Review Article

Theoretical Concepts of Lung Ultrasound in the Diagnosis of Congestion

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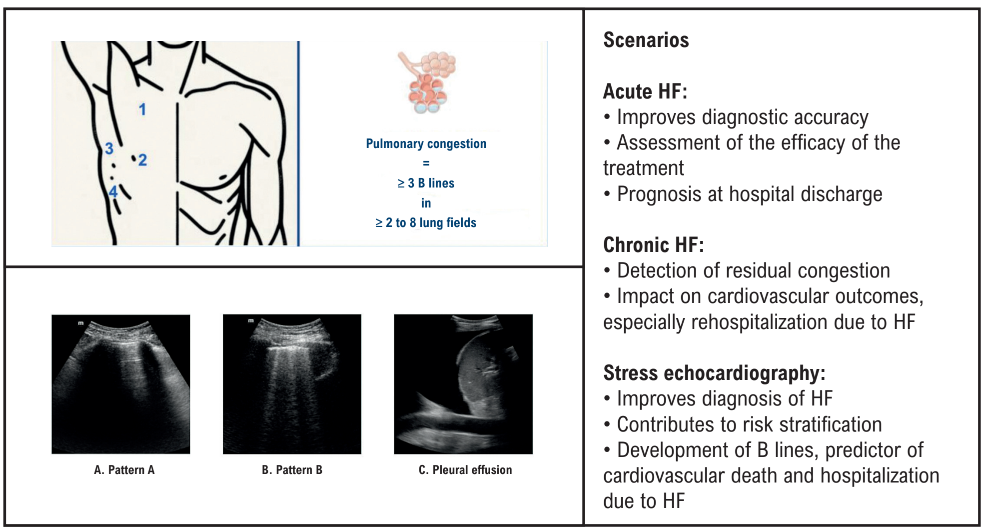
Central Illustration: Theoretical Concepts of Lung Ultrasound in the Diagnosis of Congestion

ABC Heart Failure & Cardiomyopathy



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Abstract

Accurate detection of pulmonary congestion remains a challenge in cardiology, despite advances in diagnostic methods. Traditional approaches, such as physical examination and chest radiography, have limitations in real-time assessment and dynamic monitoring of volume status. Lung ultrasound (LUS) has emerged as a promising tool, offering a non-invasive, bedside approach to detect pulmonary congestion with greater diagnostic accuracy, providing valuable information about volume status. In patients with heart failure, LUS has demonstrated high sensitivity and specificity in detecting pulmonary congestion, contributing to more accurate differential diagnosis and streamlining clinical decision-making. In the context of stress echocardiography, LUS improves risk stratification, identifying patients with a greater likelihood of adverse cardiovascular events. Beyond the context of heart failure, LUS has also been applied in other clinical scenarios, such as acute coronary syndrome and assessment of volume status in patients on dialysis. This expanded use reflects the potential of LUS as a versatile and valuable tool in different clinical settings, offering an earlier, more accurate, and more effective approach to cardiology care.

Keywords

Heart Failure; Pulmonary Edema; Ultrasonography; Stress Echocardiography

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Introduction

Despite advances in diagnostic methods in cardiology and heart failure (HF), accurate detection of pulmonary congestion still faces notable challenges. Although conventional methods such as physical examination, chest radiography, and biomarkers offer effective approaches to assessment, they have inherent limitations, especially in relation to real-time assessment and dynamic monitoring of volume status.[1]

The combination of clinical examination with biomarkers, such as brain natriuretic peptide (BNP), and imaging tests has been recommended to improve the distinction between possible differential diagnoses.[2] Nonetheless, traditional chest radiography also has limited sensitivity in assessing congestion.[3] Given this complex clinical scenario, there is a need for more accurate diagnostic and monitoring methods. In this context, lung ultrasound (LUS) has emerged as a promising tool, offering a non-invasive bedside approach to detect pulmonary congestion with better diagnostic accuracy and reproducibility than traditional clinical assessment (Table 1).[4] Compared to other imaging methods that can identify congestion, LUS stands out due to its primary features: low cost, bedside applicability, wide availability, ability to monitor therapeutic effects, usefulness in stress protocols, and association with clinical outcomes.[5]

Technical aspects

In normal lungs, LUS only identifies the pleura as a hyperechoic horizontal line that presents pleural sliding during breathing and always reverberates in the scanning area at equidistant intervals, described as pattern A (Figure 1A).

