RESEARCH ARTICLE

Utility of lung ultrasound in the management of COVID-19 respiratory infection

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Abstract

In the context of the coronavirus disease 2019 (COVID-19) pandemic, lung ultrasound has emerged as an accurate and reliable alternative for assessment of lung pathology.

The main lung ultrasound findings in COVID-19 patients are interstitial syndrome, irregular and broken aspect of the pleural line, and sub-pleural consolidation. Consolidations are usually a late finding appearing during the second week since symptoms onset.

Translating into the practice, lung ultrasound can improve diagnostic accuracy and contribute with relevant information to the triage of these patients. It can be used as part of the routinely assessment of patients admitted to the medical ward allowing early identification of disease progression. Among patients mechanically ventilated, it is useful evaluating response to prone position and/or recruiting maneuvers. Finally, in all the previous scenarios, lung ultrasound may also detect common complications seen in these patients such as cardiogenic pulmonary edema and pulmonary embolism.

In this review, we have summarized the information available and suggest simple algorithm to incorporate lung ultrasound into the assessment of COVID-19 patients.

Key words: ultrasonography, coronavirus infection, lung ultrasound, COVID-19

Introduction

The world is facing the most severe pandemic since the Spanish influenza in 1918. Coronavirus disease of 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has spread internationally. The clinical presentation varies from a mild upper respiratory tract infection to severe respiratory failure and death [1,2]. The overall mortality worldwide reported by the World Health Organization is 3 to 4% [3], reaching up to 15% among the high risk population [4], leading to health systems becoming overwhelmed with the sudden rise in the number of patients requiring hospitalization and intensive care.

The current standard for diagnosing COVID-19 requires a reverse transcription - polymerase chain reaction (RT-PCR) test to detect the genetic material of the virus. The sensitivity of the presently available test is 45% for nasopharyngeal swabs and 78% for sputum samples [5]. When the pandemic began, computed tomography (CT) of the chest was recommended to improve diagnostic accuracy, as CT findings can precede a positive RT-PCR test [6]. However, as the disease incidence increased over time, demand for CT scans overwhelmed capacity. Additionally, there were concerns about the risk of contamination to the CT scanners, and associated risk to the healthcare workers and other patients. The use of chest x-ray shared similar logistic and cross contamination concerns, and the sensitivity for viral pneumonia was reportedly low [7], often missing the initial lung abnormalities [8].

Lung ultrasound presents an opportunity to improving screening efficiency and patient care by detecting COVID-19 related lung pathology. It can be performed in any location, from screening centres to intensive care units (ICU), and has been demonstrated to reduce the need for both chest x-ray and chest CT [9]. Importantly, lung ultrasound can be performed at the patient´s bedside using portable or hand-held ultrasound devices which can be protected using protective a barrier sheath to avoid equipment contamination and disease transmission. Consequently, there has been rapid uptake in the use of lung ultrasound during this COVID-19 pandemic, most notably in the most affected countries [10].

The aims of this review are: to summarize and analyze the information available about the use of lung ultrasound in COVID-19 patients; and to suggest simple algorithms to incorporate lung ultrasound into clinical evaluation and management.

What are the most common lung ultrasound findings in COVID-19 patients?

Despite the small number of participants involved, all the studies [11-17] report similar ultrasound findings: interstitial syndrome with confluent B-lines, sub-pleural consolidations affecting predominantly the posterior lower zones of the lungs and thickened, irregular and ‘broken’ appearance of the pleural line. Pleural effusion was uncommon [11,12,14,15].

