010[12] | 4 IM residents with 3 months of training and 5 cardiologists | 304 consecutive endocrine/oncology patients referred for cardiac consultation | Diagnosis of cardiac abnormalities made in 38% with physical, improved to 70% after US use. Overall 91% SN, 76% SP | Improvement in SN, SP seen in both residents (87%, 72%) versus experts (97%, 84%). Higher false positives by residents |
| Martin 2009[14] | 10 hospitalists US trained on 5 patients and >6 hour interpretative cardiac disease | 354 inpatients referred for echo | After US use, improvement in physical assessment of LV dysfunction, cardiomegaly, pericardial effusion | No additional benefit to US for AS, AI, or MR, largely due to false positive US examinations |
| Spencer 2001[15] | 4 cardiologists | 36 outpatients recruited (6 normals) | In expert hands, in detection of major cardiac findings, physical missed 43% versus 21% after US use. | Included Colour Doppler. Largest improvement by US was in detecting LVSD |
| Cardim 2011[16] | 6 cardiologists, 2 centres. | 189 outpatient cardiology consults | In expert hands, physical examination was abnormal in 29% versus 47% with US. After physical examination, US changed testing in 9%, and therapeutic strategies in 20% | US reduced unnecessary routine echo testing, and determined release from outpatient clinic |
| DiBello 2015[18] | Cardiologists at 5 centres, extensive imaging with pocket-sized device. | 443 inpatients referred for cardiac consultation | Physical examination 75% SN and 62% SP improved to 88% SN and 86% SP after US use | When both techniques are performed by the same expert, US added significant information in 22% of inpatients |

2D, two dimensional; AI, aortic insufficiency; AS, aortic stenosis; IM, internal medicine; IVC, inferior vena cava; JVP, jugular venous pulsations; LAE, left atrial enlargement; LVSD, left ventricular systolic dysfunction; MR, mitral regurgitation; POCUS, point-of-care ultrasound; SN, sensitivity; SP, specificity; US, ultrasound; RAP, right atrial pressure.

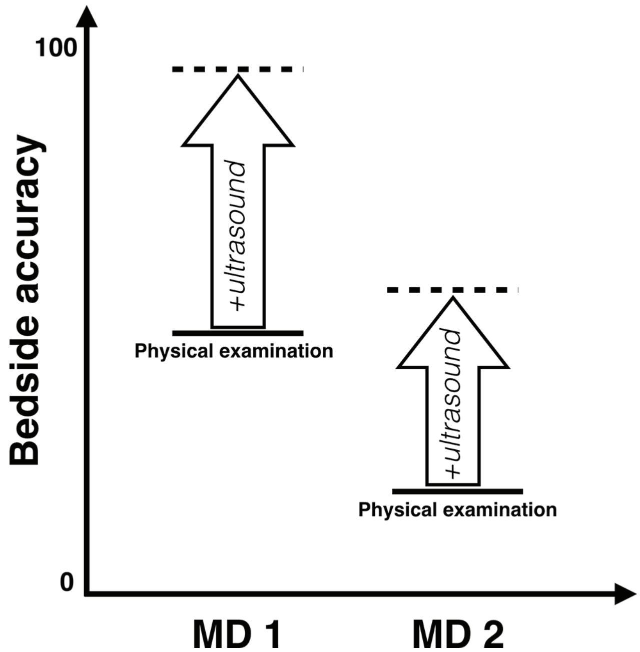


**Figure 1** Graphic representation of the effect of ultrasound (US) on two users' (MD 1 and MD 2) bedside performance. When MD 2 (eg, a non-expert) augments a poor physical examination with US, bedside accuracy equals or exceeds MD 1 (eg, a specialist) physical examination (reference 6). The additional use of US improves both physicians' bedside accuracy, however, less so in MD 2. Whether point-of-care US privileging for MD 2 should be based on incremental utility or an absolute threshold has not been defined.

and 73% specific in 52 patients with chronic LV systolic dysfunction of whom 37 had PCWP >18 mm Hg.[21] In a more contemporary study of 1376 patients with symptomatic heart failure and LVEF <35% examined by site investigators, an S3 was observed in only 15% of patients.[22] Similarly, a sustained apical impulse, although considered 'very helpful' to make the diagnosis in a systematic review,[23] is frequently absent even when sought by experts.[2] These data suggest that physical findings may relate to more advanced, decompensated stages of heart failure. As the suspicion of LV dysfunction by a primary or emergency room physician often generates testing and referral, studies of non-cardiologist ultrasound use have importantly verified a >90% accuracy of limited imaging protocols for LV systolic dysfunction, mainly employing subjective estimations of contractility or E-point septal separation[6–10 12–18 24 25] (figure 2A), across all stages of heart failure. Multiple studies[7–10 12 14] have evaluated the incremental effect of adding a limited ultrasound examination to traditional bedside evaluation specifically for LV systolic dysfunction by non-cardiologists and primarily confirm improved sensitivity with ultrasound use.

