First Line Covid-19
Emergency Ultrasound
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The application of lung ultrasound in the evaluation and management of patients with suspected Covid-19 infection (coronavirus 2019 associated disease) is based on the **I-AIM** approach (Indication, Acquisition, Interpretation and Management). [1]

The following recommendations are drawn from a consensus of experts, correlated with the clinical and ultrasound presentation of about a hundred of cases.

There is limited evidence on this subject, thus these recommendations are equally based upon the ultrasound findings in other types of interstitial lung diseases and on CT findings of Covid-19 patients.

This guideline will be modified and improved according to new evidence.

INDICATIONS

Thoracic ultrasound is indicated in patients with suspected Covid-19 infection for the following purposes:
- Diagnosis
- Monitoring
- Prognostic evaluation

Thoracic ultrasound should be complementary to cardiovascular imaging in the evaluation of volume status, right ventricular strain and other complications (myocarditis, venous thrombo-embolic disease).

ACQUISITION

CHEST
Probe → Convex (medium frequency), may be integrated by linear probe (high frequency). Convex probe is sufficient in the majority of cases.

Scan → acquisition of 6 different chest zones for each hemithorax (2 anterior, 2 lateral, 2 posterior) – Probe oriented both perpendicular and parallel to the intercostal space

Aim → evaluation of the pleural lining (sliding and morphology) and parenchymal features (artefacts or high-density tissue-like images); evaluation of pleural content (virtual space, air or fluid)
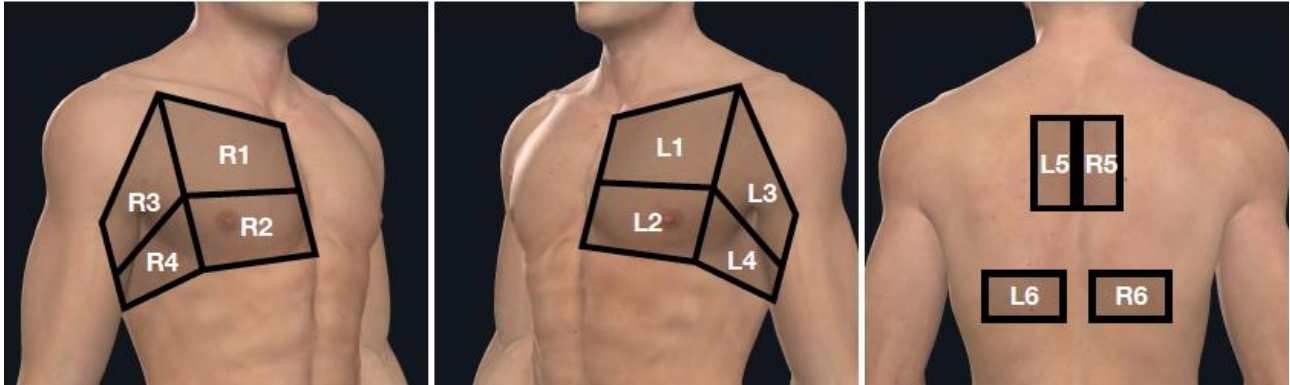
HEART

Probe → phase array (lower frequency)

Scan → standard views (parasternal, apical, sub-costal)

Aim → right and left ventricular size and function; pleural effusion; size and respiratory variations of the inferior vena cava (IVC)

VENOUS SYSTEM

Probe →linear (high frequency)

Scan → groin and popliteal fossa views and other views at different levels of thigh and leg, arms and neck

Aim → collapsibility of veins and identification of any hypoechoic matter within the vascular lumen

The examination may be performed with ultrasound machines of different technological levels (high, medium and even low-resolution) since it does not require high resolution. Bidimensional (2D) acquisition is sufficient, i.e. M-mode or Doppler are not mandatory.

If available, adequate pre-set for lung parenchyma is advisable in order to increase the quality of the images.

Avoidance of probe contamination is recommended/mandatory and it can be achieved by placing the probe into plastic gloves or in a probe cover or by sheathing the probe with cling film.

