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Role of Thoracic Fluid Content and Echocardiography in Weaning From Mechanical Ventilation

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ABSTRACT

Weaning from mechanical ventilation is a challenging step during recovery from critical illness. Thoracic fluid content (TFC) represents the fluid component in the thorax; thus, TFC was considered to provide an estimation of the extravascular lung water in absence of significant pleural or pericardial effusion. Various measures had been previously reported for evaluation of volume status such as fluid balance and echocardiography before the SBT aiming to identify patients who would benefit from diuretic therapy to achieve successful weaning from mechanical ventilation. Nowadays, there is an increasing interest in cardiac factors, such as lung congestion and hypervolemia, as contributing elements in weaning failure and that needs expert physician. Although fluid balance and other previous measures could give us a good idea about weaning of patients from mechanical ventilation, thoracic fluid content measurement may also be beneficial and more accurate in this aspect. The electrical cardiometry-derived thoracic fluid content is measured through the impedance cardiography technology; TFC is assessed through the changes in the impedance of thoracic tissue to the electric current. Trans-thoracic echocardiography is a non-invasive tool that delivers bedside cardiac function evaluation. Echocardiography is now widely used to evaluate cardiac function during the ventilator weaning process. The aim of the present study was to review the role of thoracic fluid content and echocardiography in weaning from mechanical ventilation.

Keywords: Weaning; Mechanical Ventilation; Thoracic Fluid; Echocardiography

INTRODUCTION

Thoracic fluid content represents the whole (extravascular, intravascular, and intrapleural) fluid component in the thorax; thus, TFC was considered to provide an estimation of the extravascular lung water in absence of significant pleural or pericardial effusion **(1).**

Measurement of thoracic fluid content (TFC) using Bioimpedence is based on the theory that the thoracic cavity is an inhomogeneous electrical conductor **.**TFC is derived from the thoracic electrical base impedance which is dependent on thoracic intravascular and extravascular fluid content. Larger TFC indicates a higher total thoracic fluid volume **(2).**

Potential changes in TFC are directly proportional to total fluid changes. TFC measurement has been correlated with heart failure symptoms, net fluid balance, and chest radiographic findings of abnormal pulmonary fluid content in adults **(3).**

Similarly, measurement of TFC using a non-invasive ICON device, has shown that TFC is a good indicator of fluid status in adults undergoing hemodialysis. Recently, TFC as measured by bio-reactance technique using a non-invasive cardiac output monitor showed a good correlation with body weight gain and intraoperative fluid balance in children after Fontan surgery **(4).**

Though chest radiographs have been found to reflect temporal fluid balance changes in critically ill adult patients,TFC has been shown to detect pulmonary fluid not apparent on chest radiographs. A study by Paviotti and co- authors showed good correlation between TFC and respiratory distress in newborns **(5)**.

TFC and other indices of fluid status as measured by ICON device have not been correlated with clinical parameters of fluid status in critically ill children admitted to pediatric intensive care unit (PICU) **(Figure 1)**. TFC as measured by ICON with clinical measures of fluid status such as changes in fluid intake and output and to determine correlation between indices of fluid balance as measured by ICON and patient outcomes such as ventilator days, length of PICU stay (days) and hospital stay (days), multi- organ dysfunction and mortality. TFC ranged between 20.6 and 45.8 kOhm−1, mean 32.2, SD 5.7, median 32.7**(2).**

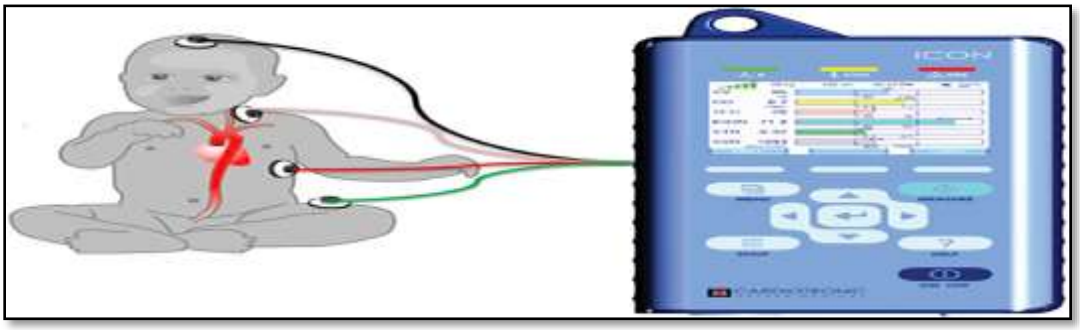

Figure (1): the placement of the electrodes on the left side of the body connected to the ICON monitor. Adopted from Icon user manual with due permission from Markus Osypka, Osypka Medical Inc, Germany (5).

