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Electrical Impedance Tomography As a Bedside Diagnostic Tool for Pulmonary Embolism

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BACKGROUND: Electrical impedance tomography (EIT) has been shown to be of value in evaluating the distribution of ventilation. In addition, several studies, particularly case reports, have demonstrated the use of EIT in the assessment of lung perfusion. EIT may be a potential diagnostic bedside tool in the diagnosis and follow-up of acute pulmonary embolism.

CASE SUMMARY: We present one case of a patient with COVID-19 who likely had pulmonary thromboembolism where perfusion scans were made before and after thrombolytic therapy. Perfusion scans showed improvement after thrombolytic therapy. This article should therefore be seen as a first step in proving the validity of EIT-derived perfusion scans as a diagnostic for pulmonary embolism.

CONCLUSION: The hypertonic saline bolus EIT method as a diagnostic tool for pulmonary embolism is a promising new technique, which can be particularly meaningful for critically ill patients. Further study is required to evaluate the sensitivity and specificity of this technique and the impact on decision-making and outcomes of critically ill patients.

KEY WORDS: COVID-19; pulmonary embolism; severe acute respiratory syndrome; thrombolytic therapy; tissue plasminogen activator

Electrical impedance tomography (EIT) offers clinicians bedside functional imaging of lung ventilation and perfusion. EIT is a noninvasive, radiation-free imaging method that can be done at the ICU.

EIT uses an external electrode belt placed around the patient's chest to measure changes in impedance and translate this to images reflecting lung ventilation. To evaluate lung perfusion, the saline bolus EIT method is used (1, 2). A bolus of 10 mL of 7.5% saline is administered during a respiratory hold. The change in impedance caused by the hypertonic saline is used as a proxy of lung perfusion.

Several studies have confirmed the usefulness and accuracy to optimize mechanical ventilation, for example, positive end-expiratory pressure titration and lung recruitment with use of EIT (3–5).

Using EIT to evaluate lung perfusion and the potential presence of pulmonary embolism is not yet validated. However, several studies have shown the feasibility of EIT in the assessment of lung perfusion (6–8).

In this report, we present one patient who had severe COVID-19 pneumonitis. During his ICU stay, attending physicians suspected the presence of pulmonary embolism. As multiple studies have shown, pulmonary embolism is a common complication in patients with COVID-19 infection, especially in the ones that are admitted to the ICU (9, 10). To assess the presence of macrovascular pulmonary embolism and to determine the severity of the COVID-19 pneumonitis, we routinely aim to perform a contrast-enhanced CT in every

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KEY POINTS

Question: This case report implies the usefulness of electrical impedance tomography (EIT) to evaluate the perfusion of the lungs, which can be promising, especially with critical ill patients who are too unstable to perform a CT.

Findings: Improvement of pulmonary circulation was seen after thrombolytic therapy, which improves the validity.

Meaning: The hypertonic saline bolus EIT method as a diagnostic tool for pulmonary embolism is a promising new technique, which can be particularly meaningful for critically ill patients. Further studies should be done to determine its usefulness in daily practice.

ICU-admitted patient with COVID-19. Unfortunately, this is not always possible, for example, when patients are deemed too unstable, as was the case in this patient. In such a particular case, EIT could be the solution for clinicians to still evaluate distribution of lung ventilation and perfusion.

CASE PRESENTATION

The patient was a 64-year-old man with a medical history of obstructive sleep apnea who was admitted to the ICU with respiratory failure due to COVID-19 infection. He had been admitted to the hospital 2 days earlier with complaints of dyspnea and chest pain for 5 days. Chest radiography showed bilateral consolidations as typically seen in COVID-19 pneumonitis.

On ICU admission, high-flow nasal oxygen (HFNO) therapy was started. Treatment with dexamethasone had already been started during admission at the ward. Patient had received treatment with tocilizumab, the day before ICU admission. Broad-spectrum antibiotics were given. At our institution, all COVID-19 patients admitted to the ICU are treated with therapeutic-dose anticoagulation. This patient received dalteparin 10,000 International units (IU) twice a day. During the first 8 days of his admission, the patient's respiratory status did not improve neither get worse. HFNO therapy could not be phased out; however, the patient refused intubation and mechanical ventilation. Repeat chest radiography showed progression of pulmonary consolidations. Due to high amounts of administered FiO_2, the patient could not be transported to undergo a CT scan.