Probe covers must be opportunely disposed of between different patients, and probes must be appropriately cleaned and sanitized (according to product instructions and published scientific evidence). [2]

When available, wireless probes or palmar ultrasound machines should be preferred since they are space-saving and easier to protect and to sanitize than traditional machines.

Multi-function and multi-frequency probes allow the examination of different body parts with a single probe.

If available, the recording, storing and transmission of images or video clips is advised in order to allow data collection, remote consultation/reporting and further revision of cases.

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INTERPRETATION OF PATHOLOGICAL FINDINGS

CHEST and LUNG FINDINGS

Typical presentation [3-10]
- Multiple (more than 3) or merging (white lung) vertical artefacts (B lines), more typically at the bases or posterior fields, with uneven distribution and lung sparing (normal parenchyma interposed)
- Peripheral lung consolidations of different width (large consolidation can occur) concordant with B lines distribution
- Irregular pleural lining, with interruptions and thickening. Small, subpleural consolidations of variable shapes; reduced pleural sliding, especially with extensive parenchymal involvement (heavy lung)
- The degree of involvement of the lung parenchyma can be evaluated in a semi-quantitative fashion, assigning a 0-3 score for each one of the 12 zones scanned (6 on the left and 6 on the right hemithorax)
    - 0 – normal lung
    - 1 – more than 3 B lines per field
    - 2 – merging B lines ("white lung")
    - 3 – consolidation
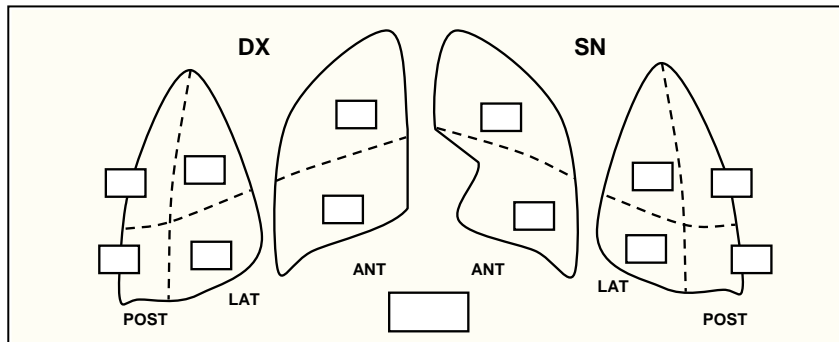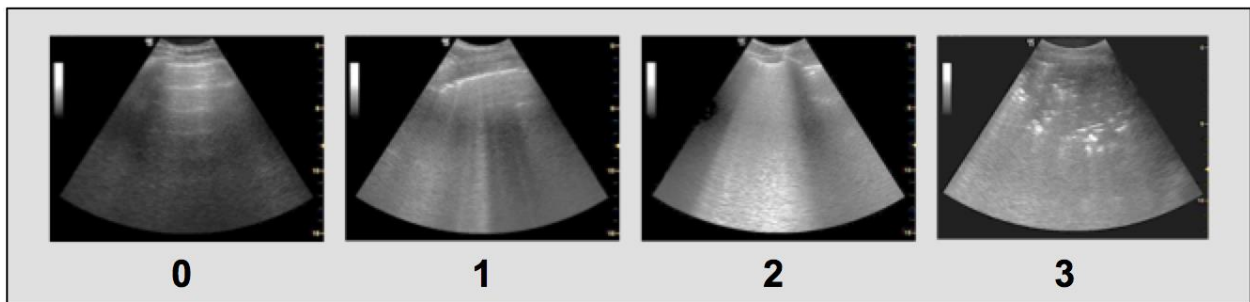
Occasional findings
- Pleural effusions
- Pneumothorax

The following findings on chest CT in patients with Covid-19 infection have been consistently reported: ground glass consolidations, pleural lining thickening, multiple consolidations, vascular engorgement with greater involvement of the posterior and basal fields. [11-15]

Ultrasound findings show high concordance with chest CT images, even though the accuracy of ultrasound images are greatly superior as compared to chest X-Ray [16-19], but CT scan remains the gold standard. Pathological findings on ultrasound correlate with CT scans in terms of distribution.