### Detection of elevated left heart filling pressures

Perhaps more important than the screening for any numerical threshold of ejection fraction is the detection of elevated filling LV pressures as a marker of heart failure. As previously noted, the presence of an S3 or S4 is evidence of elevated filling pressures at the bedside, with studies showing poor sensitivity (11%–78%) but increased specificity (80%–99%) for the S3, and minimal diagnostic value, if any, for the S4 (2,5). As the presence of an S3 gallop, elevated filling pressures, or brain natriuretic peptide

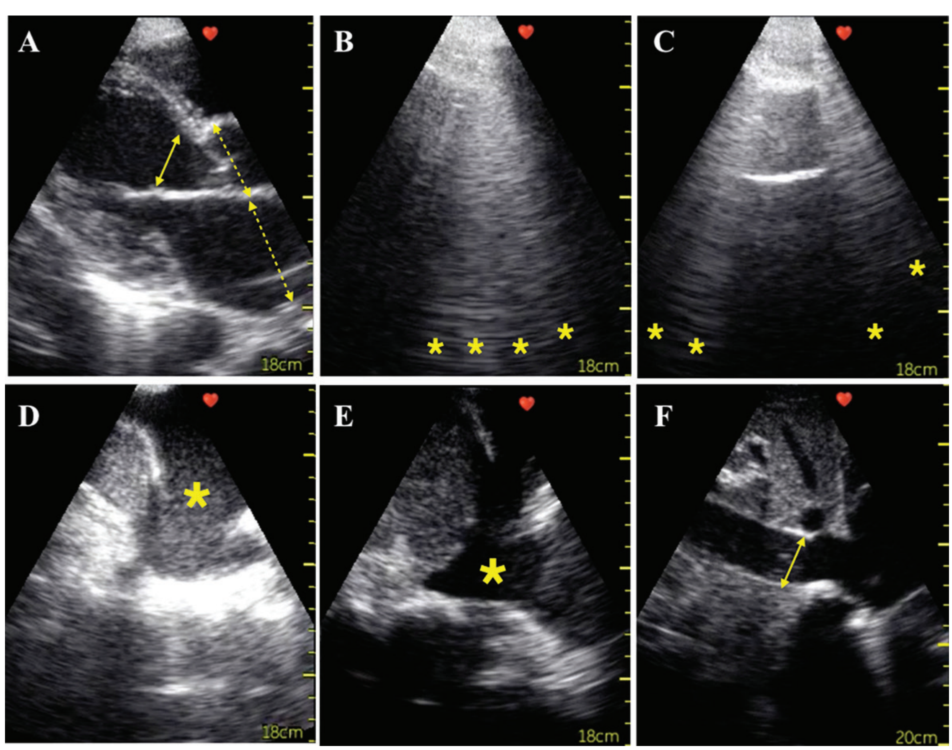


**Figure 2** Example of five individual point-of-care ultrasound signs using a pocket-sized device on a 60-year-old man with unexplained dyspnoea and found to have decompensated heart failure. (A): Both a large E-point septal separation (solid line) and left atrial enlargement (dashed left atrial diameter > aortic diameter) are noted in diastole suggesting cardiomyopathy and elevated filling pressures. (B and C): Multiple vertical B-lines (*) are noted in both upper lung fields consistent with pulmonary oedema from elevated filling pressures. (D and E) Bilateral pleural effusions (*) suggest lung congestion from subacute decompensation. (F) Plethoric inferior vena cava suggests elevation of central venous pressures and can be followed daily with medical treatment.

(BNP) levels could be transient, the detection of left atrial enlargement (LAE) may be the best indicator of sustained elevation of LA filling pressures.[26] Studies[27 28] using either M-mode or two-dimensional measures of LA size have shown prognostic implications to LAE, in regard to mortality and stroke, and in patients with cardiomyopathy and mitral disease. The size of the left atrium could be helpful in determining a cardiac source of dyspnoea, signify the onset of symptoms in LV dysfunction or aortic stenosis, predict chronicity and stroke risk in a patient with newly-recognised atrial fibrillation or confirm the significance of chronic left-sided valvular disease. Clinically significant LAE cannot be detected by physical examination techniques but can be recognised with 80% accuracy by briefly trained medical residents with a quick-look ultrasound sign that compares the LA anterior-posterior diameter to a 4 cm reference standard[29] or to the overlying aorta in a single parasternal view[24 30] (figure 2A). It is conceivable that mitral inflow by Doppler could provide additional useful information by POCUS imaging; however, it requires more extensive knowledge. As a structural adaptation, LAE importantly signifies a predisposition for acute decompensation of heart failure, where a further unaccommodated rise in filling pressures results in pulmonary congestion.

