Role of Ultrasound in Assessment of Diaphragmatic Function in COPD Patients during Weaning from Mechanical Ventilation

Thesis

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Introduction

Chronic Obstructive Pulmonary Disease (COPD), a common preventable and treatable disease, is characterized by persistent airflow limitation that is usually progressive and associated with an enhanced chronic inflammatory response in the airways and the lung to noxious particles or gases. Exacerbations and comorbidities contribute to the overall severity in individual patients. The chronic airflow limitation characteristic of COPD is caused by a mixture of small airways disease (obstructive bronchiolitis) and parenchymal destruction (emphysema), the relative contributions of which vary from person to person ***(GOLD, 2015).***

Chronic Obstructive Pulmonary Disease (COPD), the fourth leading cause of death in the world, represents an important public health challenge that is both preventable and treatable. COPD is a major cause of chronic morbidity and mortality throughout the world; many people suffer from this disease for years and die prematurely from it or its complications. Globally, the COPD burden is projected to increase in the coming decades because of continuous exposure to COPD risk factors and aging of the population ***(GOLD, 2015).***

The diaphragm is the major respiratory muscle, contributing to 75% of resting lung ventilation, with an excursion of 1–2 cm. During forced breathing, its excursion reaches 7–11 cm, variable with individual characteristics and methods ***(Yamaguti et al., 2007).***

The evaluation of diaphragmatic mobility has been traditionally performed using fluoroscopy. Although this method is considered the gold standard, it has some limitations, such as visualization of the diaphragm through a single incidence, need for corrective calculations and exposure patient to ionizing radiation. In recent years, ultrasound has also become used to evaluate diaphragmatic mobility it offers some advantages over fluoroscopy including the lack of ionizing radiation and the possibility of use at the bedside of the patient, and direct quantification of the movement of the diaphragm. So ultrasongraphy has been shown to be a promising tool in the evaluation of the diaphragm function ***(Ayoub et al., 2001).***

Mechanical ventilation (MV) is a life support measure for patients who cannot maintain adequate alveolar ventilation ***(Siner abd Manthous, 2007).***

Discontinuing mechanical ventilation is a rapid and uneventful process for most patients, but for one of every four or five patients, the transition to spontaneous breathing is a prolonged process that can consume almost half of the total time on a ventilator ***(Robriquet et al., 2006).***

Once the underlying process necessitating mechanical ventilation has started to resolve, withdrawal of ventilatory support should be considered; as increased duration of ventilation leads to a progressive rise in complications such as ventilator-associated pneumonia. However, other important parameters that must be considered include the neuromuscular state of the patient (ability to initiate a spontaneous breath), adequacy of oxygenation (typically low requirements for PEEP (5–8 cmH2O) and FiO2 < 0.4–0.5) and cardiovascular stability ***(Maclntyre et al., 2001).***

Predicting extubation outcome and preventing extubation failure is, therefore an important task. Various weaning parameters have been suggested to be useful, e.g., minute ventilation (V_E), respiratory rate (RR), tidal volume (V_T), rapid shallow breathing index (respiratory rate divided by tidal volume, f/V_T), maximum inspiratory pressure (P_I max), and trans-diaphragmatic pressure (Pdi) ***(Robriquet et al., 2006)***. However, the prediction rate of these parameters may not be satisfactory. Evaluating the strength of the respiratory muscles becomes important, since the imbalance between respiratory demand and supply will lead to weaning failure through the development of respiratory muscles fatigue ***(Perrin et al., 2004).*** There have been studies evaluating diaphragmatic function to predict weaning outcomes, including P_I max, pressure of the first 0.1second of inspiration ($P_{0.1}$) and Pdi. However these methods are limited by their invasive nature and dependency on maximal voluntary efforts of the patients ***(Hart et al., 2002).***

Aim of the Work

The aim of work is to study the role of ultrasound in assessment of diaphragmatic function in COPD patients during weaning from mechanical ventilation in relation to other ventilator parameters for weaning.