Table 1: Studies reporting lung ultrasound findings in COVID-19 patients

Author, Year of publication, Country	Study type	Population	N	LU Protocol	LU findings/percentage	Comment
Huang, 2020, China (22)	Retrospective	COVID-19 confirmed, non-critical patients admitted to hospital (Median age: 44.k5 yr)	20	12-region examination (6 per lung)	• Posterior lower views affected in 75% patients. • Multiple discontinuous and continuous fused B lines • Pleural line unsmooth and rough • Multiple small patchy subpleural consolidations • Pleural thickening 1-2mm • Subpleural effusion 2-3mm	• Minimise patient transportation • Timely bedside evaluation • Smaller contact area and ease of disinfection compared to CT
Peng, 2020, China (21)	Letter to the Editor	COVID-19 confirmed patients (Other characteristics not reported)	20	12-region examination (6 per lung)	• Thickened/irregular pleural line • B lines of variable patterns: focal, multifocal, confluent • Consolidation of variable patterns: small multifocal and lobar • A lines during recovery phase • Pleural effusion was uncommon • Patterns occurred as a continuum from mild interstitial syndrome to severe bilateral interstitial pattern and lung consolidation	• Potential use: monitoring disease progression or regression, monitoring response to prone position and lung recruitment manoeuvres, prediction of a successful mechanical ventilation weaning • Cannot detect lesions deep within the lung which are separated from the chest wall by air in lung
Poggiali, 2020, Italy (24)	Letter to the Editor	COVID-19 confirmed patients in the Emergency department (Mean age: 63 ±13 yr)	12	Not reported	• Diffuse B lines with spared areas • Posterior subpleural consolidation	• Good correlation with CT scan
Lomoro, 2020, Italy (23)	Retrospective	COVID-19 confirmed patients admitted to hospital (Mean age: 66.3 ± 16.6 yr SD)	22	Not reported	• Diffuse B lines of variable patterns: focal, multifocal, and confluent in (100%) • Subpleural consolidation (27.6%) • Thickened pleural line (13.6%) • Mixed A lines and B lines pattern (4.5%) • Pleural effusion (4.5%)	• Monitor of COVID-19 and its evolution toward ARDS in critically ill patients • Good correlation with CT

Yasukawa, 2020, USA	Retrospective	COVID-19 confirmed patients admitted to hospital	10	Along midclavicular line anteriorly; and scapular line and interscapular regions posteriorly	• Confluent B-lines 100% • Thick, irregular pleural lines 100% • Glass rockets 100% • Birolleau variant 50% • Small subpleural consolidations 5'% • Consolidation 10% • Septal rockets 20%	• Findings consistent with prior reports. • Ultrasound findings can be an aid for diagnosis when pre-test probability is high
Xing, 2020, China	Research letter		20	Not reported. All lung areas scanned	• Pleural line abnormalities 100% • B-lines 100% • Consolidation 50%, not found in moderate cases, only in severe and critical • Bilateral involvement 100%	• 5 cases with deep vein thrombosis (64% of the critical patients) • 1 case of pericardial effusion • Progression of the disease described, reach of severity reached at the 2nd week
Lu, 2020, China	Retrospective (German)	COVID-19 confirmed patients admitted to hospital	30	Not reported	• Interstitial pulmonary edema 90% • Consolidations 20%	• Moderate agreement with CT kappa=0.529

Abbreviations ARDS: acute respiratory syndrome, CT: Computed tomography

These findings are consistent with inflammation of the lung where it is involving the pleural surface. They are not pathognomonic of COVID-19 and could potentially appear similarly with any viral lung pneumonitis. More advanced or confluent patterns are consistent with acute respiratory distress syndrome (ARDS).

The ultrasound findings correlate well with CT studies in COVID-19 patients. The most common CT pattern involves peripheral and multiple lesions that combine ground-glass opacities with consolidations affecting predominantly the posterior lower zones of the lungs. An isolated consolidation without ground-glass opacities or the presence of pleural effusion are rare findings among COVID-19 patients. [18,19]

More detailed descriptions of the lung ultrasound have included presence of "Birolleau variant" or "white lung"[11,13], terms used to describe a diffuse hyperechoic appearance of the lung parenchyma; and a broad, lucent, band-shaped vertical artifact referred as "light beam" by Volpicelli et al. that they correlated with the initial ground-glass opacities seen in the CT. [20,21] When consolidations are present, areas with lack of color flow Doppler pulsatility has been reported. [11] This could be interpreted as a sign of lung infarction, which can be explained due to microangiopathy described recently by autopsies series in COVID-19 [22] and a potential association of COVID-19 with thrombotic complications such as pulmonary embolism. [23] However, further investigations are needed to support this approach.

Does the lung ultrasound images vary over time?