Value of TFC measurement in weaning from MV:

Thoracic fluid content showed moderate predictive ability for weaning failure; this predictive ability became excellent in the subgroup of patients with impaired systolic function. Measurement of the TFC depends on the impedance cardiography phenomenon which changes according to the resistance of thoracic contents to electric current **(2).**

The presence of lung congestion is an important cause for weaning failure especially in cardiac patients . Lung congestion may also be triggered by the SBT due to the increase in the left ventricular afterload, as well as the increase in the venous return and the subsequent increase in the cardiac preload . The TFC is an index for both extra and intra-vascular thoracic fluid; however, the TFC showed good correlation with ultrasound in estimation of extravascular lung water Therefore, high TFC value could be an indirect measure of lung congestion and/or hypervolemia which is a known risk factor for failed weaning **(5).**

This assumption is supported by previous reports in which the TFC was able to follow up the hemodynamic effect of diuretics and to evaluate the thoracic fluid in patients with heart failure . The TFC was also able to follow up the change in the patient body weight and the volume of the ultrafiltrate removed during hemodialysis. The TFC showed good correlation with fluid balance during cardiac surgery **(6).**

Thoracic fluid content had been classically assessed through thoracic bio-impedance technology. In the last few years, TFC had been also measured using the newer electric cardiometry technology. The electrical cardiometry-based TFC showed useful results in evaluation of the volume status of patients undergoing autologous blood transfusion. In late preterm and term newborn, TFC correlated with the occurrence of respiratory distress in the first 24 h after birth **(7)**.

Recently evaluated TFC in pre-eclamptic mothers and reported that TFC could detect mothers with high risk for pulmonary edema. TFC was evaluated in another population, the critically ill patients, and found that the TFC could be a useful tool for detection of weaning failure in cardiac patients **(8).**

It is reported that the validity of TFC in predicting weaning failure is more significant in patients with impaired systolic function. This is most probably because the impact of lung congestion, represented in our patients by increased TFC, on weaning outcome is usually more prominent in cardiac patients. It had been found that the value of brain natriuretic peptide, as a marker of hypervolemia,in guiding weaning is restricted to cardiac patients only **(6).**

Role of Echocardiography in Weaning From Mechanical Ventilation

Ventilatory support includes non-invasive or invasive mechanical ventilation. Non-invasive positive pressure ventilation (NIPPV) has been shown to reduce the need for intubation, decrease length of stay in the Intensive Care Unit (ICU) and may reduce mortality but it requires more careful monitoring than for invasive ventilation as well as it is not suitable for all patients in need of mechanical ventilation, e.g.: unconscious or shocked patients **(9).**

Invasive mechanical ventilation entails the use of ventilator to assist the patient’s ventilation through endotracheal or tracheostomy tube. Invasive mechanical ventilation is associated with numerous life threatening complications and it should be discontinued at the earliest possible time in the course of patient’s illness **(10).**

So, weaning of patients from mechanical ventilation is one of the most challenging problems faced by physicians working in the ICU. Weaning from mechanical ventilation is the process of abruptly or gradually withdrawing ventilator support when the cause of acute respiratory failure is under resolution **(11).**

The abrupt cessation of positive pressure ventilation increases venous return and left ventricular (LV) afterload,decrease LV compliance and may even induce cardiac ischemia which may present in the form of S-T segment changes in electrocardiogram .All these factors tend to increase LV filling pressure and may subsequently result in pulmonary edema **(12).**

