REVIEW

Ultrasound imaging of congestion in heart failure: examinations beyond the heart

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Congestion, related to pressure and/or fluid overload, plays a central role in the pathophysiology, presentation and prognosis of heart failure and is an important therapeutic target. While symptoms and physical signs of fluid overload are required to make a clinical diagnosis of heart failure, they lack both sensitivity and specificity, which might lead to diagnostic delay and uncertainty. Over the last decades, new ultrasound methods for the detection of elevated intracardiac pressures and/or fluid overload have been developed that are more sensitive and specific, thereby enabling earlier and more accurate diagnosis and facilitating treatment strategies. Accordingly, we considered that a state-of-the-art review of ultrasound methods for the detection and quantification of congestion was timely, including imaging of the heart, lungs (B-lines), kidneys (intrarenal venous flow), and venous system (inferior vena cava and internal jugular vein diameter).

Keywords   Ultrasound • Heart failure • B-lines • Inferior vena cava • Intrarenal venous flow • Jugular vein

Introduction

Congestion, related to pressure and/or volume overload, is fundamental to the pathophysiology, presentation and prognosis of heart failure (HF).[1,2] Early detection of elevated cardiac or venous pressures is important, as intensification of treatment before signs and symptoms worsen may reduce morbidity in patients with HF.[3]

Despite their importance, the clinical identification and quantification of HF signs or symptoms remains challenging even for experienced physicians.[4,5] Clinical symptoms and signs are late manifestations of congestion and are neither sensitive nor specific

for HF. Moreover, no agreement exists on how to grade signs of fluid overload.[6] The measurement of natriuretic peptides, a measure of myocardial wall stretch, is recommended as a diagnostic tool in the assessment of patients with suspected HF and provides important prognostic information.[1] However, natriuretic peptide levels are influenced by many factors, including age, body mass index and atrial fibrillation, and natriuretic peptide-guided treatment has not been convincingly shown to improve outcomes in patients with HF.[7] Other costly and invasive tools can monitor pulmonary artery pressure to help guide therapies. However, more evidence is needed on patient selection and the cost-effectiveness

of these devices.[3,8] Non-invasive technologies to assess fluid status such as weighing scales, cardiac bio-impedance, and remote dielectric sensing (ReDS) are being investigated but, apart from weight, have not been widely adopted.[9,10]

Ultrasound continues to play a key role in the non-invasive assessment of cardiac structure and function in patients with HF. The aim of this review is to describe ultrasound measurements that move beyond the heart and are associated with either (i) elevated venous pressures [inferior vena cava (IVC) and internal jugular vein (IJV) diameter and intrarenal venous flow] or (ii) extravascular fluid in the lungs (B-lines) that may be useful in the assessment and monitoring of patients with known or suspected HF. In the next paragraphs, we will describe how to perform and interpret these techniques (*graphical abstract*) and briefly summarise the current state of evidence supporting their clinical use.

Cardiac ultrasound (echocardiography)

Transthoracic echocardiography (TTE) plays a central role in the diagnosis and management of patients with HF. TTE is the most available method to measure left ventricular ejection fraction, which is used to categorise patients as HF with reduced (HFrEF) or preserved ejection fraction (HFpEF), a distinction relevant for their management. TTE can also rapidly exclude, or identify, the presence of significant valvular disease, previously undetected congenital problems, and pleural or pericardial effusions. However, many people with breathlessness do not have reduced left ventricular ejection fraction or valve disease to account for their symptoms, but left ventricular hypertrophy and impaired long-axis systolic dysfunction by global longitudinal strain are common findings.[11] The evaluation of mitral inflow, mitral annulus motion by tissue Doppler imaging and left atrial volumes and function provides additional estimates of left ventricular filling pressures,[12] but no universal agreement exists on how to combine them to identify individuals at greater risk.[1,13,14] Pulmonary hypertension, right ventricular dysfunction and greater severity of tricuspid regurgitation all indicate a worse outcome and can be assessed on TTE, but their evaluation might be limited by poor acoustic window or inability to obtain a clear Doppler signal.[15] As the comprehensive evaluation of cardiac structure and function in HF goes beyond the scope of this review, the following sections focus on the extracardiac ultrasound methods for the assessment of raised venous pressures and extravascular lung fluid in HF.[16]

Inferior vena cava ultrasound

The IVC is a compliant vessel, in anatomical continuation with the right atrium. Any change in right atrial pressure is transmitted backward, and modifies IVC size: a substantial and sustained increase in right atrial pressure, as seen in HF, would eventually cause IVC distention. However, studies conducted in patients undergoing cardiac catheterisation have only found modest correlations between right atrial pressure and IVC diameter measured by echocardiography[17];

these relations are even weaker in those who are mechanically ventilated (*Table 1*).[10,17–55]

How to perform inferior vena cava ultrasound

The diameter of the IVC should be measured with a phased-array or curvilinear transducer with the patient in supine position in the subcostal view at 1.0 to 2.0 cm from the junction with the right atrium, using the long-axis view.[56] For accuracy, this measurement should be made perpendicular to the long axis of the IVC.

How to quantify and interpret inferior vena cava ultrasound

Measurement of the IVC diameter and its changes with respiration is possible in most adults. An IVC smaller than 21 mm that collapses >50% suggests normal right atrial pressures.[56] IVC diameter might detect increasing intravascular volume even prior to any change in symptoms or body weight in ambulatory HF patients,[10] or monitor response to diuretics in hospitalised patients with HF.[34] Persistent IVC engorgement predicts a poor outcome.[25,35,36] Whether diuretic therapy guided by serial IVC assessments, compared with usual care, might decrease rehospitalisation in patients admitted for HF is currently under evaluation (NCT03140566; NCT02892227). In ambulatory patients with HF who are already on treatment, guidelines do not recommend monitoring cardiac function or ventricular filling pressures routinely by echocardiography, unless there is substantial clinical deterioration. However, up to half of HF patients with minimal symptoms, and without clinical signs of congestion, have a dilated IVC and other abnormal ultrasonic markers of elevated intracardiac pressures or extravascular lung fluid, which are also associated with elevated natriuretic peptides and an increase in mortality.[26]

Internal jugular vein ultrasound

An elevated jugular venous pressure (JVP) is a marker of volume or pressure overload and right ventricular failure, and associated with an increase in mortality in patients with HF.[57] Clinical evaluation of the JVP is subjective, requires clinical expertise and can be challenging in obese patients. Therefore, identifying and quantifying jugular vein distention is difficult and an elevated JVP may be missed clinically.[44,58]

How to assess internal jugular vein by ultrasound

The IJV is a superficial and distensible vessel, which lies close to the carotid artery, under the sternocleidomastoid muscle and can be easily visualised with ultrasound. Assessment of IJV should be performed with the patient reclining and head and neck elevated at 45° (semi-recumbent position). Care should be taken to avoid IJV compression during examination. When the patient is supine, the IJV is likely to be distended, but in a sitting position JVP drops and

Table 1 Novel sonographic methods that quantify congestion in patients with heart failure: evidences and limitations