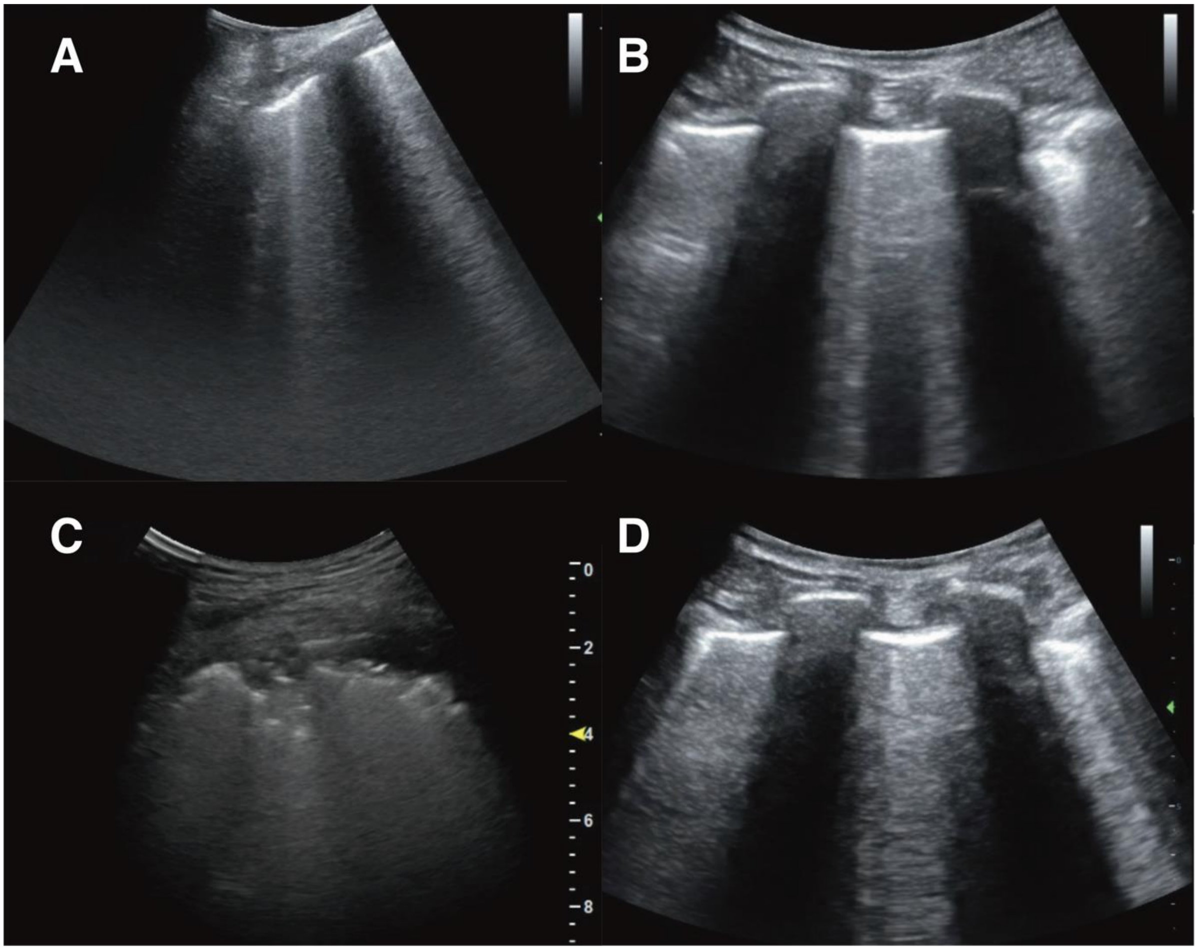
It is important to emphasize that the typical image of COVID-19 is often absent in the early phase of the disease. Even CT studies are frequently normal during the first two days. [24].

It is known from previous reports of CT images of patients recovered from COVID-19 that lung involvement progress from small sub-pleural ground-glass opacities to larger areas of ground-glass opacities with crazy-paving pattern and consolidations [25]. The severity of the lung abnormalities reach a peak around the day 10 to 14 since the symptom onset followed by gradually improvement of the lung lesions. A similar image evolution has been described using lung ultrasound: interstitial syndrome is usually present from the initial stage of the disease, while consolidation are more frequently found in the second week since symptom onset.[16]

The image severity progression correlates with the clinical deterioration described by Guan et al., in which patients with severe disease were admitted to hospital around day 7 and mechanically ventilated around day 10 post onset of symptoms [2].

