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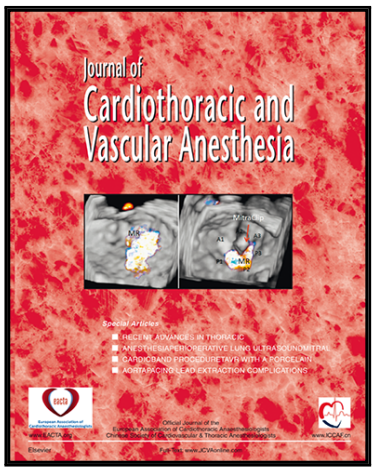

Chinese Association of Anesthesiologists Expert Consensus on the Use of Perioperative Ultrasound in Coronavirus Disease 2019 Patients

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Perioperative ultrasound has been widely used in the field of anesthesiology due to its simplicity, rapidity, practicality, low cost, absence of radiation and reproducibility. Point of care ultrasound has become an indispensable tool for anesthesiologists to evaluate cardiopulmonary status, guide procedures and manage emergencies. [1, 2] Coronavirus Disease 2019 (COVID-19) has become a public health emergency of international concerns[3] and perioperative ultrasound has played important roles in the evaluation and management of COVID-19 patients in China. Chinese Society of Anesthesiology aims to provide expert consensus from our clinical experiences in China on comprehensive applications of point of care ultrasound in the care of COVID-19 patients for anesthesiologists worldwide.

All providers should practice meticulous precautions against COVID-19 infections during performance of perioperative ultrasound. The ultrasound equipment, including an ultrasound transducer, should be protected from contamination using plastic covers and disinfected routinely and systemically.

1. Lung Ultrasound for COVID-19 Patients

In recent years, lung ultrasound has gradually gained popularity in anesthesia practices.[4] COVID-19 patients suffered from severe lung injuries, and the pathological changes included bronchiolitis and alveolitis, which were accompanied by epithelial cell proliferation, atrophy and exfoliation.[5] In addition, extensive pulmonary interstitial fibrosis, hemorrhagic pulmonary embolism and massive

inflammatory cell infiltration were also observed.[5] The average diameter of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is about 120nm, so it is speculated that the virus particles can be inhaled into the airway and lungs, even into the alveoli. This may explain why the lesions of SARS-CoV-2 viral pneumonia are mainly in the subpleural areas. Because COVID-19 generally begins in the terminal alveoli, which are close to the pleura, pathologies can be clearly observed by lung ultrasound.[6] In addition, strict infection control requirements for COVID-19 patients make transport to radiology suites complex and carry high risks of severe hypoxemia. Lung ultrasound has become an important diagnostic tool to rapidly assess of the severity of SARS-CoV2 pneumonia/acute respiratory distress syndrome (ARDS) at presentation, to track the progression of disease, to monitor lung recruitment maneuvers, to evaluate responses to prone position, to guide and manage extracorporeal membrane oxygenation therapy, and to make decisions related to weaning the patient from ventilatory support. [7]

1.1 Lung Ultrasound Examination Procedure

In general, the convex array probe is the probe of choice, while the high-frequency linear array probe is appropriate to monitor pleural or subpleural lesions. Patients are usually examined in the supine position, with the probe perpendicular to the ribs. The anterior axillary line and the posterior axillary line divides the lung of each side into three areas, the anterior, the lateral and the posterior area. Each area is further divided into two regions by the nipple line, the upper region and the lower region. All 12 lung

areas should be examined comprehensively. It should be noted that there may be a blind spot in the posterior areas due to the shadowing from the scapula.

1.2 Characteristics of Lung Ultrasound in COVID-19 Patients

The characteristics of lung ultrasound in COVID-19 patients might vary significantly from patient to patient or from day to day due to different stages of the disease, the severity of the lung lesions, secondary lung lesions caused by dysfunction of other organs, iatrogenic lung lesions, and pre-existed cardiopulmonary diseases. The predominant pattern is of varying degrees of interstitial syndrome and alveolar consolidation, the degree of which is correlated with the severity of the lung injury. COVID-19 lung lesions usually involved the subpleural area, thus abnormalities could be identified easily on lung ultrasound. [6] In rare cases, the lung lesions only affect deep lung tissues and could not be diagnosed by lung ultrasound and chest CT should be reserved for these cases when ultrasonography cannot answer the clinical question.