	Inferior vena cava	JVD ratio	Venous renal Doppler	Lung ultrasound (B-lines)
Ultrasound transducer	Phased-array or curvilinear	Linear	Curvilinear	Phased-array or curvilinear
Correlation with invasive cardiac haemodynamics	Moderate[17–21]	No data	Moderate[22]	Moderate[23,24]
Correlation with natriuretic peptides	Low to moderate[25,26]	Low to moderate[26–28]	Moderate[22]	Moderate to good[24,26,29]
Diagnostic value[a]	Little evidence[30]	Not enough evidence	Not enough evidence	Yes[30–33]
Monitoring	Yes[10,34–36]	No data	Yes[37]	Yes[38,39]
Prognostic value	Yes.[25,26,34–36,40–43]	Yes[26,28,44]	Yes[22,45]	Yes[26,29,38,46–52]
Intra-reader agreement (mean difference, 95% limits of agreement)	–	0.42 (−1.26, 2.11)[27]	Reproducibility[37] Venous impedance index: $4 \pm 13\%$	Count method: 0.05 B-lines/8 zones (−1.3, 1.4)[53]
Inter-reader agreement (mean difference, 95% limits of agreement)	−0.04 mm (−2.48, 2.40)[25]	−0.22 (−1.24, 0.80)[27]	Reproducibility[37] Venous impedance index: $5 \pm 12\%$	Count method: −0.3 B-lines/8 zones (−1.9,1.3)[46] Count-percentage method: 0.03 B-lines/zone (−1.52,1.45)[54] Score method: Cohen's Kappa 0.70−0.81/zone[55]
Limitations	Body habitus/obesity Mechanical ventilation[18] Inability to perform a deep inspiration	Inability to perform Valsalva It varies with patient's position	Obesity Severe breathlessness	Some diseases may increase B-lines (e.g. interstitial lung disease, acute respiratory distress syndrome), or limit their visualization (pneumothorax, large pleural effusion, morbid obesity)

[a]For acute heart failure.

the IJV often collapses. When central venous pressure (CVP) is low, it may be difficult to visualise the IJV; asking the patient to cough, or to perform a Valsalva manoeuvre, will lead to engorgement, allowing it to be identified on ultrasound.

The IJV can be imaged by placing a high frequency linear transducer (~10 MHz) just below the angle of the jaw, in the area of the sternocleidomastoid muscle, and then moving it inferiorly toward the angle of Louis (or manubriosternal junction). In most cases, the IJV is identified less than 5 cm below the angle of the jaw. Subsequently, the IJV diameter and its changes are measured continuously by M-mode, or in a two-dimensional frame, at rest and during a Valsalva manoeuvre. The ratio between the maximal diameter during the Valsalva manoeuvre to that at rest (at the end of the expiratory phase) is called the JVD ratio (*Figure 1*). Measuring the JVD ratio can be done in almost all patients and inter-observer variability is low.[27] Other authors have proposed measuring the cross-sectional area of the IJV, and how it changes during the Valsalva manoeuvre, to identify patients with elevated right atrial pressure.[59,60]

How to interpret images of the internal jugular vein

In people without HF, or in patients in whom congestion is adequately controlled, the diameter of the IJV is small at rest (~0.10–0.15 cm), but increases several-fold during a Valsalva manoeuvre (usually up to ~1 cm).[27,28] Because of limited vessel compliance, the maximal IJV diameter that can be achieved during a Valsalva manoeuvre is similar in people with or without HF. When intra-vascular congestion worsens, it increases the IJV diameter at rest, leading to a reduced JVD ratio. A JVD ratio <4 is abnormal and, when congestion is severe, the ratio may decrease to <2.[26–28]

In ambulatory HF patients, a low JVD ratio is poorly related to measures of left ventricular size or systolic function, but strongly associated with severe symptoms, elevated natriuretic peptides, right ventricular dysfunction and tricuspid regurgitation.[27] A low JVD ratio predicts a worse outcome in terms of HF hospitalisations or deaths, independently of N-terminal pro B-type natriuretic peptide (NT-proBNP).[26,28,44]

When the IJV cross-sectional area, rather than its diameter, is used, a large variation during a Valsalva manoeuvre identifies patients more likely to have normal right atrial pressure and better outcomes.[59,60] Obviously, a Valsalva manoeuvre depends on the patient's effort and ability to follow instructions. For those who are acutely unwell, or cannot perform a Valsalva manoeuvre, other techniques, such as passive leg raising, may increase CVP but their effects on IJV diameter have not been assessed yet.

Renal venous ultrasound

Worsening renal function in acute HF is common and has been linked to elevated CVP, leading to raised renal interstitial pressures, partial collapse of nephrons, ischaemia and neurohormonal activation.[61] Recently, ultrasound techniques to assess renal blood flow in HF have been described.[22,37,45,62] Although renal arterial flow can be assessed with Doppler ultrasound and predicts HF progression,[63] an elevated CVP primarily affects renal venous flow (RVF).

How to perform renal venous Doppler ultrasound

Doppler assessment of RVF is performed in the left lateral decubitus position, using a convex or sector transducer (2.5−5 MHz)
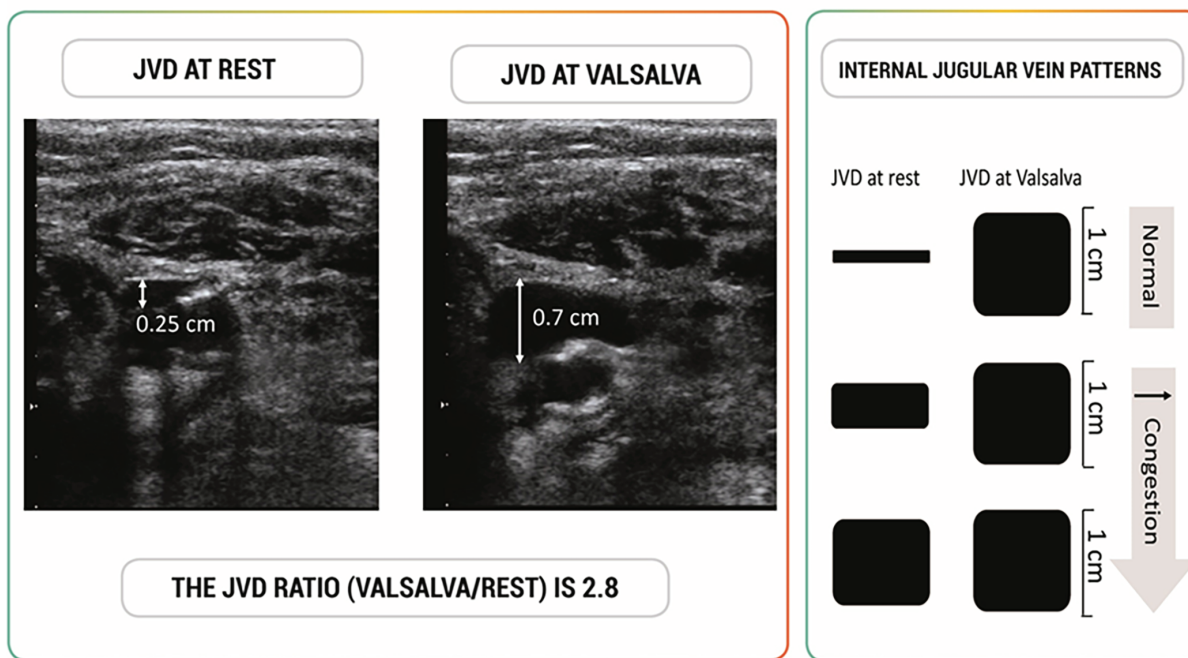
Figure 1 Jugular vein diameter (JVD) ultrasound. With the patient reclining and head and neck elevated at 45°, the internal jugular vein is identified and its diameter is measured at rest (at the end of the expiratory phase; left panel) and during a Valsalva manoeuvre (right panel). The ratio between the maximum diameter during Valsalva to that at rest is the JVD ratio. In the right panel, different examples of JVD patterns at rest and during Valsalva manoeuvre are shown, in patients without congestion (normal JVD ratio: >4; on top) and in those with increasing congestion (mid and bottom).

aligned with the lowest intercostal space rendering a longitudinal view of the right kidney. Using color Doppler imaging with the flow scale adjusted to low-flow velocities (preferably not more than 20 cm/s), the interlobar veins are identified. The best aligned vein is then sampled with pulsed-wave Doppler during an end-expiratory breath-hold. The scale should again be adjusted, maximising the amplitude of the signal (usually around −20 cm/s) and the electrocardiographic signal should be displayed to synchronise the RVF signal with the cardiac cycle.