Therefore, during the assessment of a patient with suspected or confirmed COVID-19, aligning the evaluation with the onset of symptoms is crucial. Lung ultrasound may show only localized or patchy distributed interstitial syndrome (mild pattern) as the first manifestation during the early phase. Posteriorly, confluent B lines with an irregular and thickened appearance of the pleura (intermediate pattern) generally precede sub-pleural or lobar consolidations (severe pattern). Figure 1. During the recovery phase, a transition to a normal pattern may be found.

Figure 1: Progression of the typical lung ultrasound findings in COVID-19 patients

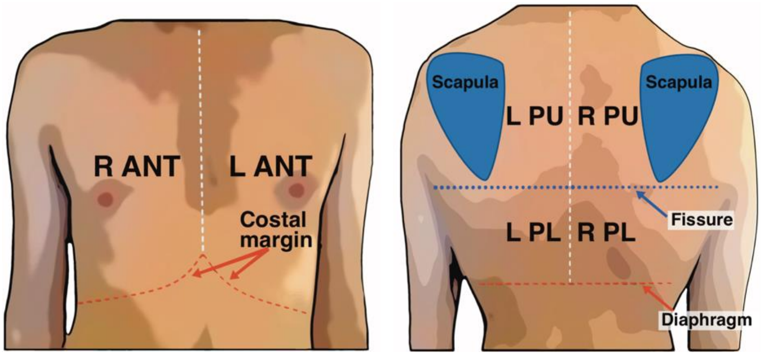


Mild pattern (A) involves localized or bilateral interstitial syndrome patchy distributed. In the intermediate pattern (B), the B-lines become more confluent and the pleura line appear thickened and irregular. Severe pattern is characterized by the presence of consolidation usually located below the pleural line (C), or on a background of interstitial syndrome with the characteristic mentioned in previous stages (D). Progression from a mild to a severe pattern is seen in the critical cases, while other may present only mild lung involvement.

How lung ultrasound can be incorporated into practice?

There are several protocols published about how to perform lung ultrasound differing mainly in the number of views or lung zones scanned. [26,27] We suggest the iLungScan protocol of the University of Melbourne which involves scanning three zones in each lung: anterior, posterior upper and posterior as most of the lung pathology will be found in that area. When patients cannot be moved from supine position, the posterior lower zone can be assessed by lateral windows.

Figure 2: Lung zones described by the iLungScan protocol.



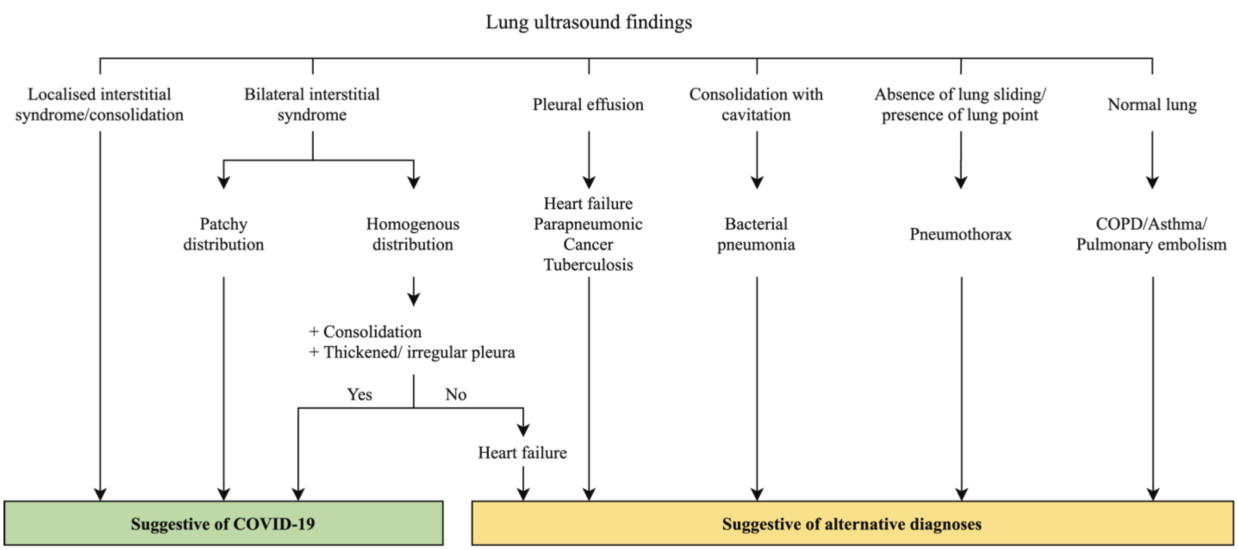
Lung ultrasound is performed scanning three anatomical zones per side. RA: right anterior, LA: left anterior, LPU: left posterior upper, LPL: left posterior lower, RPL: right posterior lower, RPU: right posterior upper.