On day 8 after ICU admission, we made the decision to start IV methylprednisolone pulse, 1 gram each day for 3 days. This treatment was combined with empiric treatment with anidulafungin and voriconazole since the patient was not yet intubated and too fragile to perform a bronchoalveolar lavage. During and after this treatment, his respiratory condition showed no improvement, and, in fact, the HFNO-FiO_2 had to be maximized. On day 15, the patient was exhausted and yet intubated and mechanically ventilated. After intubation, EIT was performed to optimize ventilation conditions. During measurement, a ventilation/perfusion mismatch ratio was noticed, showing a distribution of perfusion to the right lung of 22% and to the left lung of 78%. Since there was adequate ventilation of the right lung (65%), the presence of a significant perfusion defect suggested obstruction by pulmonary embolism (**Fig. 1**). Point-of-care ultrasound showed a dilated right ventricle with elevated estimated pulmonary artery pressures that strengthened the suspicion of pulmonary embolism.

At that time, the patient was deemed too unstable (FiO_2 100%) to perform a CT scan right away to confirm these findings. After having received informed consent by the patient representative, thrombolytic therapy with alteplase (10 mg bolus and 90 mg over 2 hr) was empirically given. To improve Ventilation/perfusion match, the patient was put on his right side. The day after treatment with alteplase, EIT was done in supine position, showing a significant improvement of perfusion distribution (**Fig. 2**). Set FiO_2 levels could initially be reduced to 80%. Improvement after treatment with thrombolytic therapy suggested that the patient indeed suffered pulmonary embolism. The CT scan that was performed the day after treatment with alteplase showed severe COVID-19 pneumonitis with a severity score of 25/25. However, no pulmonary embolism was seen on that scan. In the last attempt to further improve the patient's oxygenation, he was turned in a prone position and a second methylprednisolone pulse was given. Unfortunately, there was progressively increase of hypoxia and on the 19th day of the ICU admission, treatment was halted and the patient died.