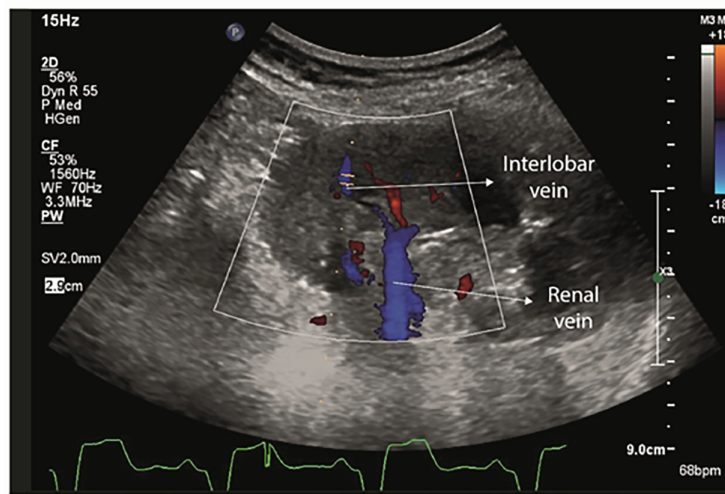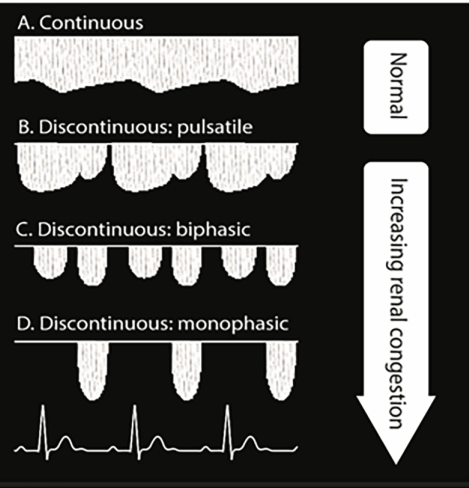## How to interpret renal venous Doppler

In normal conditions, the interlobar RVF is continuous with a small varying amplitude during the cardiac cycle.[64] When CVP increases, the variation of amplitude increases with the minimal velocity gradually approaching zero and eventually leading to an early discontinuous flow or 'pulsatile' flow[65] (*Figure 2*). If CVP increases further, a biphasic pattern can be recognised with two separate flow phases during a cardiac cycle. In very severe cases, the RVF can become monophasic with a single flow phase in diastole. Analysing the RVF pattern thus allows a semi-quantitative assessment of the effects of CVP on renal haemodynamics. Other more quantitative measures are the venous impedance index (VII) and the venous discontinuity index (VDI). The VII is the ratio of the difference between maximum and minimum velocity to the maximum velocity during a cardiac cycle with a number varying from 0 (no variation in velocity) to 1 (minimum velocity is zero).[64] As CVP increases the variation in RVF amplitude, the VII also increases until flow becomes discontinuous and VII becomes 1. Higher VDI, expressed as the percentage of no-flow time during a cardiac cycle, is another measure of congestion. Of note, other conditions that increase CVP (i.e. obstruction), intra-abdominal pressure (i.e. ascites) or intraparenchymal renal pressure (i.e. obstructive uropathy) can also impair RVF.[66]

Despite its potential, to date, only a few studies have evaluated the role of RVF assessment in HF management. For inpatients with HF ($n = 217$), a monophasic pattern suggests very high right atrial pressures and a poor prognosis.[22] Another study evaluated the effect of volume loading and diuretics on RVF in 50 patients with stable HFrEF or HFpEF.[37] After volume loading, the VII increased substantially and the number of patients with discontinuous RVF increased from 32% to 80% without any change in IVC-estimated CVP, perhaps suggesting that RVF is an earlier marker of the development of congestion. Interestingly, patients with a lower VII (indicating less renal congestion) had a better diuretic response.

Lung ultrasound

Lung ultrasound (LUS) can be used for the identification and quantification of extravascular lung fluid in patients with known
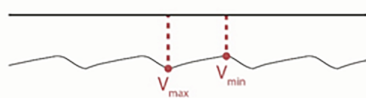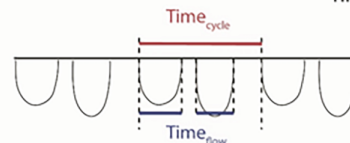
Figure 2 Renal venous Doppler. Once one of the interlobar veins has been identified, its venous flow can be assessed with pulsed-wave Doppler. Four distinct venous flow patterns can be recognised (normal continuous, discontinuous pulsatile, discontinuous biphasic, and discontinuous monophasic), according to increasing renal congestion (top to bottom). The bottom panel illustrates two proposed methods for renal flow quantification (venous impedance index and venous discontinuity index).

or suspected HF, at rest or even with exercise.[67,68] The so-called 'B-lines' are vertical lines that arise from the pleural line and extend to the far-field of the ultrasound screen[69] (*Figure 3*). B-lines are often observed in patients with HF, but can also occur in other conditions, such as non-cardiogenic pulmonary oedema and interstitial lung disease.[53,70]

How to perform lung ultrasound

Several LUS image acquisition protocols have been described, ranging from 4 to 28 chest regions or 'zones', but the simplified 8-zone protocol is increasingly used both in the clinical setting and for research. During LUS examination, patients are positioned either sitting upright, semi-recumbent or supine. Patients should preferably be imaged in the same position if serial examinations are being performed, as B-line number may be influenced by patient position, with higher B-line counts in supine position.[71] A phased-array or curvilinear transducer is placed in an intercostal

space in a chest zone either perpendicular (longitudinal, sagittal) or in parallel orientation (transverse) to the ribs at an imaging depth of ∼15–18 cm. Once the gain settings are optimised for visualisation of the pleural line and any B-lines, a 6 seconds clip is recorded with the patient breathing normally.[55,72] Large pleural effusions may interfere with B-line identification and should be reported, if seen on ultrasound.