### Determination of pulmonary congestion

Excessive extravascular lung water can manifest as interstitial oedema and pleural effusion. Rales or crackles felt to be generated by oedematous alveoli, which open on inspiration, have a poor sensitivity (19%–64%) and high specificity (82%–94%) for elevated filling pressures,[2] relate to the presence of pulmonary oedema and severity of symptoms, and are confounded by their evanescence with treatment, presence of atelectasis and gravitational forces in the supine or intubated position. The ultrasound 'equivalent' of rales, B lines or 'comet-tail' artefacts are ring-down phenomena proposed to be due to thickening of peripheral pleural or interstitial septae due to oedema or fibrosis[31] (figure 2B,C). In oedema, B-lines have similar gravitational predilections as rales and are also thought to resolve quickly, having less specificity for heart failure when found in the lung bases and more when found in the apices.[32] Despite the lack of a validating tissue model and potential interdevice variation, the presence of B-lines are a more sensitive marker of decompensated heart failure than clinical assessment,[33] may precede the appearance of rales and have significant prognostic impact whether tallied in a 28-zone lung imaging protocol, 8-zone protocol or simply detected as 3 or more in the lung apices.[34] In a recent study of 195 ambulatory patients with chronic heart failure,[35] the subgroup with 3-or-more B-lines (n=59) had a four-fold higher risk of heart failure hospitalisation or all-cause mortality and yet a relatively low 19% prevalence of rales on review of the cardiologists' clinic notes. The number of B-lines has been shown to be related to ejection fraction, degree of diastolic dysfunction and New York Health Association class.[36] Similar to rales, the presence of B-lines due to infectious, autoimmune, drug-related or fibrosing interstitial abnormalities can confound attempts at diagnosis of superimposed acute oedema.

The detection of small, bilateral pleural effusions, often indicative of decompensated heart failure and a worse prognosis, is difficult by physical techniques but much improved by using ultrasound imaging of the costophrenic angles (figure 2D,E). Physical findings such as dullness to percussion have reported sensitivity and specificity of >80% in studies that used chest radiography as a gold standard[37] and therefore likely apply to effusions of >200 ccs. Accordingly, these studies overestimate the sensitivity of physical techniques when applied to small effusions, especially compared with ultrasound studies that used CT as a gold standard. In a study of decompensated heart failure using 60 patients and 22 controls, expert examination by two cardiologists and CT as the gold standard, pulmonary auscultation had a 55% sensitivity and 91% specificity for heart failure compared with the 90% sensitivity and 95% specificity of lung ultrasound.[38] Pleural effusions were detectable in 90% of heart failure admissions. In a small study of 32 subjects with adult respiratory distress syndrome and 10 normal volunteers, lung auscultation by a senior investigator had a sensitivity and specificity for pleural effusion of 42% and 90%, and for alveolar-interstitial syndrome of 34% and 90%, as compared with ultrasound use that had a sensitivity and specificity of 92% and 93% for effusions, and 98% and 88% for alveolar-interstitial syndrome.[39] Using CT as a gold standard, ultrasound also outperformed chest radiography in this ICU population. Additionally, lung POCUS has been used to quantify the amount of effusion and detect exudative complications such as particulate matter or early septation. Lung ultrasound has been touted to have 92% sensitivity and 92% specificity in the detection of pneumonia[40] and 79% sensitivity and 98% specificity in pneumothorax,[41] both entities encountered by cardiologists and poorly detected by auscultation. Conversely, some disorders, such as airway narrowing causing stridor or wheezing, are better found by auscultation. Detection of lung congestion through ultrasound signs of B-lines and effusions provides physiological insight that complements echocardiography or BNP data and can suggest a need for more aggressive treatment to perhaps avoid hospitalisation or readmission. Although elevated LA pressures can predispose to the accumulation extravascular lung water, lymphatic drainage of the lung may also determine the temporal resolution of lung congestion through a dependence on reduction in central venous pressures.

### Determination of right heart function and central venous pressures

Enlargement of the right ventricle can be detected on physical examination by a sustained parasternal heave or right-sided S3, both with minimal validation of accuracy. Although most likely signifying chronic pulmonary hypertension, right ventricular enlargement can also occur with RV infarction, acute pulmonary embolism, isolated severe tricuspid regurgitation, atrial septal defect, acute ventricular septal rupture and RV dysplastic syndromes. In POCUS, the utility of the RV/LV ratio >0.6 as obtained in the apical four-chamber view can be used to diagnose submassive pulmonary embolism but is very subjective, has low sensitivity (55%) and specificity (69%) even in expert hands,[42] and can be falsely increased by foreshortening of the LV during imaging, underestimate RV enlargement in the setting of LV enlargement and be confounded by pre-existing cor pulmonale.

