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Lung ultrasound score as an indicator of dynamic lung compliance during veno-venous extra-corporeal membrane oxygenation

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Abstract

Decisions on weaning from veno-venous extra-corporeal membrane oxygenation (VV-ECMO) requires the ability to maintain adequate gas exchange and work of breathing with reductions in ECMO pump flow and fresh gas flow. Testing of the readiness to wean the patient from ECMO however may vary dependent upon local protocols and clinical judgment. This study sought to validate the use of the LUS-score during VV-ECMO against the changes in chest x-ray infiltrates, dynamic lung compliance (CLdyn) and VV-ECMO settings (as standard measures of native lung function and the level of ECMO support) during the ECMO cycle. This prospective cohort study of 10 patients on VV-ECMO compared the LUS score (range 0–36) within 48-h, day 5 and day 10 of commencement of ECMO (or on the day of ECMO decannulation) to dynamic lung compliance, Murray Lung Injury Score and ECMO settings. Seven Male and three Female patients were included (average age 37 years (SD 14.8) and weight 71 Kg (SD 16.9). Median (IQR) duration of ECMO, ICU and hospital length of stay was 7.5 days (5.2–19.0), 12.5 days (8.5–22.7), 19.0 days (12.1– 36.1), respectively. There was a strong negative association between LUS-score and dynamic lung compliance ($r_s(33) = -0.66$, $p < .001$) providing some validation on the use of the LUS score as a potential surrogate measure of lung aeration and lung mechanics during VV-ECMO weaning.

Keywords

Ultrasound, oxygenation, lung compliance, ECMO

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Introduction

The definition of acute respiratory distress syndrome (ARDS) includes new or worsening respiratory symptoms within 1 week of a known medical insult, with bilateral opacities on the chest x-ray or CT scan not explained by effusions, or nodules and the respiratory failure not explained by cardiac failure or fluid overload.[1] Severe ARDS (PaO2/FiO2 ⩽100) that is refractory to conventional mechanical ventilation and medical therapy, may necessitate the initiation of veno-venous extra-corporeal membrane oxygenation (VV-ECMO).[2] The portable chest x-ray is often used for the detection and tracking of recovery of bilateral pulmonary infiltrates associated with ARDS, but is substandard assessment tool when compared with the CT scan.[3] The weaning of VV-ECMO support, relies on the routine assessment of recovery of native lung function through information provided from the daily portable chest x-ray, in addition to lung mechanics and the ability for the patient to have sufficient oxygenation/ventilation with reducing ECMO support (extracorporeal blood flow and sweep gas flow).[4] Sweep gas flow is normally

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then "trialed off" and if the patient is able to maintain adequate gas exchange and work of breathing, then de-cannulation from ECMO may proceed.[4] Testing of the readiness to wean the patient from ECMO however, may vary dependent upon local protocols and clinical judgment. The poor diagnostic accuracy of the chest x-ray to differentiate radiological opacification,[3] may hamper clinical decision-making about the tracking of native lung recovery, which may delay weaning from VV-ECMO support. Considering the potential risks associated with the transport of a patient on VV-ECMO to CT scan, there are alternative bedside options to evaluate lung aeration.

Lung ultrasound (LUS) has greater diagnostic accuracy compared with the chest x-ray for the key acute parenchymal and pleural pathologies in the general intensive care patient.[5] In addition, LUS is also reproducible, sensitive, and specific tool, which allows for bedside detection of the morphologic patterns in ARDS compared with CT scan as the reference standard.[6] A LUS-score (a numerical score with a total score from 0 to 36, the higher the score the worse the lung aeration) can be generated to report on the extent of lung aeration present.[7] A recent pilot study of five cases on VV-ECMO reported on the dynamic changes in the LUS-score during the cycle of ECMO,[8] with four patients weaning from ECMO having a LUS score of 15 at the time of de-cannulation. In addition, the time course changes in lung compliance can assist in identifying the evolution of respiratory mechanics of the natural lung in ARDS during VV-ECMO.[9] There is a paucity of evidence reporting on the optimal tools to be used as weaning strategies from VV-ECMO. However, improvements in tidal volume/minute ventilation and dead space may better reflect readiness for weaning from ECMO.[4]

This study sought to validate the use of the LUS-score during VV-ECMO against the changes in chest x-ray infiltrates, dynamic lung compliance (CLdyn) and VV-ECMO settings (as standard measures of native lung function and the level of ECMO support) during the ECMO cycle.