Table 1 – Comparative diagnostic value between clinical signs and lung ultrasound in detection of pulmonary congestion

	Sensitivity (%)	Specificity (%)	Accuracy (%)
Physical examination			
Rales	55	91	65
Jugular venous distension	40	86	52
Peripheral edema	37	95	52
Lung ultrasound	90	95	91

Adapted from Kataoka and Takada (2000).[14]

When there is a decrease in the amount of air and an increase in lung density, B lines appear as vertical ultrasound artifacts that originate from the pleura and extend throughout the scanning area, omitting A lines and moving according to the patient's breathing, indicating the presence of pulmonary interstitial edema (Figure 1B).[6,7]

In addition to identifying pulmonary interstitial edema, LUS also allows diagnosis of pleural effusion, through identification of a hypoechoic image above the diaphragm in the lateral and posterior windows, close to the costophrenic angle (Figure 1C).

As high temporal and spatial resolution is not necessary, most commercially available ultrasound scanners, including portable ones, are usually sufficient to acquire quality images. Use of a 5 MHz convex transducer or a 2.5 to 5 MHz cardiac sector transducer is recommended. The convex transducer should be positioned perpendicular to the chest wall, between the ribs, in order to avoid shadows that could interfere with visualization of the pleural line and underlying pulmonary parenchyma; the cardiac transducer, due to its smaller size, typically does not hinder adequate visualization of the intercostal spaces. Harmonic imaging can be used to better identify B lines. Depth and gain settings are adjusted to optimize visualization of the pleura and pulmonary tissue.[8,9]

Multiple protocols have been described for performing LUS, varying in the number of lung fields examined.[10] The 8-field protocol is still the most widely used in clinical practice, and it is recommended by the most recent European Association of Cardiovascular Imaging (EACVI) consensus statement.[7] This protocol consists of bilateral scanning of the anterior and lateral areas of the chest, dividing each hemithorax into the following 4 fields: anterior superior and anterior inferior, in the midclavicular line; lateral superior and lateral inferior, in the mid-axillary line (Figure 2 and Video 1). The identification of 3 or more B lines in 2 or more fields suggests pulmonary congestion (Video 2).[7] The increase in the number of B lines correlates with elevated pulmonary capillary pressure (PCP), as validated by invasive hemodynamic measurements, making a non-invasive approach possible to estimate left ventricular filling pressures.[11]

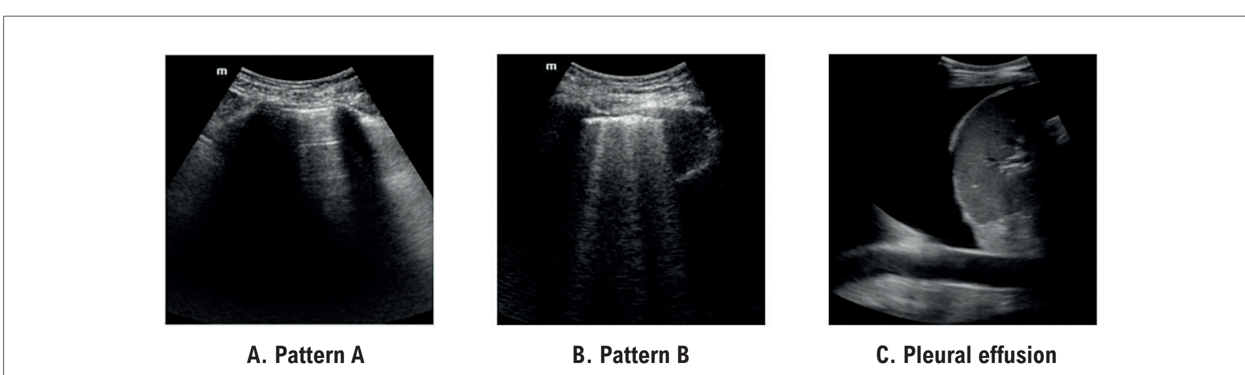


Figure 1 – *Lung ultrasound patterns: A) pattern A; B) pattern B; C) pleural effusion.*

Lung ultrasound in heart failure

In echocardiographic assessment of patients with HF, LUS is an additional marker of congestion in relation to traditionally obtained parameters. In addition to enlarged left atrium, elevated E/e′ ratio, elevated pulmonary pressures, and elevated estimated central venous pressure by assessment of the inferior vena cava, the presence of pulmonary B lines is an independent marker of left HF and increased left ventricular filling pressures, which can be obtained with the same transducer and the addition of a few minutes to the total examination time in cases with clinical suspicion or diagnosis of HF.[7]