The determination of central venous pressures by jugular venous pressure (JVP) has been considered a quintessential skill of physical examination. The accuracy of JVP assessment has an estimated 78%–95% sensitivity and 89%–93% specificity[2] for a central venous pressures >12 cm of $H_20$, with details of x and y descents providing additional diagnostic information in tamponade and constriction. However, physical techniques are diminished in more obese patients with thicker necks, and limited in supine intubated patients. Ultrasound can be used to find the height of the jugular venous column, although both visual and ultrasound observations may underestimate true central venous pressures.[43] Ultrasound can also estimate central

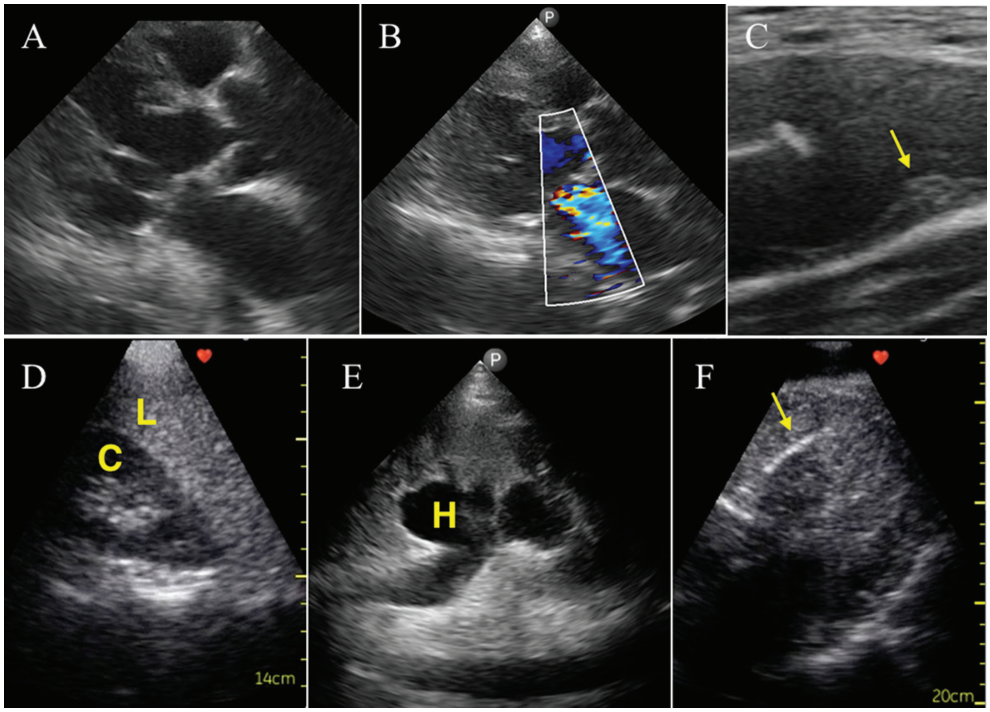


**Figure 3** Extended point-of-care ultrasound (POCUS) imaging for the cardiac patient using pocket-sized devices. (A) Patient referred for systolic murmur demonstrates both aortic stenosis and mitral valve prolapse (MVP) by POCUS. (B) (same patient as A): concomitant, significant MR is present using colour Doppler. (C) Early internal carotid plaque (arrow) suggests subclinical atherosclerosis and increased CHD risk. (D) Echogenic liver (L), brighter than renal cortex (C) consistent with fatty infiltration may suggest hypertriglyceridaemia and metabolic syndrome. (E) Hydronephrosis (H) (ie, renal abnormalities) can explain worsening fluid retention and renal insufficiency in the cardiorenal syndrome. (F) Subcostal four-chamber view shows blood pool stasis causing indistinct myocardium during asystole suggesting poor prognosis in resuscitation. Note defibrillator wire (arrow) in right ventricle.

venous pressure by the respiratory dynamics of the inferior vena cava (IVC) in longitudinal view[44] (figure 2F), a method also used to determine 'fluid responsiveness' in the critically ill.[45] When comparing physical examination of JVP versus IVC ultrasound techniques performed by four medical residents on 40 consecutive patients after right heart catheterisation, sensitivity was 14% versus 82% for right atrial pressure >10 mm Hg.[11] In addition to variability in technique, the question of accuracy may be in the actual difference between these two vessels in their behaviour to central venous pressures. The JVP estimate, as a manometer, relies on an approximation of the true phlebostatic axis[2] and stable cerebral venous return. The IVC size is confounded by diaphragmatic motion, obesity and intra-abdominal pressures. Nonetheless, IVC findings obtained at the bedside by non-cardiologists specifically in decompensated heart failure have shown prognostic value in 75 patients for predicting readmission[46] and in 80 patients for predicting in-hospital mortality.[47]

## Detection of significant valvular disease

As echocardiography is essential in modern assessment of valve disease, POCUS facilitates care by identifying which patients