The addition of lung ultrasound to the clinical evaluation of COVID-19 patients may be helpful in the following clinical scenarios:

1. Diagnosing COVID-19:

Although lung ultrasound alone is not diagnostic for COVID-19, its findings can support a diagnosis COVID-19 or identify a differential diagnosis such as exacerbation of heart failure which can have similar clinical presentation. Figure 3.

Figure 3: Lung ultrasound in the diagnostic approach of COVID-19 suspected patients presenting with dyspnea.



A proposed flow chart to differentiate COVID-19 from alternative diagnosis. We recommend to identify lung abnormalities in the order presented in this chart (from the left to the right). First - for B-lines to determine if there is interstitial syndrome which is the most common finding in COVID-19. The ultrasound findings on the right side of the chart will suggest an alternative diagnosis.

Differentiating COVID-19 from exacerbation of heart failure can be challenging in patients with known chronic cardiac disease. In both, lung ultrasound may show bilateral interstitial syndrome as the main finding. A homogenous distribution of the B-lines progressing from lower to upper zones of the lung with or without the presence of pleural effusion suggest cardiogenic pulmonary oedema. In contrast, patchy distribution of B-lines with or without consolidation and thickened pleura supports COVID-19. However, both conditions can coexist especially among the elderly population. Coexisting heart failure has been reported in 23% of patients with COVID-19 [28] caused by either an exacerbation of a pre-existing cardiac dysfunction or a new onset cardiomyopathy [29].

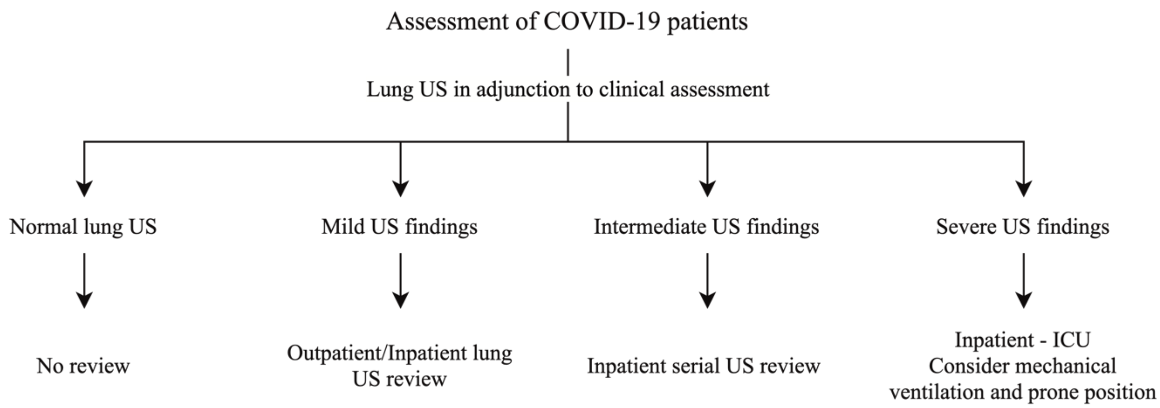
When lung ultrasound is suggestive of COVID-19, it is reasonable to manage these patients as a confirmed case if the nasopharyngeal swab or sputum result is pending, or unable to be performed, or if there is high level of suspicion of COVID-19 regardless of the RT-PCR result (e.g. contact with a confirmed case).[30]

2. Triage of patient with suspected or confirmed COVID-19:

Severity of the disease may progress from very mild flu-like symptoms to severe respiratory failure. As with other respiratory tract infection, the triaging process involves clinical evaluation and clinical judgement. One of the most challenging aspects of triage is the early identification of patients that will deteriorate rapidly to a severe condition, which has been reported in 10-15% of the patient presenting with mild or moderate symptoms [2].