How to quantify and interpret B-lines

Lung ultrasound is more sensitive for the diagnosis of interstitial pulmonary oedema and HF than the clinical examination or chest X-ray in patients with acute dyspnoea[31,73] (*Figure 3*). There are several different approaches to quantifying B-lines. Broadly, these can be grouped into two categories: score- or count-based methods. Score-based methods consider a minimum number of B-lines in one intercostal space as a 'positive' zone (typically at least three B-lines) and then adding up the number of positive
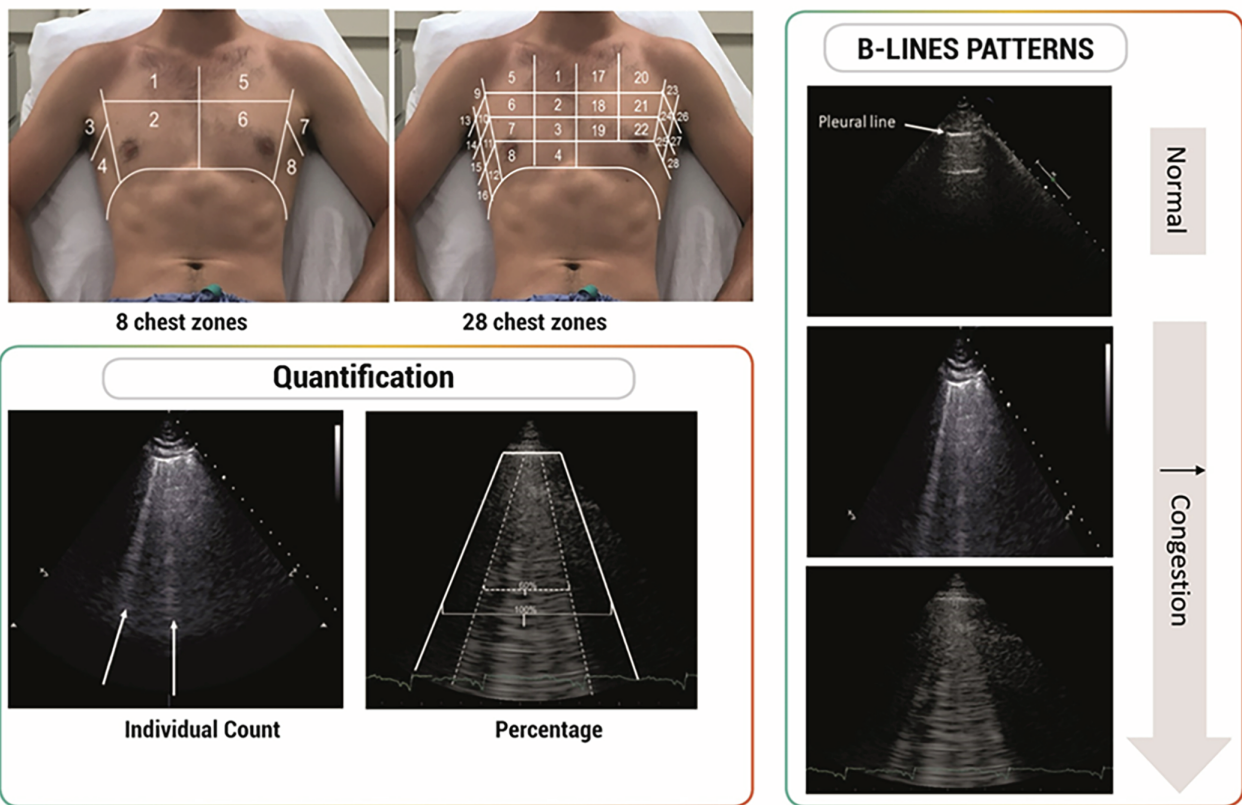
Figure 3 Lung ultrasound. In the top left panel, the 8 (left) and 28 (right) chest zone methods are shown. Count method: B-lines are counted in each zone and summed to obtain their total count. B-lines can be counted individually as seen (bottom left panel, figure on the left). Alternatively, when confluent, their number can be estimated from the percentage of space they occupy on the screen below the pleural line, divided by 10 (bottom left panel, figure on the right, in which confluent B-lines occupy about 60% of the screen below the pleural line: conventionally, this equates to 6 B-lines). Score method: ≥3 B-lines in one intercostal space per zone is considered a 'positive' zone (bottom left panel, figure on the right). Different B-lines patterns are shown in the right panel: a normal lung should appear 'dark' on lung ultrasound below the pleural line (top), but as pulmonary congestion develops and increases, more B-lines are seen. Reproduced with permission from Platz *et al.*[50]

zones.[32,55] B-lines can be counted either one by one in one chest zone[46,74] or, when confluent, their number can be estimated from the percentage of space they occupy on the screen below the pleural line, divided by 10 (i.e. if about 70% of the screen below the pleural line is occupied by B-lines, it would conventionally count as seven B-lines, up to a maximum of 10 per zone).[29,38,47,75] All these methods have demonstrated good intra- and inter-reader agreement.[54,76] In patients with dyspnoea presenting to the emergency department, a cut-off value of ≥3 B-lines in at least two zones per hemithorax (of 6−8 evaluated zones in total) identifies patients with acute HF with higher sensitivity (94−97%) and specificity (96−97%) than the physical examination and chest X-ray (and NT-proBNP) (sensitivity 85%, specificity 89−90%) compared to chart review by two physicians.[31,32] A high number of B-lines at the time of discharge from a hospitalisation for acute HF or in ambulatory patients with chronic HF identifies those at high risk of subsequent HF (re-)admissions or death in observational studies.[26,29,38,46−52] However, further information on the optimal cut-off values for risk stratification in a variety of clinical settings requires larger prospective studies. Other important methodological aspects of LUS image acquisition and B-line quantification are detailed in a recent consensus document.[77] A brief overview of a sample of the current evidence on LUS and other described techniques is provided in *Table 1*.

Future directions

Comprehensive, semi-quantitative, assessment of venous pressures (IVC and IJV diameter; intrarenal venous flow) and extravascular lung fluid (B-lines) with ultrasound has several advantages and potential applications in patients with HF. It requires relatively little training and can be rapidly done in about 15 minutes. It uses existing, largely available, technology (ranging from high-end ultrasound systems to pocket size devices), is non-invasive, does not

involve radiation and allows for serial, quantifiable examinations at the point-of-care in a variety of clinical settings. However, many echocardiographic laboratories currently lack the additional transducers needed for JVD ultrasound (linear) and renal ultrasound (curvilinear; *Table 1*), and sonographers are currently not trained in these new ultrasound techniques.

Currently, the European Society of Cardiology HF guidelines suggest that the IVC diameter can be used to assess volume status in patients with HF, whilst LUS can assist with the detection of extravascular lung fluid (class IIb, level of evidence C, for both).[1] In contrast, U.S. HF guidelines do not mention ultrasound as a tool for the evaluation of intra- or extravascular volume status.[78] While the current level of evidence of the described ultrasound methods varies, the inclusion of LUS for the detection of extravascular lung fluid in patients with undifferentiated dyspnoea could be considered in future HF guidelines.[31,32]

Further research is needed to gain a better understanding of the clinical utility of these novel ultrasound methods. For instance, more accurate assessment of congestion might optimise timing of discharge for patients hospitalised with HF or help tailor diuretic therapy for ambulatory patients. In addition to physicians, HF nurses and other health care providers can be trained to perform ultrasound examinations such as IVC ultrasound or LUS.[79] The role of non-physicians in performing point-of-care ultrasound examinations to guide HF management warrants further investigation. Ultimately, randomised trials are required to demonstrate that treatment guided by sonographic assessment in HF is safe, improves symptoms and quality of life and long-term outcomes. Trials are currently ongoing for LUS in patients during an admission for acute HF (NCT03136198 and NCT03259165), after hospital discharge and in the outpatient clinic; preliminary results are encouraging.[80–82]

Finally, with the advent of COVID-19 the sonographic assessment of patients with suspected HF who require hospitalisation has become more complex. For instance, right ventricular and IVC dilatation could be due to right ventricular failure in the setting of acute respiratory distress syndrome or pulmonary embolism associated with a COVID-19 infection.[83] As LUS findings in COVID-19 include B-lines, their presence is not specific to pulmonary congestion in undifferentiated patients.[84] However, other LUS findings, such as subpleural consolidations, are not usually seen in HF but can be found in COVID-19 or other pulmonary infections.[85] Importantly, the absence of B-lines on LUS might rule out substantial pulmonary congestion or involvement in patients in whom HF or COVID-19 are suspected. We will likely gain a better understanding of ultrasound findings in patients with COVID-19 with and without HF over the coming months as data emerge.

Conclusions

Sonographic assessment of the IVC, IJV diameter and intrarenal venous flow can facilitate detection of elevated venous pressures, while LUS enables detection and quantification of extravascular lung fluid in patients with HF. These non-invasive techniques could complement clinical skills, traditional diagnostic and monitoring tools and potentially allow for improved diagnosis and management of patients with known or suspected HF.