The ultrasonic manifestations of the lung lesions in COVID-19 patients are [6,7]: 1. thickening of the pleural line with pleural line irregularity; 2. B lines in a variety of patterns including focal, multi focal, and confluent; 3. consolidations in a variety of patterns including multifocal small, non-translobar, and translobar with occasional mobile air bronchograms; 4. appearance of A lines during recovery phase; 5. pleural effusions are uncommon. (Figure 1) The observed patterns occurred across a continuum from mild alveolar interstitial pattern, to severe bilateral interstitial pattern,

to lung consolidation. [6, 7] Lesions are mostly located in the posterior fields of both lungs. Multiple discontinuous or continuous fused B lines (waterfall sign) under the pleural line were visible or diffused B lines (white lung sign), and the A lines disappeared. Compared with the B lines caused by cardiogenic pulmonary edema, the B lines here were more likely to be fused and fixed. [8] The B lines had blurred edges and no bifurcation signs. The origination point of the subpleural lesion was more obtuse (convex array probe) compared with that of B lines of pulmonary edema. High frequency ultrasound could further show that the pleural line was unsmooth, rough, and interrupted mainly due to the decreased gas content and sound wave reflection in the subpleural alveoli and interstitial lesions.

Multiple small patchy consolidations were observed in the subpleural lesion, and strip consolidation. The echogenicity in the lesions was homogeneous or inhomogeneous, and air bronchogram sign was visible (mostly early and progressive stages because secondary pulmonary lobules were involved by interstitial inflammation, the interstitial tissues were thickened and swollen, some bronchioles and alveoli were not involved by high gas content) or air bronchogram sign (visible in severe cases or local consolidation, possibly because local inflammation storm caused the consolidation and edema of most bronchioles and alveoli, and only large bronchi and part of the alveoli were not involved. When symptoms improve, ultrasound showed irregular nodule subpleural echo shadow, with fused B lines in fixed position, localized pleural thickening and local pleural effusion around the subpleural lesion.[6]

In patients with pneumothorax, the pleural sliding sign will disappear, and the lung point sign will be present. [9]

CDFI ultrasound showed low blood flow signals in subpleural consolidation, possibly due to the pathological nature and progression of lesions in COVID-19. This is in contrast to pulmonary consolidation caused by common inflammation which generally shows abundant blood flow signals. [6]

1.3 Application of Lung Ultrasound in Anesthesia Management of COVID-19 Patients

1.3.1 Preoperative: Lung ultrasound can be used to diagnose the etiology of hypoxemia, manage the ventilator settings and evaluate fluid status in COVID-19 patients. Ultrasound can evaluate the lung conditions before the surgery to decide whether a patient is optimized along with other diagnostic modalities. Pleural effusion, pneumothorax and other pathologies could be promptly managed by a chest tube if indicated. If lung consolidation exists, lung recruitment maneuvers could be attempted to improve oxygenation under ultrasound guidance. If airway obstruction is suspected, endotracheal tube suctioning or fiberoptic bronchoscopy could be performed.

1.3.2 Intraoperative & Postoperative: Lung ultrasound can help to select the best surgical position. For example, COVID-19 patients with poor oxygenation might

benefit from prone position if possible, and lung ultrasound can help to monitor the status of lung status with position changes. [10] In addition, lung ultrasound is useful to identify patients at high risk for hypoxemia and atelectasis during and after surgery. [11-13] For these patients, restrictive fluid management, low tidal volume (<below 6ml/kg ideal body weight) and low plateau pressure (<30cmH_2O) protective mechanical ventilation should be adopted.

2. Ultrasound and Airway Management of COVID-19 Patients

The symptoms of COVID-19 include dyspnea and hypoxemia with bilateral diffuse alveolar injury. [5] Airway management is an important part of rescuing these critically ill patients. Timely invasive mechanical ventilation with endotracheal intubation will directly affect the prognosis of COVID-19 patients. Airway ultrasound is helpful to predict difficult airway at bedside, verify correct positioning of endotracheal tube, assist ultrasound guided tracheotomy and evaluate readiness before extubation.

2.1 Ultrasound Airway Evaluation

It is critical to evaluate the airway before any intubation. However, for critically ill COVID-19 patients, traditional methods such as Mallampati classification, mouth opening, interincisor gap, thyromental distance, and mandibular protrusion are difficult to perform due to infection control gears on the patient. The thickness of neck soft tissue on the anterior aspect of trachea, neck circumference, hypomental distance ratio, the width of tongue and lateral pharyngeal wall can be easily measured by

bedside ultrasound to predict difficult airways. [14] Multiple layers of personal protective equipment make lung auscultation impossible in COVID-19 patients and anesthesiologists must rely on end tidal CO2 and airway ultrasound to verify the presence of endotracheal tube artifacts in the trachea, not the esophagus. [15]