Acute heart failure

LUS has emerged as a promising diagnostic, therapeutic monitoring, and prognostic tool in the setting of acute HF. In emergency scenarios, it offers quick, non-invasive assessment, demonstrating an important role in the differential diagnosis of dyspnea, with a sensitivity of 93.7% (95% confidence interval: 86.01% to 97.9%) and specificity of 86.1% (95% confidence interval: 70.5% to 96.3%) to discriminate cardiac and non-cardiac etiology of dyspnea.[12] When associated with traditional clinical assessment in diagnosis of acute decompensated HF in the emergency setting, LUS showed greater diagnostic capacity (area under the curve [AUC] 0.95 versus AUC 0.88; $p < 0.01$), while the use of chest radiography and NT-proBNP did not perform better than traditional clinical assessment (AUC 0.87 versus AUC 0.85; $p > 0.05$).[13] Furthermore, the use of LUS reduced 8% of diagnostic errors compared to traditional clinical assessment, in addition to reducing diagnostic time by 100 minutes compared to complementary evaluation with chest radiography and NT-proBNP.[13] In a study conducted in the setting of decompensated HF, the search for pleural effusion by means of LUS demonstrated high sensitivity and specificity (90% and 95%, respectively) in detecting pulmonary congestion, outperforming physical examination signs, such as crackles or rales, jugular venous distension, and peripheral edema.[14] Moreover, it led to a

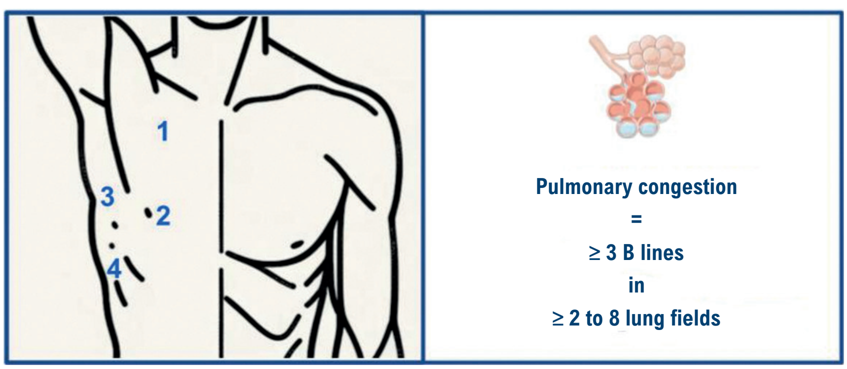
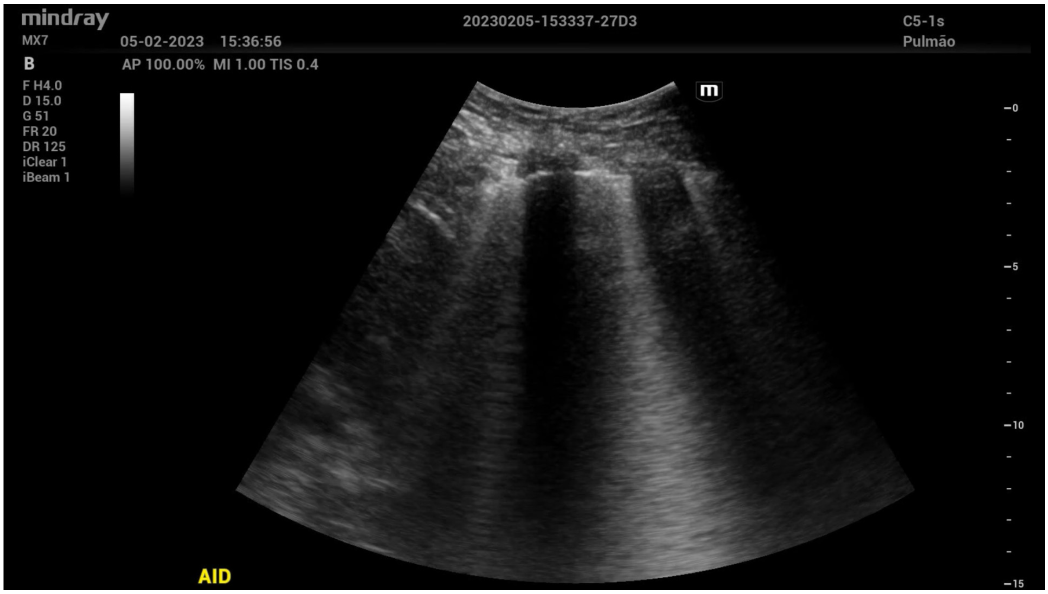