Multiple or merging vertical artefacts (B lines/white lung) represent the infectious/inflammatory interstitial involvement (with maximal peripheral distribution) and reflect the ground glass images seen on CT scan. Consolidations underlie/are the expression of alveolar involvement. The degree of alveolar and interstitial involvement correlates with functional compromise. Lung ultrasound is highly sensitive for alveolar pathological findings (superior than chest X-Ray and as sensitive as CT scan), but imaging (including CT scan) can be falsely negative in a great number of patients (up to 50%) with early-stage or minimal lung involvement. [13, 20-22]

On the other hand, pathological findings may also be found in mildly symptomatic patients, as it is the case of CT scans. [23-26]

Pneumothorax is a rare complication of positive pressure ventilatory support; its typical ultrasound findings are: absent pleural sliding, no vertical artefacts (high positive predictive value) and presence of lung point (pathognomonic feature).

CARDIAC FINDINGS
- Initially, in patients with no previous cardiac issues, the heart is normal or hyperkinetic
- Possible complications, in advanced and severe cases, are compromised right ventricular function and dilatation or reduced left ventricular function (generally without dilatation)
- IVC is usually shows normal or reduced caliber, with a possible subsequent dilation with reduced respiratory variation
- Increased right ventricular mass is also occasionally seen

The initial findings in the heart and IVC are usually secondary to reduced pre-load as the consequence of fever, dehydration and hyperventilation.

Right ventricular dysfunction, namely acute cor pulmonale (i.e. dilated and hypokinetic right chambers, with greater involvement of medial segments) is secondary to the pathological increase in right ventricular after-load (impending ARDS); in some cases acute cor pulmonale is due to pulmonary embolism (sometimes with visible, in-transient thrombi in the right chambers) or to ventilation modality (elevated PEEP). IVC dilation, with reduced respiratory variations, is often associated with dilatation of the right ventricle.

IVC findings must be interpreted according to the ventilatory support in use (NIV, CPAP, invasive ventilation). Left ventricular dysfunction with severe hypokinesia, often without dilatation, is a typical finding in fulminant myocarditis, often associated with arrhythmias (atrial fibrillation) and markedly increased cardiac markers (troponin). [27, 28]

VENOUS FINDINGS
- Non-compressible veins

- Hypoechogenic matter in the vascular lumen

Such findings in the veins draining the upper/lower limbs or the neck are secondary to venous thrombosis.

MANAGEMENT

Ultrasound findings ensure a tailored approach to the patient (diagnosis, intensity of care on admission, therapeutic approach, prognostication and monitoring of the course of the disease), but has also a great impact on the organization of the health care system and other general aspects (reduction of viral transmission, time-effective management, allocation of critical resources), which are fundamental in the fight against Covid-19 infection.

DIAGNOSIS

Typical presentation

- During the epidemic phase, when patients present with acute respiratory symptoms (cough and/or shortness of breath) and/or fever, the typical ultrasound findings of interstitial lung involvement with or without consolidations, in the absence of left ventricular dysfunction, are highly predictive or Covd-19 infection
- Sensitivity of clinical picture along with the typical findings on imaging are superior to nasal-pharyngeal swabs for viral detection, as demonstrated for chest CT
- The absence of pleuro-parenchymal involvement on chest imaging can occur in the initial stages of the disease and cannot be used to rule out Covid-19 infection, as demonstrated for CT scan [1, 20 - 22]
- In the minority of patients presenting with central involvement, the sensitivity of ultrasound is inferior to that of chest CT and may underestimate the degree of lung parenchymal involvement

Complications

PE and pulmonary infarction

Pulmonary embolism should be suspected in patients presenting with rapid/sudden deterioration of respiratory or cardiocirculatory function and can be confirmed on ultrasound with the detection of deep venous thrombosis or in-transient thrombi through the right heart chambers and/or pulmonary arteries.

Right ventricular strain (dilation and hypo-/akinesia of the myocardium) is predictive of pulmonary embolism only in the case of new- and hyperacute-onset.

Hypo-/anechoic, angular-shaped consolidations with pleural implant and no bronchogram are suspicious for pulmonary infarction, warranting an emergent CTPA evaluation.