Methods

Prospective cohort study of 10 patients on VV-ECMO in a single high-volume center with written informed consent from patients next of kin (St Vincent's Hospital Research Ethics Committee number HREC/17/SVH/118). The daily chest x-ray was reported by the intensivist (blinded to LUS findings) with each hemithorax divided into two zones (upper and lower zones) and the number of zones (out of four) for the presence infiltrates/opacification, pleural effusion, and/or pneumothorax with the chest x-ray score. The Murray Lung Injury Score[10] was calculated with the assumption that if there was any fresh gas flow on VV-ECMO at the time of the arterial blood gas sampling the fraction of inspired oxygen was presumed to be 100%, otherwise if the fresh gas flow was off at the time of the arterial blood gas sampling then the fraction of inspired oxygen of the ventilator was used for PaO2/FiO2 calculation.

For LUS assessment the anterior and posterior-axillary lines were used as anatomical markers, with six regions of interest on each hemi-thorax systematically analyzed (upper and lower parts of the anterior, lateral, and posterior chest wall). A LUS-score (total score ranging from 0 to 36, with higher scores indicating worsening aeration) was calculated by examining a total of 12 lung zones (two anterior, two mid, and two posterior chest regions L and R), with the score per zone ranging from 0 (normal aeration) to 3 (absence of aeration).[7,11] The clinicians including the nursing, medical and physiotherapy staff caring for the patients were blinded to the LUS-score and findings so as to not influence clinical management decisions or time on mechanical ventilation and/or VV-ECMO.

Mechanical ventilator (dynamic lung compliance CLdyn (mL/cm H20) was calculated from the mechanical ventilator displayed values with the standard formula of exhaled tidal volume /peak airway pressure—positive end expiratory pressure), arterial blood gas readings and VV-ECMO settings at the time of lung ultrasound imaging were also recorded with the patient sedated lying motionless in a supine position with head of bed elevated as clinically indicated. Weaning from VV-ECMO and from mechanical ventilation was undertaken as per intensive care standard management, without knowledge of the LUS findings. Survival data was identified from the patient medical record. LUS-score[7] was calculated up to 48-h, day 5 and day 10 of commencement of VV-ECMO (or on the day of ECMO de-cannulation) and was then compared (spearman rank order) to CLdyn, chest x-ray score,[10] and VV-ECMO settings.

Results

Seven Male and three Female patients were recruited from November 2017 to May 2019 (average age 37 years (SD 14.8) and weight 71 Kg (SD 16.9). Four patients required VV-ECMO following transplantations (1 heart and 3 lung) and six due to ARDS. Seven patients (70%) survived to ICU discharge and were weaned off of VV-ECMO. Median (IQR) duration of ECMO, ICU and hospital length of stay was 7.5 days (5.2–19.0), 12.0 days (8.5–22.7), 19.0 days (12.1–36.1), respectively. Summary patient data for the ECMO settings, mechanical ventilation settings, oxygenation, and LUS-scores up to day 10 after the initiation of ECMO are provided in Table 1.

The median (IQR) LUS score for all patients was 23.1 (17.0–26.1), with the non-survivors median (IQR) LUS score of 32.5 (17–36) not statistically significantly different to the survivors median (IQR) LUS score of 22.5 (16.7–24) ($z = -1.25$, $p = .21$). There was a strong negative association between LUS-score and dynamic lung

Table 1. Summary VV-ECMO patient data, with ECMO, average data for mechanical ventilation, lung compliance, oxygenation and LUS scores for up to 10 days from the time of initiation of ECMO.