References

1. Ponikowski P, Voors AA, Anker SD, Bueno H, Cleland JG, Coats AJ, Falk V, González-Juanatey JR, Harjola VP, Jankowska EA, Jessup M, Linde C, Nihoyannopoulos P, Parissis JT, Pieske B, Riley JP, Rosano GM, Ruilope LM, Ruschitzka F, Rutten FH, van der Meer P. 2016 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: the Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC). Developed with the special contribution of the Heart Failure Association (HFA) of the ESC. *Eur J Heart Fail* 2016;**18**:891–975.

2. Harjola VP, Mullens W, Banaszewski M, Bauersachs J, Brunner-la Rocca HP, Chioncel O, Collins SP, Doehner W, Filippatos GS, Flammer AJ, Fuhrmann V, Lainscak M, Lassus J, Legrand M, Masip J, Mueller C, Papp Z, Parissis J, Platz E, Rudiger A, Ruschitzka F, Schäfer A, Seferovic PM, Skouri H, Yilmaz MB, Mebazaa A. Organ dysfunction, injury and failure in acute heart failure: from pathophysiology to diagnosis and management. A review on behalf of the Acute Heart Failure Committee of the Heart Failure Association (HFA) of the European Society of Cardiology (ESC). *Eur J Heart Fail* 2017;**19**:821–836.

3. Abraham WT, Adamson PB, Bourge RC, Aaron MF, Costanzo MR, Stevenson LW, Strickland W, Neelagaru S, Raval N, Krueger S, Weiner S, Shavelle D, Jeffries B, Yadav JS; CHAMPION Trial Study Group. Wireless pulmonary artery haemodynamic monitoring in chronic heart failure: a randomised controlled trial. *Lancet* 2011;**377**:658–666.

4. Lok CE, Morgan CD, Ranganathan N. The accuracy and interobserver agreement in detecting the 'gallop sounds' by cardiac auscultation. *Chest* 1998;**114**:1283–1288.

5. Breidthardt T, Moreno-Weidmann Z, Uthoff H, Sabti Z, Aeppli S, Puelacher C, Stallone F, Twerenbold R, Wildi K, Kozhuharov N, Wussler D, Flores D, Shrestha S, Badertscher P, Boeddinghaus J, Nestelberger T, Gimenez MR, Staub D, Aschwanden M, Lohrmann J, Pfister O, Osswald S, Mueller C. How accurate is clinical assessment of neck veins in the estimation of central venous pressure in acute heart failure? Insights from a prospective study. *Eur J Heart Fail* 2018;**20**:1160–1162.

6. Gheorghiade M, Follath F, Ponikowski P, Barsuk JH, Blair JE, Cleland JG, Dickstein K, Drazner MH, Fonarow GC, Jaarsma T, Jondeau G, Sendon JL, Mebazaa A, Metra M, Nieminen M, Pang PS, Seferovic P, Stevenson LW, van Veldhuisen D, Zannad F, Anker SD, Rhodes A, McMurray J, Filippatos G; European Society of Cardiology, European Society of Intensive Care Medicine. Assessing and grading congestion in acute heart failure: a scientific statement from the Acute Heart Failure Committee of the Heart Failure Association of the European Society of Cardiology and endorsed by the European Society of Intensive Care Medicine. *Eur J Heart Fail* 2010;**12**:423–433.

7. Felker GM, Anstrom KJ, Adams KF, Ezekowitz JA, Fiuzat M, Houston-Miller N, Januzzi JL Jr, Mark DB, Piña IL, Passmore G, Whellan DJ, Yang H, Cooper LS, Leifer ES, Desvigne-Nickens P, O'Connor CM. Effect of natriuretic peptide-guided therapy on hospitalization or cardiovascular mortality in high-risk patients with heart failure and reduced ejection fraction: a randomized clinical trial. *JAMA* 2017;**318**:713–720.

8. Mullens W, Sharif F, Dupont M, Rothman AM, Wijns W. Digital health care solution for proactive heart failure management with the Cordella Heart Failure System: results of the SIRONA first-in-human study. *Eur J Heart Fail* 2020;**22**:1912–1919.

9. Amir O, Ben-Gal T, Weinstein JM, Schliamser J, Burkhoff D, Abbo A, Abraham WT. Evaluation of remote dielectric sensing (ReDS) technology-guided therapy for decreasing heart failure re-hospitalizations. *Int J Cardiol* 2017;**240**:279–284.

10. Dovancescu S, Pellicori P, Mabote T, Torabi A, Clark AL, Cleland JG. The effects of short-term omission of daily medication on the pathophysiology of heart failure. *Eur J Heart Fail* 2017;**19**:643–649.

11. Pellicori P, Kallvikbacka-Bennett A, Khaleva O, Carubelli V, Costanzo P, Castiello T, Wong K, Zhang J, Cleland JG, Clark AL. Global longitudinal strain in patients with suspected heart failure and a normal ejection fraction: does it improve diagnosis and risk stratification? *Int J Cardiovasc Imaging* 2014;**30**:69–79.

12. Pieske B, Tschope C, de Boer RA, Fraser AG, Anker SD, Donal E, Edelmann F, Fu M, Guazzi M, Lam CS, Lancellotti P, Melenovsky V, Morris DA, Nagel E, Pieske-Kraigher E, Ponikowski P, Solomon SD, Vasan RS, Rutten FH, Voors AA, Ruschitzka F, Paulus WJ, Seferovic P, Filippatos G. How to diagnose heart failure with preserved ejection fraction: the HFA-PEFF diagnostic algorithm: a consensus recommendation from the Heart Failure Association (HFA) of the European Society of Cardiology (ESC). *Eur Heart J* 2019;**40**:3297–3317.

13. Nagueh SF, Smiseth OA, Appleton CP, Byrd BF 3rd, Dokainish H, Edvardsen T, Flachskampf FA, Gillebert TC, Klein AL, Lancellotti P, Marino P, Oh JK, Alexandru Popescu B, Waggoner AD. Recommendations for the evaluation of left ventricular diastolic function by echocardiography: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* 2016;**17**:1321–1360.

14. Huttin O, Fraser AG, Coiro S, Bozec E, Selton-Suty C, Lamiral Z, Frikha Z, Rossignol P, Zannad F, Girerd N. Impact of changes in consensus diagnostic recommendations on the echocardiographic prevalence of diastolic dysfunction. *J Am Coll Cardiol* 2017;**69**:3119–3121.

15. Damy T, Goode KM, Kallvikbacka-Bennett A, Lewinter C, Hobkirk J, Nikitin NP, Dubois-Randé JL, Hittinger L, Clark AL, Cleland JG. Determinants and prognostic value of pulmonary arterial pressure in patients with chronic heart failure. *Eur Heart J* 2010;**31**:2280–2290.

16. Mitchell C, Rahko PS, Blauwet LA, Canaday B, Finstuen JA, Foster MC, Horton K, Ogunyankin KO, Palma RA, Velazquez EJ. Guidelines for performing a comprehensive transthoracic echocardiographic examination in adults: recommendations from the American Society of Echocardiography. *J Am Soc Echocardiogr* 2019;**32**:1–64.

17. Kircher BJ, Himelman RB, Schiller NB. Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. *Am J Cardiol* 1990;**66**:493–496.

18. Nagueh SF, Kopelen HA, Zoghbi WA. Relation of mean right atrial pressure to echocardiographic and Doppler parameters of right atrial and right ventricular function. *Circulation* 1996;**93**:1160–1169.

19. Magnino C, Omedè P, Avenatti E, Presutti D, Iannaccone A, Chiarlo M, Moretti C, Gaita F, Veglio F, Milan A; RIGHT1 Investigators. Inaccuracy of right atrial pressure estimates through inferior vena cava indices. *Am J Cardiol* 2017;**120**:1667–1673.