**Table 4** Other potential POCUS 2D applications for the cardiac patient inadequately addressed by physical examination

| Cardiac entities | Non-cardiac entities |
|---|---|
| ▶ Left ventricular hypertrophy or non-obstructive hypertrophic cardiomyopathy | ▶ Subclinical atherosclerosis of the carotid or femoral arteries |
| ▶ Thoracic aortic aneurysm | ▶ Femoral haematoma versus pseudoaneurysm (postprocedure) |
| ▶ Abdominal aortic aneurysm (small or moderate sized) | ▶ Lower extremity deep vein thrombosis |
| ▶ Pericardial effusion (small or moderate sized) | ▶ Fatty liver (in hypertriglyceridaemia) |
| ▶ Preparticipation athletic screening | ▶ Cholelithiasis (as potential source of atypical chest pain) |
| ▶ Preoperative screening | ▶ Ascites (due to cardiac aetiology) |
| ▶ Cardiac arrest (particularly PEA) | ▶ Early interstitial lung disease (eg, in smokers, amiodarone toxicity) |
| ▶ Tamponade | ▶ Hemidiaphragm (postcardiac surgery) |
| ▶ LV/RV function | ▶ Cardiorenal syndromes |
| ▶ CVP assessment | ▶ Hydronephrosis |
| ▶ Pneumothorax/haemothorax | ▶ Cortical thickness, renal size |
| ▶ Assist arterial/venous access | ▶ Bladder postvoid residual (nocturia) |
| ▶ Assess intubation of trachea | ▶ Thyroid abnormalities (in atrial fibrillation or high-output state) |
| ▶ Guide temporary pacing wire | ▶ Splenomegaly (suspected SBE or thrombocytopenia) |
| ▶ placement | |
| ▶ Assess chest compression and | |
| ▶ patency of intravenous access | |

CVP, central venous pressure; LV, left ventricle; PEA, pulseless electrical activity; POCUS, point-of-care ultrasound; RV, right ventricle; SBE, subacute bacterial endocarditis.

should be referred for echocardiography. The common echo referral generated by auscultation of a systolic murmur frequently demonstrates benign or 'functional' morphology but can also detect aortic valve sclerosis, early aortic valve stenosis or mitral valve prolapse.[48] Supporting the sensitivity of auscultation, in a study of 100 patients referred for 'systolic murmur', only 21% were free of abnormal findings on echocardiography;[49] however, the ability of two cardiologists to identify specific cardiac lesions by physical examination was limited especially when more than one lesion was present. Using POCUS, limited imaging protocols have demonstrated the capability to detect significant calcific aortic stenosis[50] with 84% sensitivity and 89% specificity and screen for mitral prolapse (figure 3A) or rheumatic heart disease. In the evaluation of murmur, the use of POCUS to localise the abnormal valve morphology improves specificity and the addition of colour Doppler imaging further increases sensitivity, detecting as little as mild regurgitation[51] (figure 3B). However, in the setting of an asymptomatic patient with normal left atrial size and LV systolic function by POCUS, it is unclear whether the discovery of a murmur or small colour flow jets have clinical value that justify subsequent costs of formal echocardiography referral. In suspected endocarditis, POCUS could screen for pre-existing valve disease or significant regurgitation but cannot be expected to find small vegetations, inheriting at least the limitations of standard transthoracic echocardiography. Although POCUS detection of severe valvular disease is feasible by non-cardiologists, the use of POCUS to diagnose and categorise lesser valvular pathology is unknown and would require expert familiarity with specific valve lesions and the use of Doppler.

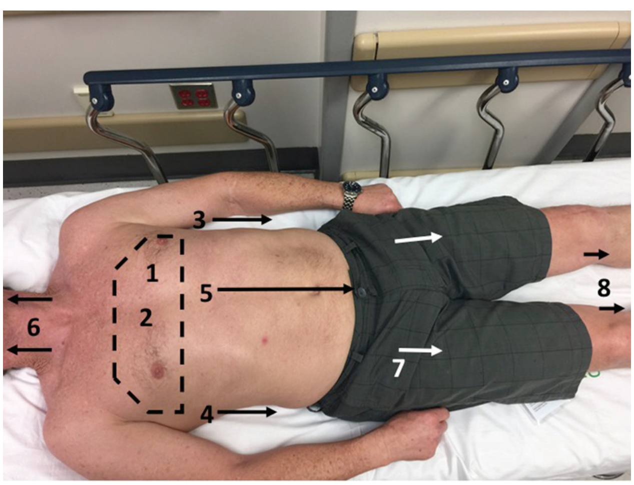


**Figure 4** A 5 min expanded ultrasound physical of the cardiac patient. Using the cardiac transducer, the parasternal long axis detects signs of left ventricular (LV) dysfunction and left atrial (LA) enlargement (site 1, anterior chest). Dependent on LA size, lung B-lines can suggest either decompensated heart failure or an interstitial pulmonary process (region 2). Proper posterior transducer location while imaging the lung base for effusions is confirmed by limited views of the kidneys (for cardiorenal), ascites (if present) and the spleen (evaluated for size) (line 3, posterior axillary line). Renal cortex echogenicity is compared with liver (for fatty liver) (line 4, posterior axillary line). The subcostal window is used for an alternate cardiac view and for inferior vene cava (IVC) imaging (site 5). The IVC (for central venous pressure (CVP)) and abdominal aorta must be differentiated in the longitudinal plane and the infrarenal aorta is then evaluated moving caudally for aneurysm (line 5, midline), followed by the bladder for postvoid residual. Abdominal and pelvic organs can be viewed during this sweep. A vascular transducer is then used to evaluate juglar venous pressure (for CVP), carotid vessels (for subclinical atherosclerosis) and thyroid (region 6, neck), and the femoral and popliteal vessels (for deep vein thrombosis and peripheral arterial disease) (lines 7, inguinal, and site 8, popliteal fossa).