Figure 2 – *Left: lung fields assessed in the 8-field protocol, 4 in each hemithorax; 1) anterior superior; 2) anterior inferior; 3) lateral superior; 4) lateral inferior. Right: definition of pulmonary congestion according to lung ultrasound.*

Video 1 – *Example of left hemithorax lung ultrasound acquisition of the four lung fields: anterior superior, anterior inferior, lateral superior and lateral inferior respectively. Link: http://abcheartfailure.org/supplementary-material/2024/401/2024-0022_AR_video_1.mp4.*



Video 2 – *Example of B lines: vertical ultrasound artifacts that originate from the pleura and distribute throughout the scanning area. Link: http://abcheartfailure.org/supplementary-material/2024/401/2024-0022_AR_video_2.MP4.*

faster decision to recommend hospital admission, as well as a 33% reduction in the total length of hospital stay.[15] In serial evaluation of patients hospitalized for HF, in parallel with other markers of congestion such as E/e' ratio, BNP, and estimated central venous pressure by measurement of the inferior vena cava, LUS was shown to be the only predictor of all-cause mortality, as well as a composite outcome of mortality and rehospitalization.[16]

In the setting of patients who are hospitalized for decompensated HF, monitoring of congestion through assessment of pulmonary B lines is highly useful, due to the rapid response of the decreased B lines with improved congestion, which can assist in detection of subclinical congestion and management of diuretics, potentially reducing the length of hospital stay.[7,17]

During pre-hospital discharge assessment, the presence of residual congestion seems to identify patients with worse prognosis and, especially, higher need for new hospitalization due to HF during follow-up within 6 months.[7,18,19] In this scenario, a randomized clinical trial that evaluated the use of pre-hospital discharge LUS to guide the clinical management of residual congestion compared to traditional clinical management by a general practitioner, including at-home LUS performed after hospital discharge by trained nurses, reduced the need for rehospitalization within 30 days by 66% and 37% in 90 days compared to traditional management.[20] The presence of 12 or more B lines at hospital discharge was shown to be an independent predictor of hospital readmission and 6-month mortality.[21] Another recently published cohort study showed that the presence of 2 to 3 lung fields with B patterns posed a 25% greater risk of readmission for HF within 30 days, and the presence of more than 4 fields with B patterns increased the risk of hospitalization within 30 days by 50%, compared to patients discharged with 0 to 1 positive fields.[22] In line with these findings, a recently published meta-analysis demonstrated that a greater number of B lines at admission, at hospital discharge, and at the outpatient level was associated with rehospitalization due to HF and general mortality, and that the addition of LUS to the MAGGIC and AHEAD scores reclassified the prognosis of patients in all three scenarios.[23]

Chronic heart failure

In the outpatient setting, the majority of stable patients with controlled symptoms can be adequately assessed by means of anamnesis and physical examination.[2,7] However, at least three randomized clinical trials have demonstrated that patients with LUS-guided outpatient management, when compared to those guided by traditional clinical assessment alone, showed a reduction in HF-related events, including the composite outcome of death, hospitalization, and urgent emergency visits due to worsening HF in the first 6 months after hospital discharge, especially due to a reduction in the last outcome mentioned, and the number of patients needed to assess with LUS to reduce an emergency visit event was 5.[24-26] Accordingly, the association of LUS with traditional clinical assessment improves detection of residual congestion, with an impact on reduced cardiovascular events, especially hospital admission for HF.