Days since ECMO start	Pump flow	Sweep flow	PEEP	Vent FiO2	TV	CLdyn	DP	PF ratio	LUS score	Murray LIS	Number of patients
Day 1	3.4	5.1	9.6	0.5	159.3	10.8	13.9	99.8	23.0	3.2	10
Day 2–5	3.4	4.7	10.4	0.5	234.2	17.4	14.2	140.5	25.5	2.9	10
Day 6–10	3.5	4.1	9.2	0.5	176.0	36.9	13.3	170.0	24.8	2.8	6

Day: day from commencement of ECMO, TV ventilator tidal volume; DP: ventilator driving pressure (PIP-PEEP); FiO2 (V): fraction of inspired oxygen—ventilator; Ppeak: peak airway pressure ventilator; CLdyn: dynamic lung compliance (ml/cm H_2O); P/F ratio: partial pressure of arterial oxygen to inspired fraction of oxygen ratio (mmHg); MurrayLIS: Murray lung injury score; Pump flow: pump flow from ECMO (L/Min); Sweep flow: ECMO sweep gas flow (L/Min).

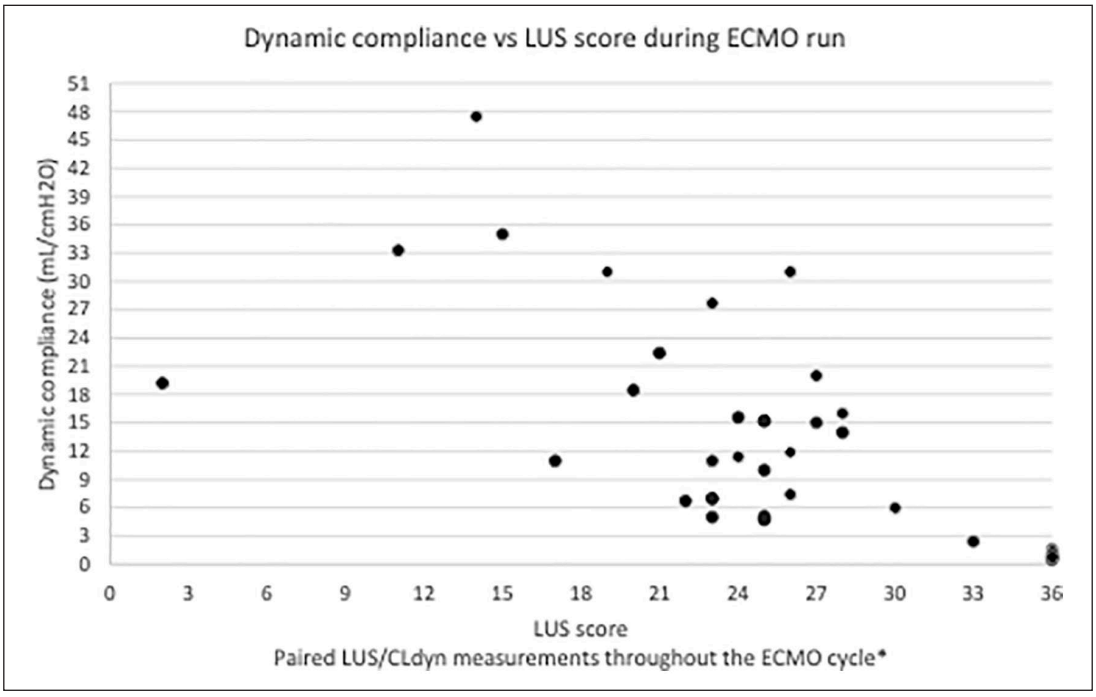

Figure 1. LUS score versus CLdyn during VV-ECMO (total of 32 paired LUS score/CLdyn measurements for 10 patients, with one measurement for patient 3 removed due to inaccurate CLdyn measurement).