## Expanded cardiac POCUS applications where the physical examination is known to be inadequate

Many diseases that pertain to the care of the cardiac patient manifest few or no physical findings and can now be diagnosed using POCUS (table 4). In the outpatient, the detection of early, non-stenotic subclinical atherosclerosis in the carotid (figure 3C) or femoral artery bifurcation portends a prognosis of a coronary heart disease equivalent and can affect lipid management. Similarly, the presence of an echogenic or fatty liver (figure 3D) can be a marker for the metabolic syndrome, liver disease or occult alcohol use. The detection of left ventricular hypertrophy may affect treatment decisions in hypertension or suggest hypertrophic cardiomyopathy in preparticipation athletic screening. Non-cardiac findings of the urinary tract in cardiorenal syndromes (figure 3E) and the spleen in subacute bacterial endocarditis or unexplained thrombocytopaenia may be helpful. For the interventionalist, a brief vascular ultrasound survey for peripheral arterial disease or deep vein thrombosis can be used to guide or deter femoral arterial and venous cannulation. During cardiac arrest, in the least, ultrasound can note the presence of cardiac motion, assess the clearance of blood pool stasis (figure 3F) and update prognostic signs during pulse checks.

## The future of an ultrasound-augmented physical

An evidence-based, multifaceted POCUS cardiac examination that detects the above-mentioned ultrasound 'signs' of traditional pathologies (figure 2) has already been described[3] and successfully integrated into an internal medicine residency curriculum[52] and can be easily expanded for comprehensive medical evaluation or subspecialty use (figure 4). The prototypical quick-look imaging protocol is constructed to synthesise diagnoses from findings and minimise technique errors due to transducer misplacement. Device design in the future may reduce cost and further leverage technological advancements in wireless transmission, potentially enabling remote, expert interpretation or telementoring of new users. Earlier, more accurate detection of disease as afforded by POCUS technologies will likely result in the saving of downstream costs,[16 17] testing of clinical outcomes and changes in current clinical pathways by the next generation of ultrasound-enabled, cost-conscious physicians.

## CONCLUSION

The patient's bedside has become a critical site for the future of healthcare. Despite the promise of telemedicine, laboratory biomarker assessment, proliferation of comprehensive radiological imaging and the team approach in medical care, the physician's physical presence at the patient's bedside to perform a skilful examination develops patient trust, endorses physician responsibility and remains a cornerstone in patient-centred care. Evidence suggests that ultrasound increases the sensitivity of physical examination by detecting disease at an earlier, asymptomatic stage or by improving inadequacies in current practice for both cardiologists and non-cardiologists. The recent use of ultrasound at the point of care strengthens a traditional medical care model that is well worth preserving—at a location well worth recognising.

**Acknowledgements** Lee Luniewski and Sondhaya McGowan, MLIS, AHIP, Scripps Mercy medical librarians for assistance in review of the literature.