Lung ultrasound in stress echocardiography

Stress echocardiography is considered a cost-effective imaging modality, and it is recommended by the most recent guidelines for evaluating patients with coronary artery disease

(CAD)[27] and HF.[2,28] In addition to providing a detailed analysis of wall motility, it allows dynamic assessment of valvular heart disease, pulmonary hypertension, diastolic function, and B lines.[29,30]

In particular, B lines represent a practical and direct approach to assessing the presence of extravascular pulmonary water and its variation during stress.[31,32] In healthy individuals, exercise leads to only a slight increase in PCP and pulmonary artery pressure, without significantly impacting the pulmonary vascular bed. On the other hand, in patients with substantial left ventricular dysfunction, exercise increases left ventricular end-diastolic filling pressure and PCP.[33-35] When PCP exceeds 25 mmHg during exercise, there occurs an increased transfer of water from the vascular compartment to the extravascular compartment, overcoming the attraction exerted by oncotic pressure and resulting in an accumulation of extravascular pulmonary water.[36]

The presence of 10 or more B lines at peak stress (or immediately after), in a 4-field protocol with any form of physical or pharmacological stress, was an independent predictor for death and non-fatal acute myocardial infarction in patients with CAD and/or HF during a mean follow-up of 15.2 months (hazard ratio: 3.544; 95% confidence interval: 1.466 to 8.687; $p = 0.006$).[37] In a study with patients referred for physical exercise echocardiography, B lines increased during exercise in all groups studied (CAD, HF, and ischemic mitral regurgitation ≥ moderate at rest), except in controls. In multivariate analysis, the presence of B lines at peak stress was an independent predictor of all-cause death after a mean follow-up of 29 months (hazard ratio: 2.179; 95% confidence interval: 1.015 to 4.680; $p = 0.046$).[38]

In HF with reduced ejection fraction, the number of B lines during physical stress echocardiography showed a strong correlation with resting NT-proBNP values (r: 0.88; $p < 0.0001$), peak VO_2 (r: −0.90; $p < 0.0001$), and pulmonary artery systolic pressure under stress (r: 0.84; $p < 0.0001$).[39] The detection of a greater number of B lines at peak exercise was associated with greater risk of hospitalization and death due to HF (12-month event-free survival of 95% in patients with < 30 B lines versus 7% in patients with ≥ 30 B lines; $p < 0.0001$), in an analysis protocol with 28 pulmonary fields.[39]

In patients with HF with preserved ejection fraction, the development of pulmonary congestion during exercise occurs concomitantly with worsening diastolic function, predominantly with an increase in the mean E/e′ ratio and a reduction in the late diastolic strain rate (R^2: 0.776; $p < 0.04$).[40] Both the number of B lines at peak (hazard ratio: 1.50; 95% confidence interval: 1.21 to 1.85; $p < 0.001$) and the change in relation to baseline (hazard ratio: 1.34; 95% confidence interval: 1.12 to 1.62; $p = 0.002$) during physical exercise echocardiography were predictors of cardiovascular death or hospitalization for HF within 1 year in this population.[41]

These findings indicate that LUS can improve the diagnosis of HF and contribute to risk stratification when combined with stress echocardiography. Along these lines, LUS has been integrated into expanded physical stress echocardiography protocols[42] and protocols performed in conjunction with cardiopulmonary exercise testing,[43,44] providing an additional range of parameters for analysis.

Lung ultrasound in other scenarios

In up to a third of cases, patients with acute coronary syndrome may develop HF, which is associated with an increased risk of total mortality.[45,46] In ST-segment elevation myocardial infarction, LUS combined with the Killip classification forms the LUCK (Lung Ultrasound Combined with Killip) score, which has shown higher diagnostic accuracy than Killip alone for predicting in-hospital mortality, as well as high negative predictive value for ruling out pulmonary congestion.[47]

Fluid overload poses a continuous challenge in the dialysis population given the difficulty in assessing volume status in this patient profile,[48] leading to hypertension, prolonged hospitalization, and increased hospital readmission rates.[49,50] For a long time, the process of determining a patient's dry weight and assessing extravascular lung water were based on vital signs and physical examination data. With the advent of LUS, this tool has become valuable to the identification of pulmonary congestion in patients with chronic disease on dialysis, with resolution of B lines following the removal of fluids during hemodialysis,[51] showing potential use in monitoring response to dialysis.[52]

Challenges and limitations

Other pulmonary interstitial diseases can also be shown on LUS through the presence of B lines. Acute respiratory distress syndrome (ARDS) presents with non-cardiogenic pulmonary edema, with difficult differential diagnosis from cardiogenic pulmonary congestion. Some features, such as the presence of some spared areas among areas with many B lines and the presence of subpleural consolidation, may be more suggestive of ARDS. Pulmonary fibrosis, compared to cardiogenic edema, less frequently presents a gravitational association (cardiogenic edema is more frequent in posterior and inferior fields), and its pattern does not show changes after therapy with diuretics.[53]

Conclusion

LUS has been established as a highly valuable diagnostic tool in detecting pulmonary congestion in patients with both acute and chronic HF. With practical and non-invasive application, this ultrasound method offers better diagnostic accuracy, dynamic monitoring of pulmonary congestion, and identification of patients with worse prognosis (Table 2), overcoming the limitations of traditional assessment methods.