History of Ultrasound

The use of ultrasound in medicine began during and shortly after the 2nd World War in various centres around the world. The work of Dr. Karl Theodore Dussik in Austria in 1942 on transmission ultrasound investigation of the brain was the first published work on medical ultrasonics. From the mid-1960s onwards, the advent of commercially available systems allowed the wider dissemination of the art. Rapid technological advances in electronics and piezoelectric materials provided further improvements from bistable to greyscale images and from still images to real-time moving images. The technical advances at this time led to a rapid growth in the applications to which ultrasound could be put. The development of Doppler ultrasound had been progressing alongside the imaging technology but the fusing of the two technologies in duplex scanning and the subsequent development of colour doppler imaging provided even more scope for investigating the circulation and blood supply to organs, tumours, etc. The advent of the microchip in the 1970s and subsequent exponential increases in processing power have allowed faster and more powerful systems incorporating digital beam forming, more enhancements of the signal and new ways of interpreting and displaying data, such as power Doppler and 3-dimensional imaging ***(Bolliger et al., 2009).***

Chest Ultrasonography Overview

Physics of ultrasonography:-

Diagnostic ultrasonography is the only clinical imaging technology currently in use that does not depend on electromagnetic radiation. This modality is based on the properties of sound waves, and hence the mechanical and acoustic properties of tissues. Diagnostic ultrasound is mechanical energy that causes alternating compression and rarefaction of the conducting medium, traveling in the body as a wave usually at frequencies of 2–10MHz. In general it is assumed that the speed of sound in tissue is constant at 1,540 m/s ***(Middleton et al., 2004).***

When a pulse of ultrasound energy is incident upon the body, it interacts with the tissue in a variety of ways. Some of the incident energy is directed back towards the source and is detected. The time delay between the energy going into the body and returning to the ultrasound probe determines the depth from which the signal arises, with longer times corresponding to greater depths. This information is used in the creation of an image. Other factors that make the tissues distinguishable on a screen are their slightly different acoustical properties; one is known as the acoustic impedance ***(Hedrick et al., 2004).***

At the boundary between two different tissue types the sound waves can be:- **(a) Reflected**, like light off a mirror, this being the primary interaction of interest for diagnostic ultrasound, as it allows the major organ outlines to be seen; the diaphragm and pericardium are specular reflectors; **(b) Refracted**, like light rays passing through a lens and hence having their directions altered; **(c) Scattered**, like sunlight in the sky, sending sound waves off in different directions; this occurs when the ultrasound wave encounters a surface that is 'rough' and **(d) Attenuated or absorbed**, as they lose energy, which is converted to heat in the tissue ***(McDicken, 1991)***.

Acoustic Shadowing and Artifacts:-

In biologic tissues the speed of the sound is lowest in gas, faster in fluid, and fastest in bone, where the molecules are more closely packed. The sound pulses transmitted into the body can be reflected, scattered, refracted or absorbed. Absorption or attenuation is the loss of acoustic energy by conversion to heat energy, more prevalent in bone than soft tissue, and more prevalent in soft tissue than in fluid. It is a key cause of acoustic shadowing. Where there is a distinct loss of the echoes behind an imaged structure. Acoustic shadowing is so common in ultrasound images that it is sometimes called an artifact. It is the result of the energy (of transmitted sound) that is being decreased by reflection and/or absorption. The shadowing behind gas is due to strong reflections at gas/tissue interfaces. The reflected pulse interacts with interfaces in front of the gas causing secondary reflections, which leads to low level echoes, causing 'dirty' images. However, the shadowing that occurs behind stones, calcifications and bones is reduced by sound absorption, resulting in only minimal secondary reflection, and therefore 'clean' images ***(Middleton et al., 2004).***

While performing ultrasound images of a liver, one may see multiple, vertical, long, narrow bands or lines extending down from the posterior surface of the right hemidiaphragm. These are ring-down artifacts. These findings have been noted to be most prevalent in patients with emphysema, idiopathic interstitial pneumonia, bronchopneumonia and interstitial edema. It is speculated that the ring-down arises from thickened intralobular or interlobular septa filled with fluid touching the visceral pleural surface ***(Lim et al., 1999).***

The comet tail artifact is a reverberation artifact; reverberation artifacts are strong reflections, in multiples, from the same surface. These artifacts look similar to ringdown. The comet tail artifact is an antishadow, a trail of dense continuous echoes simulating a comet tail. They are usually associated with foreign bodies, especially metallic objects such as surgical clips, and cholesterol foci ***(Avruch and Cooperberg, 1985).***

The more the acoustic impedance of the object differs from the surroundings, the greater the number of reverberant echoes. The smaller the object is, the closer is the spacing between these echoes. If echo bands are strong and close together, they merge to produce the comet tail pattern. The reverberation is strongest when the object is perpendicular to the ultrasound beam. In comparison to the ringdown artifact, the comet tail artifact tapers fast and is short. Posterior enhancement occurs when fluid-containing structures attenuate the sound less than solid structures, the strength of the sound pulse increasing after passing through fluid compared to passing through a solid structure. This increase through transmission distinguishes cysts and fluid collections from solid masses ***(Ziskin et al., 1982).***