**Competing interests** None declared.

**Provenance and peer review** Commissioned; externally peer reviewed.

## REFERENCES


1 Elder A, Japp A, Verghese A. How valuable is physical examination? *BMJ* 2016;354:i330.
2 McGee S. *Evidence-based physical diagnosis*. 3rd edn: Elsevier Saunders, Philadelphia, PA, 2012.
3 Kimura BJ, Shaw DJ, Amundson SA, *et al*. Cardiac limited ultrasound examination techniques to augment the bedside cardiac physical examination. *J Ultrasound Med* 2015;34:1683–90.
4 Otto CM. Echocardiography: the transition from master of the craft to admiral of the fleet. *Heart* 2016;102:899–901.
5 Martindale JL, Wakai A, Collins SP, *et al*. Diagnosing acute heart failure in the emergency department: a systematic review and meta-analysis. *Acad Emerg Med* 2016;23:223–42.
6 Kobal SL, Trento L, Baharami S, *et al*. Comparison of effectiveness of hand-carried ultrasound to bedside cardiovascular physical examination. *Am J Cardiol* 2005;96:1002–6.
7 Decara JM, Kirkpatrick JN, Spencer KT, *et al*. Use of hand-carried ultrasound devices to augment the accuracy of medical student bedside cardiac diagnoses. *J Am Soc Echocardiogr* 2005;18:257–63.
8 Panoulas VF, Daigeler AL, Malaweera AS, *et al*. Pocket-size hand-held cardiac ultrasound as an adjunct to clinical examination in the hands of medical students and junior doctors. *Eur Heart J Cardiovasc Imaging* 2013;14:323–30.
9 Stokke TM, Ruddox V, Sarvari SI, *et al*. Brief group training of medical students in focused cardiac ultrasound may improve diagnostic accuracy of physical examination. *J Am Soc Echocardiogr* 2014;27:1238–46.
10 Kimura BJ, Amundson SA, Willis CL, *et al*. Usefulness of a hand-held ultrasound device for bedside examination of left ventricular function. *Am J Cardiol* 2002;90:1038–9.
11 Brennan JM, Blair JE, Goonewardena S, *et al*. A comparison by medicine residents of physical examination versus hand-carried ultrasound for estimation of right atrial pressure. *Am J Cardiol* 2007;99:1614–6.
12 Galderisi M, Santoro A, Versiero M, *et al*. Improved cardiovascular diagnostic accuracy by pocket size imaging device in non-cardiologic outpatients: the NaUSiCa (Naples ultrasound stethoscope in cardiology) study. *Cardiovasc Ultrasound* 2010;8:51.
13 Razi R, Estrada JR, Doll J, *et al*. Bedside hand-carried ultrasound by internal medicine residents versus traditional clinical assessment for the identification of systolic dysfunction in patients admitted with decompensated heart failure. *J Am Soc Echocardiogr* 2011;24:1319–24.
14 Martin LD, Howell EE, Ziegelstein RC, *et al*. Hand-carried ultrasound performed by hospitalists: does it improve the cardiac physical examination? *Am J Med* 2009;122:35–41.
15 Spencer KT, Anderson AS, Bhargava A, *et al*. Physician-performed point-of-care echocardiography using a laptop platform compared with physical examination in the cardiovascular patient. *J Am Coll Cardiol* 2001;37:2013–8.
16 Cardim N, Fernandez Golfin C, Ferreira D, *et al*. Usefulness of a new miniaturized echocardiographic system in outpatient cardiology consultations as an extension of physical examination. *J Am Soc Echocardiogr* 2011;24:117–24.
17 Mehta M, Jacobson T, Peters D, *et al*. Handheld ultrasound versus physical examination in patients referred for transthoracic echocardiography for a suspected cardiac condition. *JACC Cardiovasc Imaging* 2014;7:983–90.
18 Di Bello V, La Carrubba S, Conte L, *et al*; SIEC (Italian Society of Cardiovascular Echography). Incremental value of pocket-sized echocardiography in addition to physical examination during inpatient cardiology evaluation: a multicenter Italian study (SIEC). *Echocardiography* 2015;32:1463–70.
19 Kimura BJ, Sliman S, Waalen J, *et al*. Retention of ultrasound skills and training. *J Am Soc Echocardiogr* 2016;29:992–7.
20 Madhok V, Falk G, Rogers A, *et al*. The accuracy of symptoms, signs and diagnostic tests in the diagnosis of left ventricular dysfunction in primary care: a diagnostic accuracy systematic review. *BMC Fam Pract* 2008;9:56.
21 Butman SM, Ewy GA, Standen JR, *et al*. Bedside cardiovascular examination in patients with severe chronic heart failure: importance of rest or inducible jugular venous distension. *J Am Coll Cardiol* 1993;22:968–74.
22 Caldentey G, Khairy P, Roy D, *et al*. Prognostic value of the physical examination in patients with heart failure and atrial fibrillation: insights from the AF-CHF trial (atrial fibrillation and chronic heart failure). *JACC Heart Fail* 2014;2:15–23.
23 Badgett RG, Lucey CR, Mulrow CD. Can the clinical examination diagnose left-sided heart failure in adults? *JAMA* 1997;277:1712–9.
24 Kimura BJ, Yogo N, O'Connell CW, *et al*. Cardiopulmonary limited ultrasound examination for "quick-look" bedside application. *Am J Cardiol* 2011;108:586–90.
25 Johnson BK, Tierney DM, Rosborough TK, *et al*. Internal medicine point-of-care ultrasound assessment of left ventricular function correlates with formal echocardiography. *J Clin Ultrasound* 2016;44:92–9.