20. Lee SL, Daimon M, Kawata T, Kohro T, Kimura K, Nakao T, Koide D, Watanabe M, Yamazaki T, Komuro I. Estimation of right atrial pressure on inferior vena cava ultrasound in Asian patients. *Circ J* 2014;**78**:962–966.

21. Agricola E, Bove T, Oppizzi M, Marino G, Zangrillo A, Margonato A, Picano E. "Ultrasound comet-tail images": a marker of pulmonary edema: a comparative study with wedge pressure and extravascular lung water. *Chest* 2005;**127**:1690–1695.

22. Iida N, Seo Y, Sai S, Machino-Ohtsuka T, Yamamoto M, Ishizu T, Kawakami Y, Aonuma K. Clinical implications of intrarenal hemodynamic evaluation by Doppler ultrasonography in heart failure. *JACC Heart Fail* 2016;**4**:674–682.

23. Hubert A, Girerd N, Le Breton H, Galli E, Latar I, Fournet M, Mabo P, Schnell F, Leclercq C, Donal E. Diagnostic accuracy of lung ultrasound for identification of elevated left ventricular filling pressure. *Int J Cardiol* 2019;**281**:62–68.

24. Miglioranza MH, Gargani L, Sant'Anna RT, Rover MM, Martins VM, Mantovani A, Weber C, Moraes MA, Feldman CJ, Kalil RA, Sicari R, Picano E, Leiria TL. Lung ultrasound for the evaluation of pulmonary congestion in outpatients: a comparison with clinical assessment, natriuretic peptides, and echocardiography. *JACC Cardiovasc Imaging* 2013;**6**:1141–1151.

25. Pellicori P, Carubelli V, Zhang J, Castiello T, Sherwi N, Clark AL, Cleland JG. IVC diameter in patients with chronic heart failure: relationships and prognostic significance. *JACC Cardiovasc Imaging* 2013;**6**:16–28.

26. Pellicori P, Shah P, Cuthbert J, Urbinati A, Zhang J, Kallvikbacka-Bennett A, Clark AL, Cleland JG. Prevalence, pattern and clinical relevance of ultrasound indices of congestion in outpatients with heart failure. *Eur J Heart Fail* 2019;**21**:904–916.

27. Pellicori P, Kallvikbacka-Bennett A, Zhang J, Khaleva O, Warden J, Clark AL, Cleland JG. Revisiting a classical clinical sign: jugular venous ultrasound. *Int J Cardiol* 2014;**170**:364–370.

28. Pellicori P, Kallvikbacka-Bennett A, Dierckx R, Zhang J, Putzu P, Cuthbert J, Boyalla V, Shoaib A, Clark AL, Cleland JG. Prognostic significance of ultrasound-assessed jugular vein distensibility in heart failure. *Heart* 2015;**101**:1149–1158.

29. Coiro S, Porot G, Rossignol P, Ambrosio G, Carluccio E, Tritto I, Huttin O, Lemoine S, Sadoul N, Donal E, Zannad F, Girerd N. Prognostic value of pulmonary congestion assessed by lung ultrasound imaging during heart failure hospitalisation: a two-centre cohort study. *Sci Rep* 2016;**6**:39426.

30. Anderson KL, Jenq KY, Fields JM, Panebianco NL, Dean AJ. Diagnosing heart failure among acutely dyspneic patients with cardiac, inferior vena cava, and lung ultrasonography. *Am J Emerg Med* 2013;**31**:1208–1214.

31. Pivetta E, Goffi A, Nazerian P, Castagno D, Tozzetti C, Tizzani P, Tizzani M, Porrino G, Ferreri E, Busso V, Morello F, Paglieri C, Masoero M, Cassine E, Bovaro F, Grifoni S, Maule MM, Lupia E; Study Group on Lung Ultrasound from the Molinette and Careggi Hospitals. Lung ultrasound integrated with clinical assessment for the diagnosis of acute decompensated heart failure in the emergency department: a randomized controlled trial. *Eur J Heart Fail* 2019;**21**:754–766.

32. Pivetta E, Goffi A, Lupia E, Tizzani M, Porrino G, Ferreri E, Volpicelli G, Balzaretti P, Banderali A, Iacobucci A, Locatelli S, Casoli G, Stone MB, Maule MM, Baldi I, Merletti F, Cibinel GA, Baron P, Battista S, Buonafede G, Busso V, Conterno A, del Rizzo P, Ferrera P, Pecetto PF, Moiraghi C, Morello F, Steri F, Ciccone G, Calasso C, Caserta MA, Civita M, Condo' C, D'Alessandro V, del Colle S, Ferrero S, Griot G, Laurita E, Lazzero A, Lo Curto F, Michelazzo M, Nicosia V, Palmari N, Ricchiardi A, Rolfo A, Rostagno R, Bar F, Boero E,

Frascisco M, Micossi I, Mussa A, Stefanone V, Agricola R, Cordero G, Corradi F, Runzo C, Soragna A, Sciullo D, Vercillo D, Allione A, Artana N, Corsini F, Dutto L, Lauria G, Morgillo T, Tartaglino B, Bergandi D, Cassetta I, Masera C, Garrone M, Ghiselli G, Ausiello L, Barutta L, Bernardi E, Bono A, Forno D, Lamorte A, Lison D, Lorenzati B, Maggio E, Masi I, Maggiorotto A, Novelli G, Panero F, Perotto M, Ravazzoli M, Saglio E, Soardo F, Tizzani A, Tizzani P, Tullio M, Ulla M, Romagnoli E; SIMEU Group for Lung Ultrasound in the Emergency Department in Piedmont. Lung ultrasound-implemented diagnosis of acute decompensated heart failure in the ED: a SIMEU multicenter study. *Chest* 2015;**148**:202–210.

33. Gargani L, Frassi F, Soldati G, Tesorio P, Gheorghiade M, Picano E. Ultrasound lung comets for the differential diagnosis of acute cardiogenic dyspnoea: a comparison with natriuretic peptides. *Eur J Heart Fail* 2008;**10**:70–77.

34. Laffin LJ, Patel AV, Saha N, Barbat J, Hall JK, Cain M, Parikh K, Shah J, Spencer KT. Focused cardiac ultrasound as a predictor of readmission in acute decompensated heart failure. *Int J Cardiovasc Imaging* 2018;**34**:1075–1079.

35. Goonewardena SN, Gemignani A, Ronan A, Vasaiwala S, Blair J, Brennan JM, Shah DP, Spencer KT. 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.

36. Cubo-Romano P, Torres-Macho J, Soni NJ, Reyes LF, Rodríguez-Almódovar A, Fernández-Alonso JM, González-Davia R, Casas-Rojo JM, Restrepo MI, de Casasola GG. Admission inferior vena cava measurements are associated with mortality after hospitalization for acute decompensated heart failure. *J Hosp Med* 2016;**11**:778–784.

37. Nijst P, Martens P, Dupont M, Tang WH, Mullens W. Intrarenal flow alterations during transition from euvolemia to intravascular volume expansion in heart failure patients. *JACC Heart Fail* 2017;**5**:672–681.

38. Gargani L, Pang PS, Frassi F, Miglioranza MH, Dini FL, Landi P, Picano E. Persistent pulmonary congestion before discharge predicts rehospitalization in heart failure: a lung ultrasound study. *Cardiovasc Ultrasound* 2015;**13**:40.

39. Öhman J, Harjola VP, Karjalainen P, Lassus J. Focused echocardiography and lung ultrasound protocol for guiding treatment in acute heart failure. *ESC Heart Fail* 2018;**5**:120–128.