Lung ultrasound findings could assist healthcare providers in determining the disposition of patients presented for assessment, be it hospital admission for monitoring or home isolation and outpatient follow-up. Figure 4. With the information currently available, we cautiously suggest that the presence of any lung inflammation signs should be considered an early indication for potential deterioration regardless of the symptoms.

Figure 4: Proposed algorithm for the role of lung ultrasound in the initial or repeated assessment of COVID-19 with or without symptoms.



In the initial or repeated assessment of COVID-19, a normal lung ultrasound (US) will exclude significant lung pathology. In these patients no further review may be needed unless there is a clinical decline. Any presence of lung inflammation will confirm lung involvement, which will escalate management. When mild ultrasound findings are present hospital admission versus outpatient management should be decided based on the patient's comorbidities and clinical assessment. However in both cases we recommend an early control with a new lung ultrasound assessment to evaluate possible progression of the disease even in the absence of clinical deterioration. From intermediate findings or worse, we recommend in hospital management. Severe ultrasound findings should be analyzed in addition to oxygenation and ventilation parameters to support mechanical ventilation.

3. COVID-19 in patient monitoring:

Most of the patients with COVID-19 managed in-hospital were admitted to general medical wards. Within this group, it has been described that 15 to 20% progress from severe to a critical condition requiring mechanical ventilation and intensive care management [1]. Early identification of these patients is vital for improving patient prognosis. Since ultrasound is non-invasive and can be performed at the patient's bedside, this enables repeated imaging of the lung in order to monitor worsening or improvement of lung pathology whilst avoiding transportation of patients for diagnostic imaging. The veracity of this measurement is enhanced when using ultrasound devices that allow for centralized or cloud based image archiving allowing comparison of original acquisitions over time.

Incorporating lung ultrasound examination into routine clinical assessment will help identify progression of lung abnormalities and to anticipate potential clinical deterioration. Conversely, improvement seen on lung ultrasound will support timely patient hospital discharge. Soldati et al. recently proposed a standardized lung ultrasound acquisition and scoring protocols for evaluating progression of lung abnormalities in patients with COVID-19. [31] This protocol may be too extensive since divides the lung into 14 zones. However, we share the principle behind this endeavor – to assess patients with lung ultrasound and document changes over time in a standardized and repeatable manne

4. ICU-management

The utility of lung ultrasound has been widely described in the management of patients with ARDS pre SARS-Cov-2 pandemic [32]: Lung consolidations on ultrasound implies the patient may benefit from a prone position ventilation [33]; Improvements in the lung ultrasound findings such as changing from consolidation to interstitial syndrome are used to assess response to recruitment manoeuvre [34] and to prone positioning [35]; ultrasound evaluation of diaphragm and lung pathologies are used to predict the success of weaning from mechanical ventilation [36].

In COVID-19 critical patients, lung ultrasound can complement the assessment of the two phenotypes recently described: L-type (low-elastance) and H-type (High-elastance). [37] Presence of confluent patterns and consolidations would support H-type.[38]

Furthermore, lung ultrasound can identify other causes of clinical deterioration commonly seen in these patients such as pulmonary oedema and pleural effusion caused by heart failure, pneumothorax secondary to central line placement and pulmonary embolism. When pulmonary embolism is suspected, the addition of a brief ultrasound assessment of the femoral and popliteal veins looking for deep venous thrombosis is strongly recommended to improve diagnostic accuracy.

Conclusion

Lung ultrasound is a reliable, accurate and safe tool to assess lung pathology. Moreover, it is both sensitive and specific for lung inflammation; though such pathological changes need to involve the surface of the lung in order to be imaged. We highlighted patchy distribution of interstitial syndrome with or without consolidation as the main non-specific finding in COVID-19 lung ultrasound and correlated this with commonly accepted CT findings. We further proposed algorithms to incorporate ultrasound into the existing triaging and diagnosing processes. Nevertheless, our key message is that any evidence of lung inflammation confirms involvement of the lung irrespective of symptoms, and thus can act as an early indicator of progressive lung involvement. Future research will likely reveal the sensitivity and specificity of lung ultrasound in detecting COVID-19 and its clinical impact when used as a part of the triage evaluation and follow-up tool.

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Conflict of interest

The authors declare they have no conflict of interest.

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