Pneumothorax

Pneumothorax can be suspected in patients with worsening gas exchange on positive pressure ventilatory support (CPAP, NIV, invasive mechanical ventilation); absence of pleural sliding and presence of "lung point" (pathognomonic) are the typical ultrasound findings.

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Myocarditis

Fulminant myocarditis complicates up to 1/3 of cases of severe Covid-19 infection [28] and is associated with a marked increase in serum troponin, presenting with severe left ventricular dysfunction on ultrasound, usually without acute ventricular dilation.

PATIENTS' MANAGEMENT

In patients with suspected Covid-19 infection with minimal or mild symptoms and without respiratory failure (both at rest and after a walking test), the identification on minor interstitial involvement on ultrasound does not contraindicate the out-of-hospital management with active monitoring (i.e. daily oxygen saturation).

In case of extensive interstitial-alveolar involvement (merging B lines or consolidations), prolonged monitoring (24-48 hours in the clinical decision unit) before discharge, even in the absence of respiratory failure, is advisable.

Decisions on admission or discharge should not be based solely on ultrasound assessment, especially when moderate parenchymal involvement is detected: correlation with the comprehensive clinical picture is fundamental. Lung function, performance status (including comorbidities) and estimation of the risk of unfavorable clinical evolution, according to course of the disease, are superior to imaging alone in estimating the need of monitoring and patients' allocation.

MONITORING

Monitoring of parenchymal involvement through the ultrasound-based scoring system, along with the assessment of ventilatory function, should be performed once or twice daily in order to ensure an accurate clinical and functional evaluation.

Left and right ventricular systolic function and pre-load status should also be monitored.

PROGNOSTIC EVALUATION

The degree of lung involvement (which can be assessed in a semi-quantitative fashion with the scoring system illustrated above) correlates with prognosis, with extensive interstitial (merging b lines, "white lung") and alveolar involvement (consolidations) predicting a worse outcome.

Other negative prognostic parameters are the spread to the antero-superior lung fields and signs of right ventricular overload.

On the other end, a reduction in terms of parenchymal involvement is predictive of positive outcome.

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THERAPY

- The detection of extensive parenchymal involvement (interstitial-alveolar), progressively broader and/or spreading to the antero-superior lung fields, may prompt the initiation of ventilatory support (CAPA, NIV or mechanical ventilation) and anti-inflammatory therapy (steroids, tocilizumab, etc.).
- In severe cases with prevailing interstitial pattern, but with no significant consolidations, a positive ventilatory support - with PEEP not exceeding 10 cmH20 - is advisable, given the reduced need for alveolar recruitment and the risk of hemodynamic compromise
- Higher rates of consolidations with irregular pleural lining as compared to interstitial involvement indicates a reduction in alveolar air content and compliance. In these cases ventilation applying a PEEP greater than 10 cm H_2O and pronation may be beneficial [29]
- During invasive ventilation, ultrasound has been proven useful to detect the degree of alveolar recruitment in correlation with the ventilation settings. During weaning, ultrasound may also help in predicting the likelihood of success of spontaneous breathing attempts
- Pre-load and volume assessment through IVC and right chambers ultrasound evaluation may prove useful in guiding fluid management (fluid administration and diuresis)

GENERAL ASPECTS and HEALTH CARE MANAGEMENT

Ultrasound not only improves the management of patients with possible or proven Covid-19 infection, but also leads to some broader advantages in terms of management and organization of the health care system. Benefits are related to the access of the general population to hospital facilities, time-effective processing of patients, adequate allocation of resources and reduction of the likelihood of viral transmission.
Ultrasound carries several positive aspects:
- Feasible in multiple locations, both in- and out-of-hospital, as well as in remote areas with shortage of human and/or technical resources
- Low-cost
- Avoids the exposure to ionizing radiation
- Ensures time-effective diagnosis
- Lowers the number of health care providers involved, reducing the chances of Covid 19 transmission
- Reduces the mobilization of infected patients, reducing the chances of Covid 19 transmission
- Meets the criteria for mass casualty management (imbalance between available resourced and patients' needs) [29]

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