40. Pellicori P, Cleland JG, Zhang J, Kallvikbacka-Bennett A, Urbinati A, Shah P, Kazmi S, Clark AL. Cardiac dysfunction, congestion and loop diuretics: their relationship to prognosis in heart failure. *Cardiovasc Drugs Ther* 2016;**30**:599–609.

41. Lee HF, Hsu LA, Chang CJ, Chan YH, Wang CL, Ho WJ, Chu PH. Prognostic significance of dilated inferior vena cava in advanced decompensated heart failure. *Int J Cardiovasc Imaging* 2014;**30**:1289–1295.

42. Curbelo J, Aguilera M, Rodriguez-Cortes P, Gil-Martinez P, Suarez Fernandex C. Usefulness of inferior vena cava ultrasonography in outpatients with chronic heart failure. *Clin Cardiol* 2018;**41**:510–517.

43. Palazzuoli A, Ruocco G, Franci B, Evangelista I, Lucani B, Nuti R, Pellicori P. Ultrasound indices of congestion in patients with acute heart failure according to body mass index. *Clin Res Cardiol* 2020;**109**:1423–1433.

44. Pellicori P, Clark AL, Kallvikbacka-Bennett A, Zhang J, Urbinati A, Monzo L, Dierckx R, Anker SD, Cleland JG. Non-invasive measurement of right atrial pressure by near-infrared spectroscopy: preliminary experience. A report from the SICA-HF study. *Eur J Heart Fail* 2017;**19**:883–892.

45. Puzzovivo A, Monitillo F, Guida P, Leone M, Rizzo C, Grande D, Ciccone MM, Iacoviello M. Renal venous pattern: a new parameter for predicting prognosis in heart failure outpatients. *Cardiovasc Dev Dis* 2018;**5**:52.

46. Platz E, Lewis EF, Uno H, Peck J, Pivetta E, Merz AA, Hempel D, Wilson C, Frasure SE, Jhund PS, Cheng S, Solomon SD. Detection and prognostic value of pulmonary congestion by lung ultrasound in ambulatory heart failure patients. *Eur Heart J* 2016;**37**:1244–1251.

47. Coiro S, Rossignol P, Ambrosio G, Carluccio E, Alunni G, Murrone A, Tritto I, Zannad F, Girerd N. Prognostic value of residual pulmonary congestion at discharge assessed by lung ultrasound imaging in heart failure. *Eur J Heart Fail* 2015;**17**:1172–1181.

48. Dwyer KH, Merz AA, Lewis EF, Claggett BL, Crousillat DR, Lau ES, Silverman MB, Peck J, Rivero J, Cheng S, Platz E. Pulmonary congestion by lung ultrasound in ambulatory patients with heart failure with reduced or preserved ejection fraction and hypertension. *J Card Fail* 2018;**24**:219–226.

49. Palazzuoli A, Ruocco G, Beltrami M, Nuti R, Cleland JG. Combined use of lung ultrasound, B-type natriuretic peptide, and echocardiography for outcome prediction in patients with acute HFrEF and HFpEF. *Clin Res Cardiol* 2018;**107**:586–596.

50. Platz E, Merz AA, Jhund PS, Vazir A, Campbell R, McMurray JJ. Dynamic changes and prognostic value of pulmonary congestion by lung ultrasound in acute and chronic heart failure: a systematic review. *Eur J Heart Fail* 2017;**19**:1154–1163.

51. Miglioranza MH, Picano E, Badano LP, Sant'Anna R, Rover M, Zaffaroni F, Sicari R, Kalil RK, Leiria TL, Gargani L. Pulmonary congestion evaluated by lung ultrasound predicts decompensation in heart failure outpatients. *Int J Cardiol* 2017;**240**:271–278.

52. Cogliati C, Casazza G, Ceriani E, Torzillo D, Furlotti S, Bossi I, Vago T, Costantino G, Montano N. Lung ultrasound and short-term prognosis in heart failure patients. *Int J Cardiol* 2016;**218**:104–108.

53. Wang Y, Gargani L, Barskova T, Furst DE, Cerinic MM. Usefulness of lung ultrasound B-lines in connective tissue disease-associated interstitial lung disease: a literature review. *Arthritis Res Ther* 2017;**19**:206.

54. Gargani L, Sicari R, Raciti M, Serasini L, Passera M, Torino C, Letachowicz K, Ekart R, Fliser D, Covic A, Balafa O, Stavroulopoulos A, Massy ZA, Fiaccadori E, Caiazza A, Bachelet T, Slotki I, Shavit L, Martinez-Castelao A, Coudert-Krier MJ, Rossignol P, Kraemer TD, Hannedouche T, Panichi V, Wiecek A, Pontoriero G, Sarafidis P, Klinger M, Hojs R, Seiler-Mußler S, Lizzi F, Onofriescu M, Zarzoulas F, Tripepi R, Mallamaci F, Tripepi G, Picano E, London GM, Zoccali C. Efficacy of a remote web-based lung ultrasound training for nephrologists and cardiologists: a LUST trial sub-project. *Nephrol Dial Transplant* 2016;**31**:1982–1988.

55. Pivetta E, Baldassa F, Masellis S, Bovaro F, Lupia E, Maule MM. Sources of variability in the detection of B-lines, using lung ultrasound. *Ultrasound Med Biol* 2018;**44**:1212–1216.

56. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, Flachskampf FA, Foster E, Goldstein SA, Kuznetsova T, Lancellotti P, Muraru D, Picard MH, Rietzschel ER, Rudski L, Spencer KT, Tsang W, Voigt JU. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr* 2015;**28**:1–39.e14.

57. Drazner MH, Rame JE, Stevenson LW, Dries DL. Prognostic importance of elevated jugular venous pressure and a third heart sound in patients with heart failure. *N Engl J Med* 2001;**345**:574–581.

58. McGee SR. Physical examination of venous pressure: a critical review. *Am Heart J* 1998;**136**:10–18.

59. Simon MA, Kliner DE, Girod JP, Moguillansky D, Villanueva FS, Pacella JJ. Detection of elevated right atrial pressure using a simple bedside ultrasound measure. *Am Heart J* 2010;**159**:421–427.

60. Simon MA, Schnatz RG, Romeo JD, Pacella JJ. Bedside ultrasound assessment of jugular venous compliance as a potential point-of-care method to predict acute decompensated heart failure 30-day readmission. *J Am Heart Assoc* 2018;**7**:e008184.

61. Tang WH, Mullens W. Cardiorenal syndrome in decompensated heart failure. *Heart* 2010;**96**:255–260.

62. de la Espriella-Juan R, Núñez E, Miñana G, Sanchis J, Bayés-Genís A, González J, Chorro J, Núñez J. Intrarenal venous flow in cardiorenal syndrome: a shining light into the darkness. *ESC Heart Fail* 2018;**5**:1173–1175.

63. Ciccone MM, Iacoviello M, Gesualdo L, Puzzovivo A, Antoncecchi V, Doronzo A, Monitillo F, Citarelli G, Paradies V, Favale S. The renal arterial resistance index: a marker of renal function with an independent and incremental role in predicting heart failure progression. *Eur J Heart Fail* 2014;**16**:210–216.

64. Jeong SH, Jung DC, Kim SH, Kim SH. Renal venous doppler ultrasonography in normal subjects and patients with diabetic nephropathy: value of venous impedance index measurements. *J Clin Ultrasound* 2011;**39**:512–518.

65. Tang WH, Kitai T. Intrarenal venous flow: a window into the congestive kidney failure phenotype of heart failure? *JACC Heart Fail* 2016;**4**:683–686.

66. Bateman GA, Cuganesan R. Renal vein Doppler sonography of obstructive uropathy. *AJR Am J Roentgenol* 2002;**178**:921–925.