2.2 Ultrasound Guided Tracheotomy

Tracheotomy plays an important role in the care of critically ill COVID-19 patients because many patients require prolonged mechanical ventilation before their lungs eventually recover. Although tracheotomy is considered minimally invasive, the blind technique could reduce the success rate and increase tracheal and adjacent tissue injuries. Ultrasound-guided tracheotomy could improve the success rate of locating the trachea and significantly shorten the procedure, which is particularly beneficial in critically ill COVID-19 patients with severe hypoxemia. [16]

2.3 Ultrasound Assisted Weaning from Mechanical Ventilation and Extubation

When respiratory failure occurs in COVID-19 patients, mechanical ventilation is inevitable. However, prolonged endotracheal intubation leads to tracheal mucosal damage, edema and granuloma formation. Premature extubation is also detrimental and increase re-intubation rate and mortality. During mechanical ventilation weaning, ultrasound should be used to evaluate the status of lung, diaphragm and chest walls to guide the progress of spontaneous breathing.[17] Lung ultrasound can also be used to predict extubation risks and there is a high possibility of having complications after

extubation if the lung ultrasound score is greater than 17. [18, 19] Such COVID-19 patients should remain intubated after surgery, and transported to ICU directly.

3. Ultrasound Guided Regional Anesthesia

When providing anesthesia to COVID-19 patients, anesthesiologists must wear multiple layers of heavy personal protective equipment and pose many unforeseen challenges. Airway manipulation poses the greatest infectious risks to anesthesiologists and all the healthcare providers in the operating rooms through aerosol generation. [20] Ultrasound-guided peripheral nerve block, epidural or spinal anesthesia could avoid airway manipulations, reduce transmission risks and improve respiratory functions in COVID-19 patients. [21] Regional anesthesia should be preferred whenever possible[21]. The ultrasound equipment, including an ultrasound transducer, should be protected from contamination using plastic covers. Spinal anesthesia is not contraindicated in COVID-19 patients and early epidural analgesia is recommended to reduce the need for general anesthesia for emergent cesarean delivery[22].

The hand sensation for landmarks will be severely compromised by wearing multiple layers of protective equipment and gloves. Real-time ultrasound-guided spinal or epidural anesthesia should be performed if possible due to its high success rate[23]. Attempts should be made to choose the block that is least likely to interfere with respiratory function. In other words, axillary or infraclavicular brachial plexus block

should be chosen over supraclavicular brachial plexus block, and superior trunk block or other alternatives are preferred over interscalene block. [21] Ultrasound guidance makes these peripheral nerve blocks safer, easier and quicker. (Figure 2) In addition, these blocks should be performed with ultrasound guidance to reduce the risk of local anesthetic systemic toxicity. It may be advisable to choose a block that does not require patient repositioning over those that require repositioning if appropriate. Ultrasound guided transverse abdominis plane block, ilioinguinal block may provide excellent postoperative analgesia in respiratory compromised COVID-19 patients. [21, 24]

4. **Perioperative echocardiography in COVID-19 Patients**

There is an association between preexisting cardiovascular disease and severe COVID-19 and patients with cardiovascular comorbidities suffer higher mortality rate.[25] Myocardial injury, myocarditis, acute coronary syndromes, cardiac arrhythmia, cardiomyopathy and cardiac arrest are common sequelae and could certainly happen perioperatively in COVID-19 patients. [25-27] Bedside echocardiography is an invaluable tool to monitor the cardiovascular functions of COVIS-19 patients perioperatively.

4.1 Recommended Views for Transthoracic Echocardiography

Transesophageal echocardiography is an aerosol-generating procedure and should be avoided if possible, to reduce infections. Transthoracic echocardiography should be

used instead. Parasternal long axis, parasternal short axis, apical 4 chamber, 2 chamber and 5 chamber views, sub-xiphoid views and inferior vena cava measurements with and without color Doppler should be obtained and stored.

4.2. Evaluate Hemodynamic Status with Echocardiography in COVID-19 Patients

The main factors affecting hemodynamics include cardiac preload, pump function and cardiac afterload. Preload parameters include left ventricular end-diastolic volume, left atrial pressure estimation, inferior vena cava diameter and respiratory variation. Left ventricular systolic function include ejection fraction by M mode, modified Simpson method, left ventricular outflow tract time-velocity time integral, and three-dimensional calculations. Left ventricular diastolic function is assessed with the E and A waves of mitral valve diastolic blood flow, the tissue Doppler E 'and E' / E ratio. Right ventricular systolic function can be measured with right ventricular fractional area change, tricuspid plane annular systolic exertion, right ventricular wall strain and strain rate, and three-dimensional method.

4.3. COVID-19 Specific Echocardiography

Hemodynamic disorders in COVID-19 patients could be from septic shock, hypoxemia, deterioration of pre-existing cardiovascular diseases or innate myocardial damage from SARS-CoV2. [5] Patients with COVID-19 may not have completed an echocardiography before surgery. If the patient has a history of cardiovascular disease

or the patient is currently hemodynamic unstable, a focused bedside echocardiography should be performed in the operating room to assess the structure and function of the heart, guide the volume replacement and cardiac medications use during surgery.