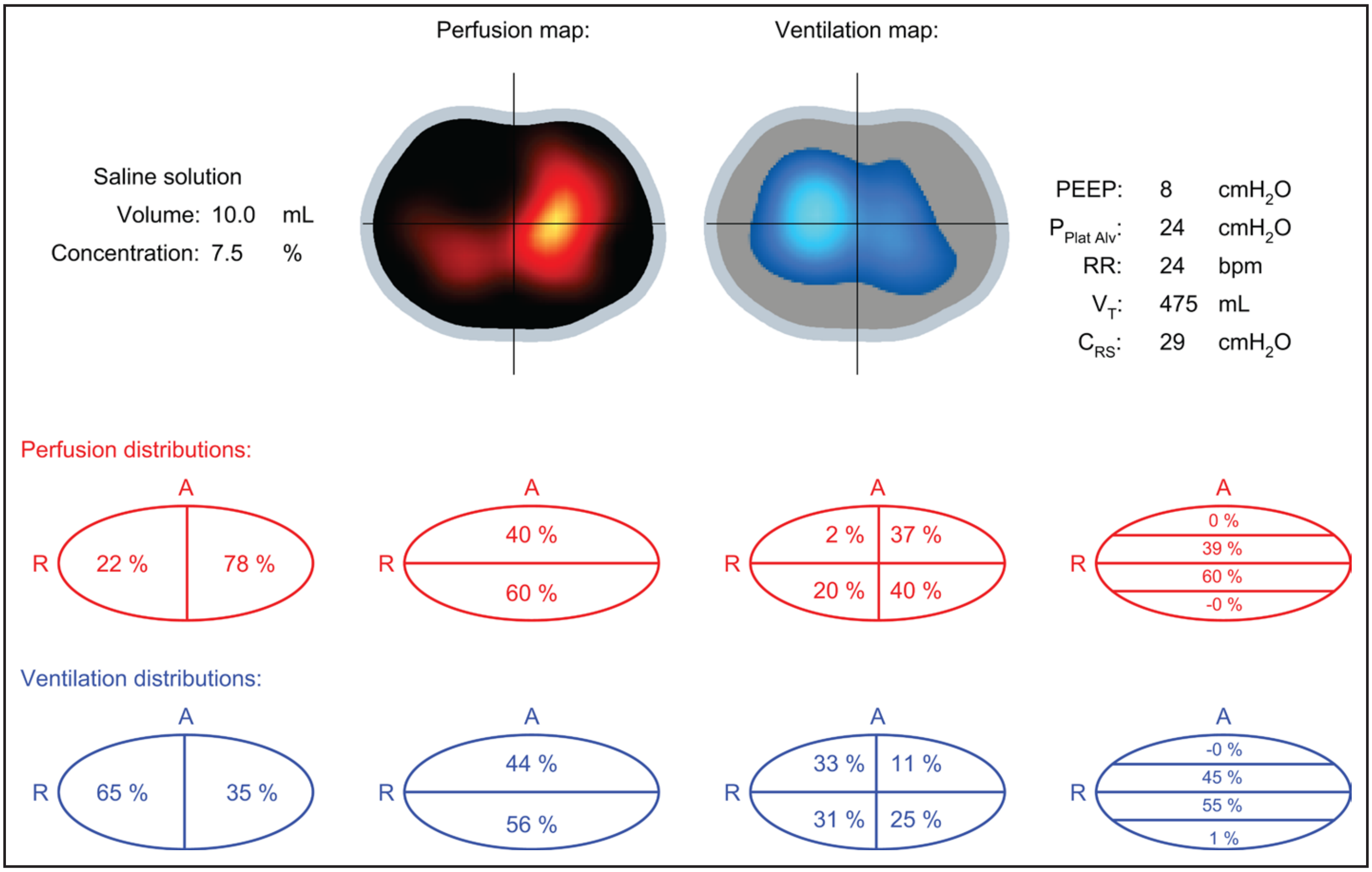

Figure 1. Electrical impedance tomography performed before treatment with thrombolysis was given. C_{RS} = respiratory compliance, PEEP = positive end-expiratory pressure, Pplat Alv = alveolair/plateau pressure, RR = respiratory rate, V_T = tidal volume.

DISCUSSION AND CONCLUSIONS

To the best of our knowledge, this is the first clinical report-to-report cases where EIT perfusion scans were made to guide the decision to start thrombolytic therapy. We demonstrate the improved control measurements. Improving perfusion after treatment may imply the efficacy of treatment with alteplase.

Our case is limited by the fact that the presence of a macrovascular pulmonary embolism was not confirmed by contrast-enhanced CT. However, this does not affect the likelihood of the presence of pulmonary embolism, given the rapid resolvement of clots following administration of alteplase, increasing the possibility of not seeing a pulmonary embolism on CT 1 day after thrombolytic therapy (11, 12). This case also presents a clinical situation in which patients can be deemed too unstable for transportation. A diagnostic tool such as EIT offers a solution in evaluating lung perfusion without risking a possibly dangerous transport to perform a CT.

In **Supplemental Figures 1–4** (http://links.lww.com/CCX/B126), we show completely anonymized images of EIT perfusion scans made before and after thrombolytic therapy in a similar case. Unfortunately, this patient's next of kin refused giving written informed consent, so we were limited by only using the images. This patient had the presence of pulmonary embolism confirmed by contrast-enhanced CT, which contributes to the validity of EIT.

Several studies describe the presence of microvascular thrombosis as part of the pulmonary syndrome caused by COVID-19 (13, 14). Microvascular thrombosis can be problematic to detect with CT. Nevertheless, microvascular thrombosis could be a therapeutic target. In a small randomized controlled trial, the early administration of thrombolytic therapy in COVID-19 was investigated (15). The study was limited by size but showed promising results, such as improved oxygenation. A diagnostic tool such as EIT may also capture perfusion defects from microvascular thrombosis and could therefore be of help in decision-making on starting thrombolytic therapy.

Our patient was fully anticoagulated according to COVID-19 treatment protocol. That makes the presence of pulmonary embolism more unlikely. However,