67. Scali MC, Cortigiani L, Simionuc A, Gregori D, Marzilli M, Picano E. Exercise-induced B-lines identify worse functional and prognostic stage in heart failure patients with depressed left ventricular ejection fraction. *Eur J Heart Fail* 2017;**19**:1468–1478.

68. Simonovic D, Coiro S, Carluccio E, Girerd N, Deljanin-Ilic M, Cattadori G, Ambrosio G. Exercise elicits dynamic changes in extravascular lung water and haemodynamic congestion in heart failure patients with preserved ejection fraction. *Eur J Heart Fail* 2018;**20**:1366–1369.

69. Volpicelli G, Elbarbary M, Blaivas M, Lichtenstein DA, Mathis G, Kirkpatrick AW, Melniker L, Gargani L, Noble VE, Via G, Dean A, Tsung JW, Soldati G, Copetti R, Bouhemad B, Reissig A, Agricola E, Rouby JJ, Arbelot C, Liteplo A, Sargsyan A, Silva F, Hoppmann R, Breitkreutz R, Seibel A, Neri L, Storti E, Petrovic T; 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**:577–591.

70. Copetti R, Soldati G, Copetti P. Chest sonography: a useful tool to differentiate acute cardiogenic pulmonary edema from acute respiratory distress syndrome. *Cardiovasc Ultrasound* 2008;**6**:16.

71. Frasure SE, Matilsky DK, Siadecki SD, Platz E, Saul T, Lewiss RE. Impact of patient positioning on lung ultrasound findings in acute heart failure. *Eur Heart J Acute Cardiovasc Care* 2015;**4**:326–332.

72. Platz E, Pivetta E, Merz AA, Peck J, Rivero J, Cheng S. Impact of device selection and clip duration on lung ultrasound assessment in patients with heart failure. *Am J Emerg Med* 2015;**33**:1552–1556.

73. Buessler A, Chouihed T, Duarte K, Bassand A, Huot-Marchand M, Gottwalles Y, Pénine A, André E, Nace L, Jaeger D, Kobayashi M, Coiro S, Rossignol P, Girerd N. Accuracy of several lung ultrasound methods for the diagnosis of acute heart failure in the ED: a multicenter prospective study. *Chest* 2020;**157**:99–110.

74. Platz E, Campbell RT, Claggett B, Lewis EF, Groarke JD, Docherty KF, Lee MM, Merz AA, Silverman M, Swamy V, Lindner M, Rivero J, Solomon SD, McMurray JJ. Lung ultrasound in acute heart failure: prevalence of pulmonary congestion and short- and long-term outcomes. *JACC Heart Fail* 2019;**7**:849–858.

75. Gargani L. Ultrasound of the lungs: more than a room with a view. *Heart Fail Clin* 2019;**15**:297–303.

76. Jambrik Z, Monti S, Coppola V, Agricola E, Mottola G, Miniati M, Picano E. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. *Am J Cardiol* 2004;**93**:1265–1270.

77. Platz E, Jhund PS, Girerd N, Pivetta E, McMurray JJ, Peacock WF, Masip J, Martin-Sanchez FJ, Miró Ò, Price S, Cullen L, Maisel AS, Vrints C, Cowie MR, DiSomma S, Bueno H, Mebazaa A, Gualandro DM, Tavares M, Metra M, Coats AJ, Ruschitzka F, Seferovic PM, Mueller C; Study Group on Acute Heart Failure of the Acute Cardiovascular Care Association and the Heart Failure Association of the European Society of Cardiology. Expert consensus document: reporting checklist for quantification of pulmonary congestion by lung ultrasound in heart failure. *Eur J Heart Fail* 2019;**21**:844–851.

78. Yancy CW, Jessup M, Bozkurt B, Butler J, Casey DE Jr, Colvin MM, Drazner MH, Filippatos GS, Fonarow GC, Givertz MM, Hollenberg SM, Lindenfeld J, Masoudi FA, McBride P, Peterson PN, Stevenson LW, Westlake C. 2017 ACC/AHA/HFSA focused update of the 2013 ACCF/AHA guideline for the management of heart failure: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Failure Society of America. *Circulation* 2017;**136**:e137–e161.

79. Gundersen GH, Norekval TM, Haug HH, Skjetne K, Kleinau JO, Graven T, Dalen H. Adding point of care ultrasound to assess volume status in heart failure patients in a nurse-led outpatient clinic. A randomised study. *Heart* 2016;**102**:29–34.

80. Rivas-Lasarte M, Alvarez-Garcia J, Fernandez-Martinez J, Maestro A, López-López L, Solé-González E, Pirla MJ, Mesado N, Mirabet S, Fluvià P, Brossa V, Sionis A, Roig E, Cinca J. Lung ultrasound-guided treatment in ambulatory patients with heart failure: a randomized controlled clinical trial (LUS-HF study). *Eur J Heart Fail* 2019;**21**:1605–1613.

81. Marini C, Fragasso G, Italia L, Sisakian H, Tufaro V, Ingallina G, Stella S, Ancona F, Loiacono F, Innelli P, Costantino MF, Sahakyan L, Gabrielyan S, Avetisyan M, Margonato A, Agricola E. Lung ultrasound-guided therapy reduces acute decompensation events in chronic heart failure. *Heart* 2020;**106**:1934–1939.

82. Araiza-Garaygordobil D, Gopar-Nieto R, Martinez-Amezcua P, Cabello-López A, Alanis-Estrada G, Luna-Herbert A, González-Pacheco H, Paredes-Paucar CP, Sierra-Lara MD, Briseño-de la Cruz JL, Rodriguez-Zanella H, Martinez-Rios MA, Arias-Mendoza A. A randomized controlled trial of lung ultrasound-guided therapy in heart failure (CLUSTER-HF study). *Am Heart J* 2020;**227**:31–39.

83. Bikdeli B, Madhavan MV, Jimenez D, Chuich T, Dreyfus I, Driggin E, Nigoghossian C, Ageno W, Madjid M, Guo Y, Tang LV, Hu Y, Giri J, Cushman M, Quéré I, Dimakakos EP, Gibson CM, Lippi G, Favaloro EJ, Fareed J, Caprini JA, Tafur AJ, Burton JR, Francese DP, Wang EY, Falanga A, McLintock C, Hunt BJ, Spyropoulos AC, Barnes GD, Eikelboom JW, Weinberg I, Schulman S, Carrier M, Piazza G, Beckman JA, Steg PG, Stone GW, Rosenkranz S, Goldhaber SZ, Parikh SA, Monreal M, Krumholz HM, Konstantinides SV, Weitz JI, Lip GY; Global COVID-19 Thrombosis Collaborative Group, endorsed by the ISTH, NATF, ESVM, and the IUA, supported by the ESC Working Group on Pulmonary Circulation and Right Ventricular Function. COVID-19 and thrombotic or thromboembolic disease: implications for prevention, antithrombotic therapy, and follow-up: JACC State-of-the-Art Review. *J Am Coll Cardiol* 2020;**75**:2950–2973.

84. Lomoro P, Verde F, Zerboni F, Simonetti I, Borghi C, Fachinetti C, Natalizi A, Martegani A. COVID-19 pneumonia manifestations at the admission on chest ultrasound, radiographs, and CT: single-center study and comprehensive radiologic literature review. *Eur J Radiol Open* 2020;**7**:100231.

85. Gargani L, Soliman-Aboumarie H, Volpicelli G, Corradi F, Pastore MC, Cameli M. Why when and how to use lung ultrasound during the COVID-19 pandemic: enthusiasm and caution. *Eur Heart J Cardiovasc Imaging* 2020;**21**:941–948.