The reduction in oxygen delivery and subsequent hypoxemia seen in weaning may be due to worsening of ventilation perfusion ratios, or weaning induced pulmonary edema, especially in those with left heart disease. The hypoxemia and respiratory acidosis during weaning may cause reduction in oxygen delivery to the myocardium **(13).**

Echocardiography is being used routinely in some intensive care units (ICUs). It permits direct observation of all cardiac structures and the patient's hemodynamics, allowing immediate intervention related to volume replacement and the use of inotropic agents **(14).**

In patients on MV, use of echocardiography can explain some cardiac morphological and functional analyses that may influence weaning from MV, particularly when weaning is difficult or there is refractory hypoxemia that cannot be explained by lung disease alone **(15).**

Inferior Vena Cava Diameter Measurement:

Point-of-care ultrasound (POCUS) has been increasingly used in evaluating shocked patients including the measurement of inferior vena cava diameter (IVC) **(16).**

Nevertheless, there have been conflicting results regarding its value. It is important to highlight the technical and clinical difficulties that may be encountered in measuring the IVC diameter as these limit its use. There are four components that affect the outcome of ultrasound studies. These are the effectiveness and technical limitations of the ultrasound machine, the experience of the operator, the body built of the patient, and the pathology studied **(17).**

Operators should standardize their technique in scanning the IVC. IVC can be measured through different approaches including the subxiphoid or subcostal approach **(18).**

We prefer to measure the IVC directly through a trans-hepatic approach using a portable machine and a small print convex array probe with a frequency of 3-5 MHz while the patient is in supine position. The probe is located in the mid-clavicular line between the ribs of the right lower chest wall at 90 degrees perpendicular to the skin. The marker points proximally towards the head **(Fig.** 2**).** The probe may be slightly directed towards the right to be parallel to the IVC. The probe is then shifted slowly transversely to get the best longitudinal perpendicular view. We think that this is better than the subxiphoid approachas the IVC is located slightly to right and the diameter of the IVC may be overestimated by getting an oblique section **(19).**

Figure (2): Technique to measure the inferior vena cava diameter longitudinally. A small print convex array probe with a frequency of 3-5 MHz is located in the mid-clavicular line at 90 degrees perpendicular to the skin. The marker is pointing proximally towards the head (arrow) (19).

The ultrasound cross section should be vertical to the IVC. Common pitfalls in measurement include measuring the IVC obliquely or peripherally **(Fig. 3).** In general, it is advised to use the B mode to evaluate the gross collapsibility of the IVC and the M mode to accurately measure the changes in IVC diameter. The IVC can be measured in both longitudinal and transverse sections **(19).**

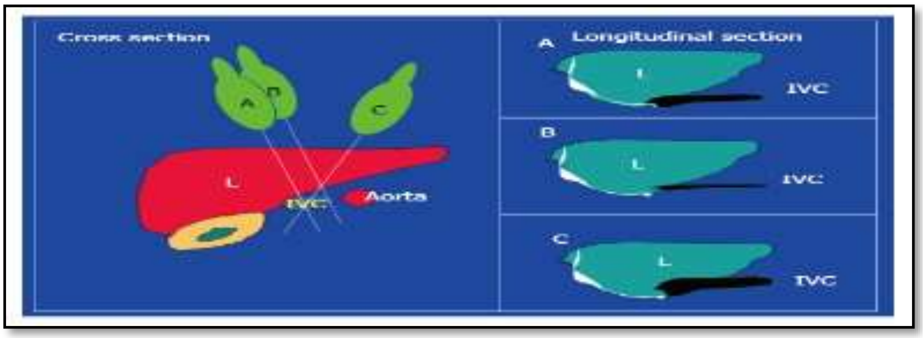

Figure (3): Common pitfalls in measurement include measuring the IVC obliquely or peripherally (19).