In the challenging clinical contexts of decompensated HF, LUS has emerged as a reliable predictor of congestion, demonstrating its usefulness in the early identification of patients at risk of adverse outcomes. The ability to detect pulmonary interstitial edema and subclinical volume overload through B lines allows for earlier therapeutic interventions, with a positive impact on morbidity and mortality associated with HF.

Table 2 – Lung ultrasound and its prognostic role in different clinical scenarios

Scenario	Study design	Findings/prognosis	Reference
Acute HF	Observational retrospective	LUS in the emergency room reduced the total length of hospital stay by 33%	Núñez-Ramos et al., 2023, Am J Emerg Med[15]
	Observational prospective	Greater number of B lines at admission was associated with more in-hospital adverse events. Higher number of B lines at discharge was associated with readmission and death within 90 and 180 days.	Platz et al., 2019, J Am Coll Cardiol HF[18]
	Prospective cohort	Resolution of pulmonary congestion on LUS during hospitalization was the best predictor of absence of mortality or readmission within 6 months.	Öhman et al., 2018, Eur Heart J Acute Cardiovasc Care[16]
	Randomized clinical trial	Residual congestion on pre-discharge LUS (≥ 10 B lines) was associated with early readmission (< 14 days) and multiple readmissions within 90 days.	Zisis et al., 2024, J Card Fail[20]
	Prospective cohort	≥ 12 B lines at discharge predicted readmission and mortality within 6 months.	Rattarasarnet al., 2022, BMC Cardiovasc. Disord[21]
	Prospective cohort	ELUS with 2 to 3 fields with a B pattern at discharge was associated with a 25% increase in the risk of readmission within 30 days; ≥ 4 fields with B pattern increased risk by 50%.	Cohen et al., 2023, J. Ultrasound Med[22]
Outpatient/ chronic HF	Randomized clinical trial	LUS-guided treatment demonstrated improved functional capacity and reduced hospitalization for HF in 180 days.	Rivas-Lasarte et al., 2019, Eur J Heart Fail[24]
	Randomized clinical trial	LUS-guided treatment reduced the risk of hospitalization for HF by 45% within 6 months.	Araiza-Garaygordobil et al., 2020, Am Heart J[25]
	Randomized clinical trial	Addition of LUS to physical examination reduced risk of rehospitalization by 56% in 6 months.	Marini et al., 2020, Heart[26]
Stress echocardiography	Prospective cohort	≥ 10 B lines at peak stress predicted death and non-fatal acute myocardial infarction within 15 months in patients with CAD and/or HF.	Scali et al., 2020, JACC Cardiovasc Imaging[37]
	Prospective cohort	Increased B lines at peak stress was an independent predictor of all-cause death at 29 months in patients with CAD, HF, and moderate mitral regurgitation.	Merli et al., 2022, Circ Cardiovasc Imaging[38]
	Prospective cohort	Greater number of B lines at peak and change in relation to baseline were predictors of death and hospitalization at 1 year in HF with preserved EF.	Coiro et al., 2020, Circ Heart Fail[41]
Acute myocardial infarction	Prospective cohort	Addition of LUS to Killip classification improved prognostic accuracy and re-stratified risk of in-hospital mortality in ST-segment elevation myocardial infarction.	Araújo et al., 2020, Circ Cardiovasc Imaging[47]

CAD: coronary artery disease; EF: ejection fraction; HF: heart failure; LUS: lung ultrasound.

Moreover, LUS has proven to be a valuable tool in the context of stress echocardiography, expanding diagnostic capacity and improving risk stratification. Nonetheless, the presence of B lines is not exclusive to cardiogenic congestion, underscoring the need for careful interpretation when facing other pulmonary interstitial diseases, such as ARDS and pulmonary fibrosis.

The advent of LUS reflects a qualitative leap in cardiac care, making it a fundamental component in cardiologists' diagnostic arsenal, offering an earlier, more accurate, and effective approach to the management of HF.

Author Contributions

Conception and design of the research; Writing of the manuscript and Critical revision of the manuscript for content: Menegazzo WR, Saadi MP, Silvano GP, Gonzalez VLG, Silveira AD.

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Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

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