26 Abhayaratna WP, Seward JB, Appleton CP, *et al*. Left atrial size: physiologic determinants and clinical applications. *J Am Coll Cardiol* 2006;47:2357–63.
27 Bouzas-Mosquera A, Broullón FJ, Álvarez-García N, *et al*. Left atrial size and risk for all-cause mortality and ischemic stroke. *CMAJ* 2011;183:E657–64.
28 Rossi A, Vassanelli C. Left atrium: no longer neglected. *Ital Heart J* 2005;6:881–5.
29 Kimura BJ, Fowler SJ, Fergus TS, *et al*. Detection of left atrial enlargement using hand-carried ultrasound devices: implications for bedside examination. *Am J Med* 2005;118:912–6.
30 Kimura BJ, Kedar E, Weiss DE, *et al*. A bedside ultrasound sign of cardiac disease: the left atrium-to-aorta diastolic diameter ratio. *Am J Emerg Med* 2010;28:203–7.
31 Picano E, Pellikka PA. Ultrasound of extravascular lung water: a new standard for pulmonary congestion. *Eur Heart J* 2016;37:2097–104.
32 Liteplo AS, Marill KA, Villen T, *et al*. Emergency thoracic ultrasound in the differentiation of the etiology of shortness of breath (ETUDES): sonographic B-lines and N-terminal pro-brain-type natriuretic peptide in diagnosing congestive heart failure. *Acad Emerg Med* 2009;16:201–10.
33 Miglioranza MH, Gargani L, Sant'Anna RT, *et al*. Lung ultrasound for the evaluation of pulmonary congestion in outpatients: a comparison with clinical assessment, natriuretic peptides, and echocardiography. *JACC Cardiovasc Imaging* 2013;6:1141–51.
34 Volpicelli G, Elbarbary M, Blaivas M, *et al*; International Liaison Committee on Lung Ultrasound (ILC-LUS) for International Consensus Conference on Lung Ultrasound (ICC-LUS). International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med* 2012;38:577–91.
35 Platz E, Lewis EF, Uno H, *et al*. Detection and prognostic value of pulmonary congestion by lung ultrasound in ambulatory heart failure patients. *Eur Heart J* 2016;37:1244–51.
36 Frassi F, Gargani L, Gligorova S, *et al*. Clinical and echocardiographic determinants of ultrasound lung comets. *Eur J Echocardiogr* 2007;8:474–9.
37 Wong CL, Holroyd-Leduc J, Straus SE. Does this patient have a pleural effusion? *JAMA* 2009;301:309–17.
38 Kataoka H, Takada S. The role of thoracic ultrasonography for evaluation of patients with decompensated chronic heart failure. *J Am Coll Cardiol* 2000;35:1638–46.
39 Lichtenstein D, Goldstein I, Mourgeon E, *et al*. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. *Anesthesiology* 2004;100:9–15.
40 Chavez MA, Shams N, Ellington LE, *et al*. Lung ultrasound for the diagnosis of pneumonia in adults: a systematic review and meta-analysis. *Respir Res* 2014;15:50.
41 Alrajab S, Youssef AM, Akkus NI, *et al*. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. *Crit Care* 2013;17:R208.
42 Mansencal N, Vieillard-Baron A, Beauchet A, *et al*. Triage patients with suspected pulmonary embolism in the emergency department using a portable ultrasound device. *Echocardiography* 2008;25:451–6.
43 Deol GR, Collett N, Ashby A, *et al*. Ultrasound accurately reflects the jugular venous examination but underestimates central venous pressure. *Chest* 2011;139:95–100.
44 Brennan JM, Blair JE, Goonewardena S, *et al*. Reappraisal of the use of inferior vena cava for estimating right atrial pressure. *J Am Soc Echocardiogr* 2007;20:857–61.
45 Zhang Z, Xu X, Ye S, *et al*. Ultrasonographic measurement of the respiratory variation in the inferior vena cava diameter is predictive of fluid responsiveness in critically ill patients: systematic review and meta-analysis. *Ultrasound Med Biol* 2014;40:845–53.
46 Goonewardena SN, Gemignani A, Ronan A, *et al*. Comparison of hand-carried ultrasound assessment of the inferior vena cava and N-terminal pro-brain natriuretic peptide for predicting readmission after hospitalization for acute decompensated heart failure. *JACC Cardiovasc Imaging* 2008;1:595–601.
47 Cubo-Romano P, Torres-Macho J, Soni NJ, *et al*. Admission inferior vena cava measurements are associated with mortality after hospitalization for acute decompensated heart failure. *J Hosp Med* 2016;11:778–84.
48 Etchells E, Bell C, Robb K. Does this patient have an abnormal systolic murmur? *JAMA* 1997;277:564–71.
49 Attenhofer Jost CH, Turina J, Mayer K, *et al*. Echocardiography in the evaluation of systolic murmurs of unknown cause. *Am J Med* 2000;108:614–20.
50 Abe Y, Ito M, Tanaka C, *et al*. A novel and simple method using pocket-sized echocardiography to screen for aortic Stenosis. *J Am Soc Echocardiogr* 2013;26:589–96.
51 Kobal SL, Tolstrup K, Luo H, *et al*. Usefulness of a hand-carried cardiac ultrasound device to detect clinically significant valvular regurgitation in hospitalized patients. *Am J Cardiol* 2004;93:1069–72.
52 Kimura BJ, Amundson SA, Phan JN, *et al*. Observations during development of an internal medicine residency training program in cardiovascular limited ultrasound examination. *J Hosp Med* 2012;7:537–42.

Heart

# Point-of-care cardiac ultrasound techniques in the physical examination: better at the bedside

Bruce J Kimura

*Heart* 2017 103: 987-994 originally published online March 4, 2017
doi: 10.1136/heartjnl-2016-309915