Echogenicity Ultrasound images are displayed on a gray scale. The strongest echo appears white while it is black when no sound wave is reflected from the organs. Depending on the reflected wave amplitude, the following terms are used to define echogenicity. When no sound wave is reflected and the image appears black it is ***anechoic*** as in pleural effusion. It is ***isoechoic*** when the echoes are of comparable amplitude with the surrounding tissue as with kidneys or spleen. It is ***hyperechoic*** when echoes are stronger than the surrounding tissue as in diaphragm, and ***hypoechoic*** when it is weaker than that from the surrounding tissue ***(Ziskin et al., 1982).***

Diagnostic Ultrasound Equipments:-

Regarding diagnostic ultrasound equipment, ceramic crystals in the transducer deform and vibrate when electronically stimulated to produce the sound pulses. Echoes that return to the transducer distort these crystal elements and produce an electric pulse, which is processed into an image. High-amplitude echoes create greater crystal deformation and produce a larger electronic voltage. Resolution of an image is very important for diagnosing pathology. Resolution is determined by the frequency and duration of the transmitted sound pulse. Axial resolution refers to the ability to resolve objects within the imaging plane at different depths along the direction of the pulse, best with higher frequency probes with their shorter pulses. Lateral resolution is the ability to resolve objects in the imaging plane that are located side by side ***(Bushberg and Seibert, 2002).***

The pulsed ultrasound energy is controlled by the system's electronics and emitted from the probe or transducer. The probe can have a single element or be composed of an array of many small elements that can be individually addressed and controlled. The latter is referred to as a phased array transducer. The elements are used both to transmit the ultrasound as well as to detect the energy directed back towards them ***(Bushberg and Seibert, 2002).***

It should be noted that the individual elements cannot simultaneously transmit and receive so following the emission of a pulse, an element in the probe or transducer starts listening for the echo. After a sufficient amount of time has passed, corresponding to a certain desired depth for acquiring information for an image, another pulse can be emitted. The size of the transmitted beam is related to both the size and number of elements that are used. By controlling the timing of transmission from individual (or groups of) elements, the ultrasound beam's direction and focusing can be controlled to obtain the image of the organ being studied. Most transducers today are multielement probes called arrays. They contain groups of small crystal elements in a sequential linear fashion. By changing the timing and sequence of activation of the different arrayed elements, the pulse can be directed to different places and focused at specific depths depending on the organ being interrogated. In the phased array transducer each element in the array helps in the formation of each pulse. A sector image is created by this probe, which is small and can fit between ribs ***(Bushberg and Seibert, 2002).***

Curved-array transducers have a convex shape for a wider field of view. A 3.5-MHz curvilinear probe provides visualization of deeper structures, and the sector scan field allows a wider field of view through a small acoustic window. These transducers are required to image a thicker thoracic wall. The chest wall, pleura, and lungs can be evaluated using this probe. The posterior chest is best imaged with the patient sitting upright, the anterior and lateral aspects of the chest in the lateral decubitus position. The suprasternal approach is the best way to view the upper anterior and middle mediastinum; the aorta and superior vena cava can be seen ***(Koh et al., 2002).***

In abdominal and pelvic imaging curved-array transducers are used to image the general abdomen including the pelvis for obstetrical cases. Curved array transducers with a short radius can be used as intraluminal or endoluminal probes. These transducers are small and can be positioned close to the organ of interest, use higher frequencies, and thus obtain higher resolution for very detailed images. Not having to transmit sound through the abdominal wall minimizes the major degradation by adipose tissue. With linear-array transducers (a limited group of adjacent elements produce a pulse), which is perpendicular to the transducer face ***(Middleton et al., 2004).***

The image is rectangular. Line array transducers of high frequency are well-suited for patients with thin thoracic walls. The major benefit of this large transducer is high resolution in the near field and a large superficial field of view ***(Meuwly and Gudinchet, 2004).***

The newer harmonic imaging uses higher integer multiples of the fundamental transmitted frequency. These sound waves progressively increase in intensity before they attenuate. A filter allows only the high-frequency harmonic signal to be processed into an image ***(Middleton et al., 2004).***