The incidence of hypotension seems to be high in parturient with COVID-19 undergoing caesarean section under neuraxial anesthesia. [28] Evaluation of the volume status with echocardiography is crucial to avoid congestive heart failure, respiratory dysfunction and organ hypoperfusion.

In conclusion, perioperative point of care ultrasound is a useful tool in COVID-19 patients to assess the cardiopulmonary function, manage the airway, and guide procedures. Proper application of perioperative ultrasound could improve safety and prognosis of COVID-19 patients.

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Figure Legends

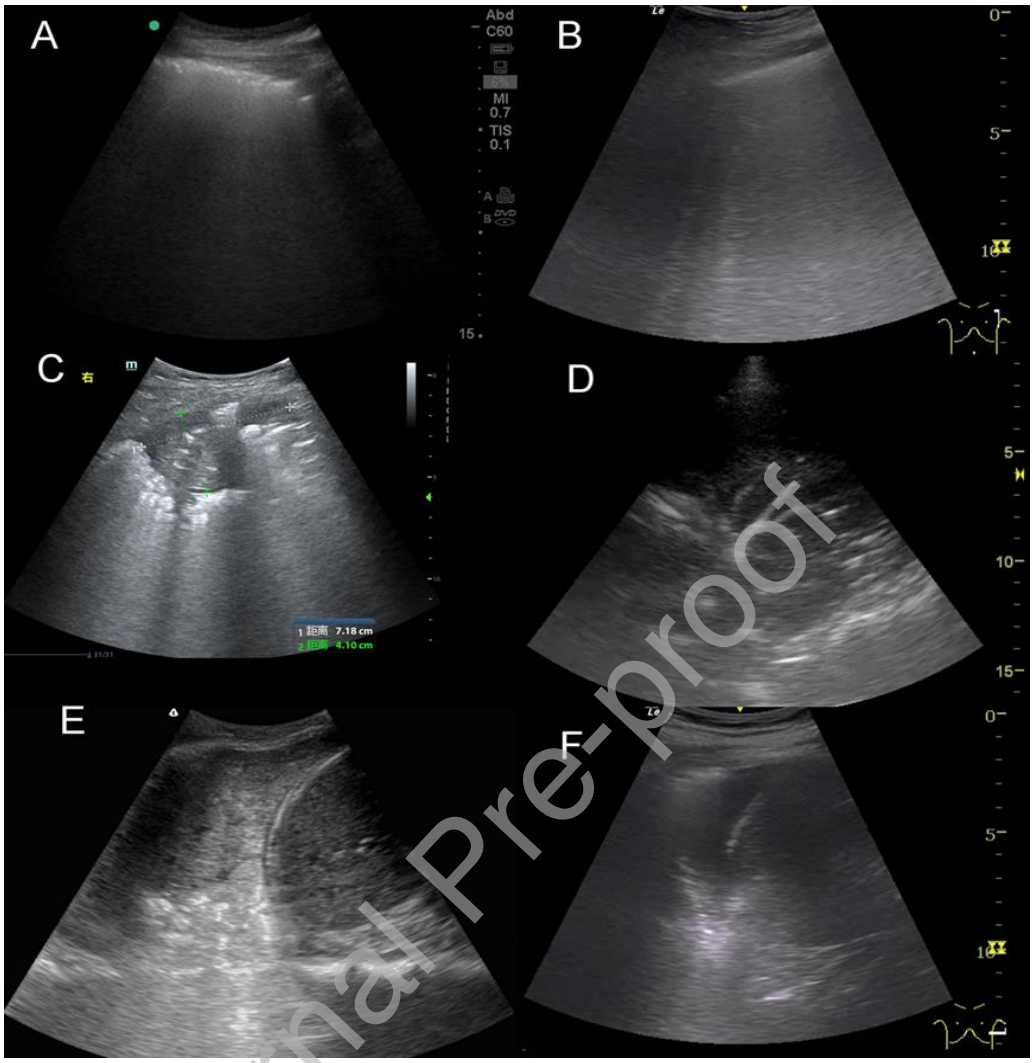

Figure 1: Typical lung sonographic findings in Coronavirus Disease 2019 patients.

A. Thickened pleural line with pleural irregularity; B. B lines; C. Consolidations; D. Ari bronchograms; E. Tissue like changes; F. Pleural effusion.

Figure 2: Two anesthesiologists performed ultrasound guided popliteal nerve block for a Coronavirus Disease 2019 patient