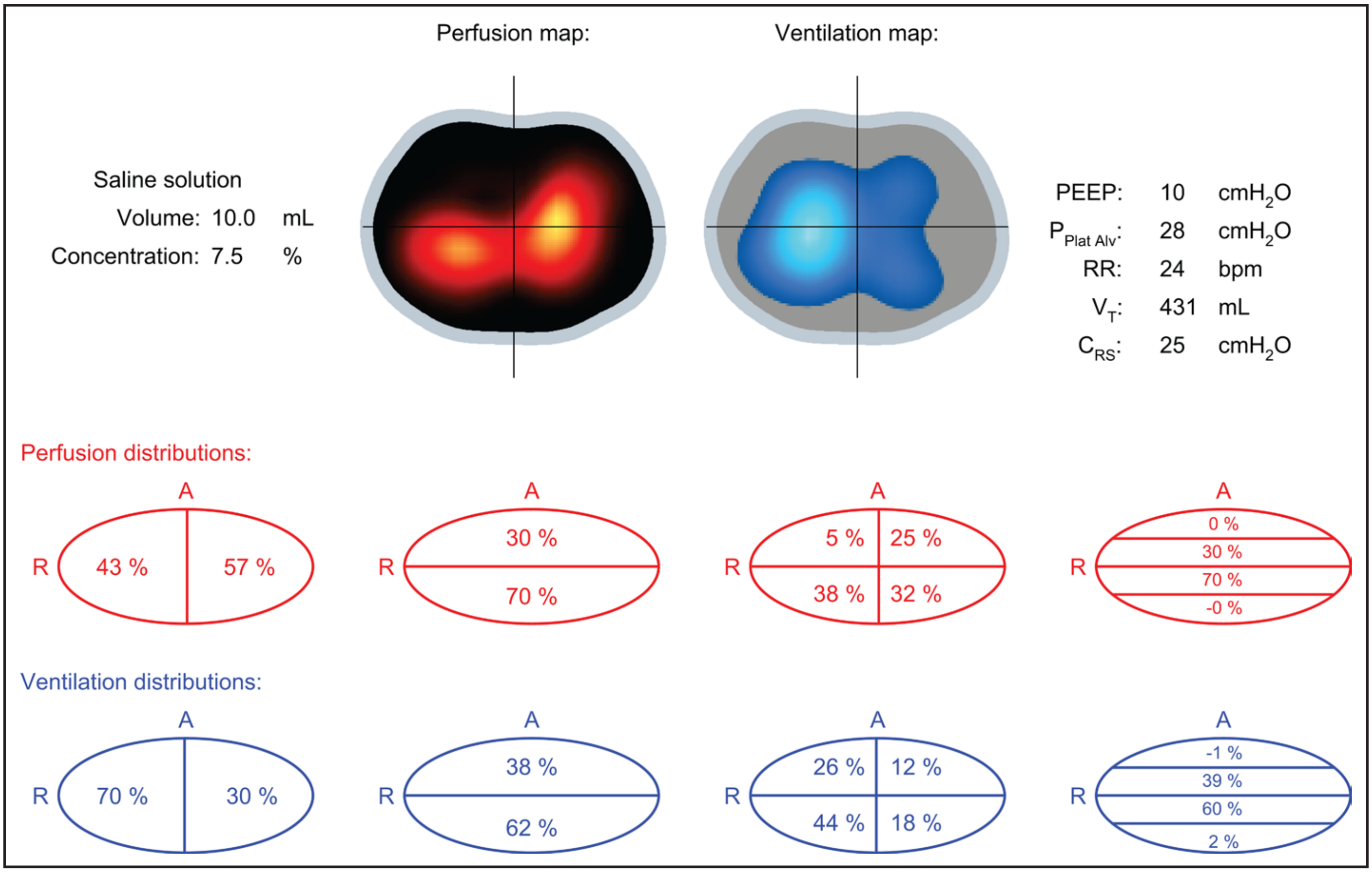

Figure 2. Electrical impedance tomography performed after treatment with thrombolysis was given. CRS = respiratory compliance, PEEP = positive end-expiratory pressure, Pplat Alv = alveolair/plateau pressure, RR = respiratory rate, VT = tidal volume.

multiple studies describe a higher occurrence of pulmonary embolism and deep vein thrombosis in patients suffering COVID-19 pneumonitis (9, 10). The occurrence of major thrombotic events remains, even when anticoagulated therapeutically (16).

Although not confirmed in our patient, treatment with thrombolytic therapy can be lifesaving but is not without risk (17). Administration of thrombolytic therapy should, therefore, only be done when physicians judge the possible benefit to be superior to the possible risk: an assessment that may be more easily made with the use of EIT.

The hypertonic saline bolus used as a contrast bolus in the saline bolus EIT method in our clinic is 7.5% saline. Literature has not reached consensus on concentration and volume of saline solution. The injections given with 10 cc of 7.5% saline, to perform the perfusion scan, could temporarily make the serum sodium level rise up to 1–3 mmol/L, based on our own calculations, which we consider to be safe. When patients suffer from hypernatremia, it should be considered to normalize serum sodium level in advance of administering the hypertonic saline.

To validate the usefulness of hypertonic saline bolus EIT, further studies are required to determine sensitivity and specificity. Further studies should ideally compare perfusion reports with CT or other modalities done at the same time. In addition, control measurements should be done at standardized time frames following thrombolytic therapy. The hypertonic saline bolus EIT method as a diagnostic tool for pulmonary embolism is, therefore, a promising new technique, which can be particularly meaningful for critically ill patients. Further studies should be done to determine its usefulness in daily practice.

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Written informed consent was obtained from patient's next of kin.

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