Cross section of the abdomen on the left side of the figure showing the liver, inferior vena cava, and aorta. The B mode longitudinal ultrasound image will depend on the angle between the plane of the ultrasound section and the IVC. Three different planes are shown on the cross section (A-B-C) and the corresponding longitudinal IVC images are shown to the right. Longitudinal section A is the proper one as it crosses the IVC vertically at the midpoint. Section B crosses the IVC vertically but peripherally and gives a false low measurement of the IVC diameter. Section C crosses the IVC obliquely and gives a false high IVC diameter measurement. IVC: Inferior vena cava **(19).**

Pitfalls in measuring IVC include increased intra-thoracic pressure resulting from mechanical ventilation or increased right atrial pressure resulting from heart failure or pulmonary embolism. These conditions will increase the diameter of the abdominal IVC **(20).**

We have recently reported that IVC diameter was not useful in guiding resuscitation, and was even misleading in abdominal compartment syndrome. The increased pressure in abdominal compartment syndrome will compress the IVC and reduce its antero-posterior diameter **(21).**

The unexperienced clinician may increase the fluid resuscitation which would further decrease the diameter. Furthermore, direct pressure on the IVC as in late pregnancy and acute gastric dilatation can affect the measurement. The IVC diameter should be combined with focused echocardiography and correlated with the clinical picture as a whole to be useful **(17).**

IVC measurement can be used as part of defined protocols in diagnosing shocked patients to optimize its value. These protocols evaluate the heart, IVC, chest, and the abdomen to try defining the cause of the shock. This group follows the RUSH protocol which examines the pump (heart), tubes (great vessels) and reservoir (free intra-peritoneal or intra-thoracic fluid) **(22).**

The same principles but in a different approach, whereby they classify the shocked patients into those with reduced mean systemic venous pressure; increased right atrial pressure; and increased resistance to the venous return. They study the size of IVC, respiratory variation of the IVC, and the hepatic venous flow to define the type of shock **(19)**.

Trans Mitral To Mitral Annular Early Diastolic Velocity Ratio(E\Ea or E/E' ratio):

Patients with chronic kidney disease (CKD) associated with cardiovascular disease (CVD) have a higher risk of death than the general population .Heart failure (HF) associated with CKD increases the risk of death, and these patients have a poor prognosis **(23).**

Therefore, in patients with CKD, HF needs to be diagnosed and treated early. In general, the level of B-type natriuretic peptide (BNP), which reflects an increase in the volume of the left ventricle, is elevated in patients with CKD or end-stage renal disease (ESRD), often in the presence of normal cardiac function **(24)**.

This means that BNP cannot be used as an accurate marker for the diagnosis of HF in patients in whom the left ventricular (LV) ejection fraction (EF) is preserved. Presently, the ratio of early diastolic mitral inflow velocity to early diastolic mitral annulus velocity (E/e' ratio) is used for the evaluation of LV filling pressure, and it has been used as a marker to diagnose diastolic HF **(25)**.

In hypertensive patients with elevated E/e' ratio the annual mortality rate is 10% and the ratio is considered to be a prognostic factor for the development of CVD. However, with respect to the different degrees of CKD associated with HF, studies on the usefulness of the tissue Doppler E/e' ratio as a predictive factor for the development of CVD and mortality have not been conducted **(18)**.

Measurement of E/Ea ratio:

Two-dimensional echocardiography was performed according to the recommendations of the American Society of Echocardiography. EF was measured using the two-dimensional M-mode method, and the left arterial volume was measured using the cylinder method with two orthogonal apical views. A patient with EF > 50% was assigned to the 'normal' group, while a patient with EF < 50% was assigned to the 'reduced' group. To record the trans-mitral blood flow at the apical four-chamber view, pulsed-wave Doppler was used. The rate of the E, the rate of the late diastolic blood flow (mitral peak velocity of late filling, A), the ratio of E/A, and the deceleration time (DT) of the E wave were measured. In the septum and the lateral annulus, e' was measured by tissue Doppler, and the E/e' ratio was calculated. **(21).**

CONCLUSION:

Patients may experience serious complications if they are not successful in weaning off their ventilator or if they go back on it too soon. Weaning failure is most commonly caused by cardiac dysfunction.

A higher LV filling pressure (E/e′ ratio) and measures indicating a worse LV diastolic function (E/e′, e′ wave, and E wave) have been linked to weaning failure. It is less clear how LV systolic dysfunction as measured by LVEF and weaning failure are related. Further research is required to elucidate this aspect and the function of the right ventricle.

Conflict of interest: The authors declare no conflict of interest.
Author contribution: Authors contributed equally in the study.

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