compliance ($r_s(33) = -0.66$, $p < .001$, see Figure 1) and a moderate non-significant positive association between LUS-score and chest radiograph score ($r_s(32) = 0.21$, $p = .24$), and ECMO sweep flow ($r_s(32) = 0.31$, $p = .09$). There were also strong negative associations between dynamic lung compliance and ECMO sweep flow ($r_s(30) = -0.69$, $p < .001$), and a strong positive association between the Murray Lung Injury Score and ECMO sweep flow ($r_s(31) = 0.70$, $p < .001$) and moderate positive association between the chest radiograph score and ECMO sweep flow ($r_s(30) = 0.54$, $p = .002$).

Discussion

This preliminary work provides some validation of the use of the LUS score in this cohort of VV-ECMO patients during the cycle of ECMO, with a strong negative association between the LUS-score and the dynamic lung compliance. The LUS score may be perceived as a surrogate measure for the changing dynamic lung compliance during the ECMO cycle and could be a potentially useful non-invasive bedside tool for clinical decision making in regards to weaning from VV-ECMO support.

The accurate measurement of static or dynamic lung compliance is dependent on the absence of any spontaneous patient breathing effort with the patient in a mandatory ventilator mode, whereas the LUS score is not dependent on the ventilator mode or patient effort. A previous small study of five patients, reported that a LUS score of less than or equal to 15 was associated with the successful decannulation of four patients from VV-ECMO.[8] Previous work has also demonstrated an absence of improvement LUS-score during VV-ECMO to be associated with increased risk of mortality.[8,12] The weak association

between the LUS score and the chest x-ray score in our current study indicates that the LUS score may be a more sophisticated signal of lung aeration not evident with the standard chest x-ray. Persistently low CLdyn and static lung compliance is associated with non-survival during VV-ECMO.[9,13] The weaning of patients from VV-ECMO support, relies on the detection of improvements native respiratory function, which is complicated by the fact that measures such as arterial oxygenation are directly influenced by the high fraction of inspired oxygen delivered during VV-ECMO and native lung function.[14] The measurement of lung mechanics at the bedside relies on the absence of patient spontaneous breathing. However, mechanical ventilator strategies during ECMO often use pressure control modes.[15] LUS can be measured independent of patient's respiratory muscle effort or ventilator mode. The routine measurement of the LUS score during the VV-ECMO support would allow the tracking of changes in native respiratory function and aeration, respectively without being affected by the levels of VV-ECMO support, ventilatory mode, and patient spontaneous breathing effort.

The limitations with this study primarily relate to the small sample size and hence the association between the LUS score and dynamic lung compliance and other associations or absence of may be a chance finding. In addition, as we measured CLdyn which incorporates the airway resistance of the patient, this compliance may be lower than the static lung compliance (CLstat),[16] and hence not truly reflect the true respiratory mechanics of the lungs. However, the predominant use of pressure control modes of mechanical ventilation during VV-ECMO both in this study and internationally,[15] may limit the bedside monitoring of CLstat. Also, as the accurate measurement of CLstat requires the patient to be deeply sedated and/or paralyzed with neuromuscular blocking agents, in a volume control mode of ventilation with constant inspiratory flow this may also restrict its bedside use.[16] In addition, in this study we did not have CT scan images as a gold standard tool, hence some pathologies located deep within the lungs may have been missed by LUS.[6]

The prospective investigation of the LUS-score during weaning of support from VV-ECMO may provide insight as to the recovery of native lung function evident with patterns of lung aeration and lung compliance, that may assist with clinical-decisions about weaning and de-cannulation from VV-ECMO support. More specifically the change in LUS score during periods with fresh gas flow on and off may determine if the LUS score can act as a surrogate for native lung function to tolerate weaning from ECMO. Its clinical use with other standard measures of weaning from ECMO needs to be determined in future trials.

Author Note

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Declaration of conflicting interests

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Trial registration

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