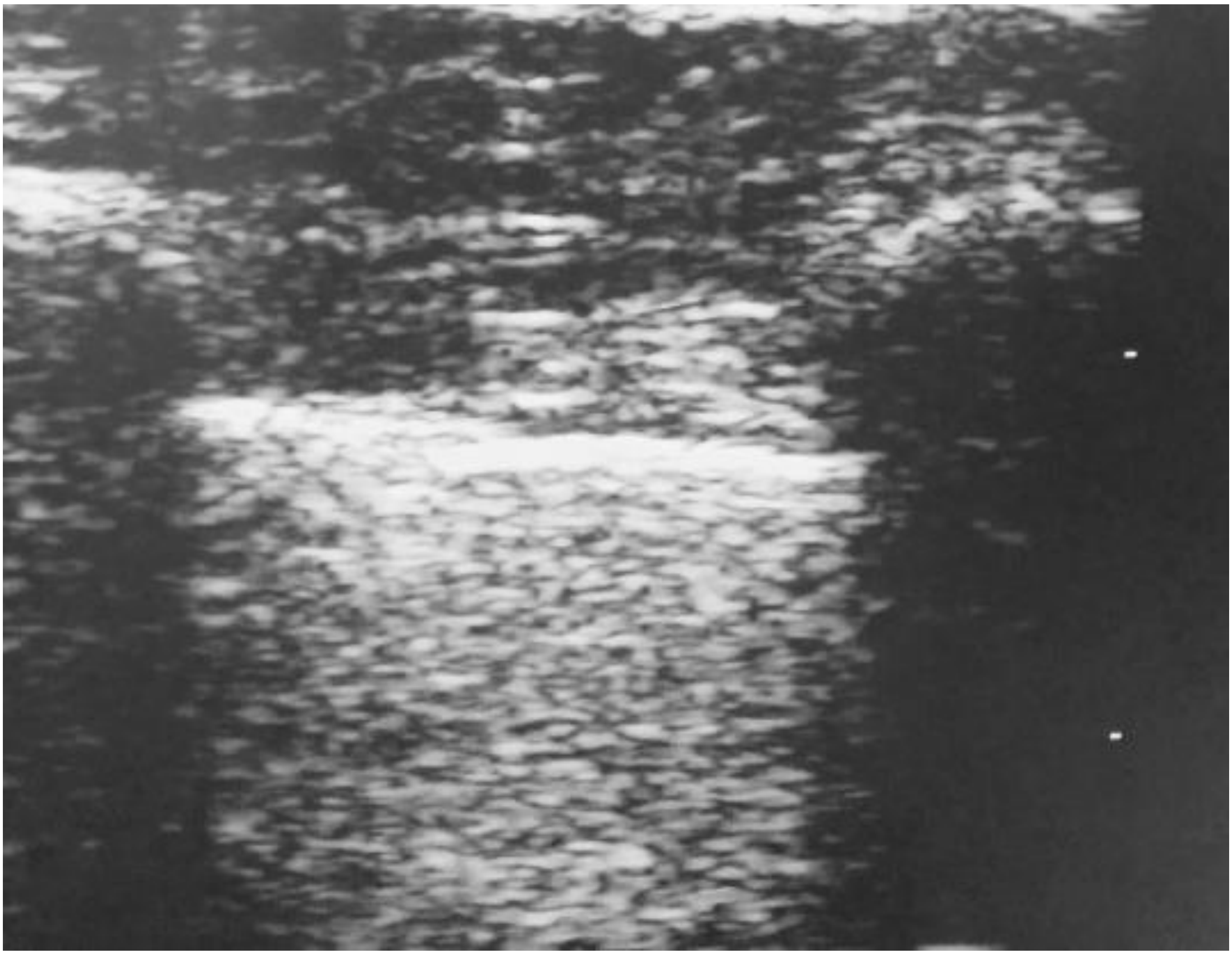
Lung Ultrasonography to Detect Pneumothorax after Insertion of Central Venous Line – A pilot study



Degree project in Medicine

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Abstract

Background

Central venous catheterization is a common and sometimes lifesaving procedure. Most patients undergoing cytostatic treatment usually receive one, as well as most patients in intensive care. The most common veins cannulated are the subclavian and the internal jugular veins. One of the major mechanical complications is pneumothorax. The risk of pneumothorax is relatively low, at 1.5%. However, a pneumothorax can have serious adverse effects and sometimes lead to death in certain patients. After CVC placement, patients usually undergo a chest radiograph to rule out major mechanical complications as well as confirm location of the central venous catheter tip. Recently, lung ultrasound has been more and more used in a clinical setting. Studies have proven lung ultrasound to be more sensitive compared to chest radiograph in ruling out pneumothorax (35).

Objective

The purpose of this pilot study is to elucidate whether lung ultrasound after CVC insertion is a useful tool for ruling out pneumothorax.

Method

To understand the mechanics and theory surrounding lung ultrasound, a review of the literature was performed. I also attended a lung ultrasound seminar. An experienced physician instructed me in the handling of the ultrasound machine. I examined patients at two wards at Sahlgrenska Universitetssjukhus where central venous catheters are commonly placed. The lung ultrasound exam was performed after placement of the CVC, an improvised screening protocol was used during lung ultrasound examination.

Results

In total, 155 patients were examined with lung ultrasound. 56 at ward 22 and 99 at preoperative ward 4. There were nine patients with positive findings on lung ultrasound. Out of these, seven pneumothoraces were confirmed by chest x-ray. In two patients, the pneumothorax is believed to be caused by the CVC insertion. Sensitivity was 1 and specificity 0.98. When comparing lung ultrasound with chest radiograph, lung ultrasound proved non-inferiority.

Conclusion

Lung ultrasound is a fast and easy to use tool and may be used to rule out pneumothorax after CVC insertion.

Introduction

Basic anatomy

It is advantageous to have at least basic knowledge of the vascular anatomy surrounding the neck and upper thorax to better understand the various details surrounding central venous catheterization and pneumothorax.

In the neck, hidden behind the sternocleidomastoid muscle, the internal jugular vein runs down the neck in a vertical fashion. The vein is slightly lateral to the internal carotid artery. The right internal jugular vein joins the right subclavian vein and forms the right brachiocephalic vein. The right external jugular vein which forms from among others the retromandibular plexa, runs down the neck superficial to the sternocleidomastoid muscle and joins the internal jugular and subclavian vein near the formation of the right brachiocephalic vein.

The left side is almost the same, however there are a few anatomical differences. The junction of the left internal jugular vein and the left subclavian vein forms at a right angle, and the subsequent formation of the left brachiocephalic vein is more horizontally oriented. This is in contrast to the orientation of the right brachiocephalic vein which is oriented in a more vertical plane and offers an almost straight path into the superior vena cava.

The subclavian vein is a continuation of the axillary vein coming from the axilla and passing above the first rib and below the clavicular bone. The vein is slightly more ventral in comparison to the artery.

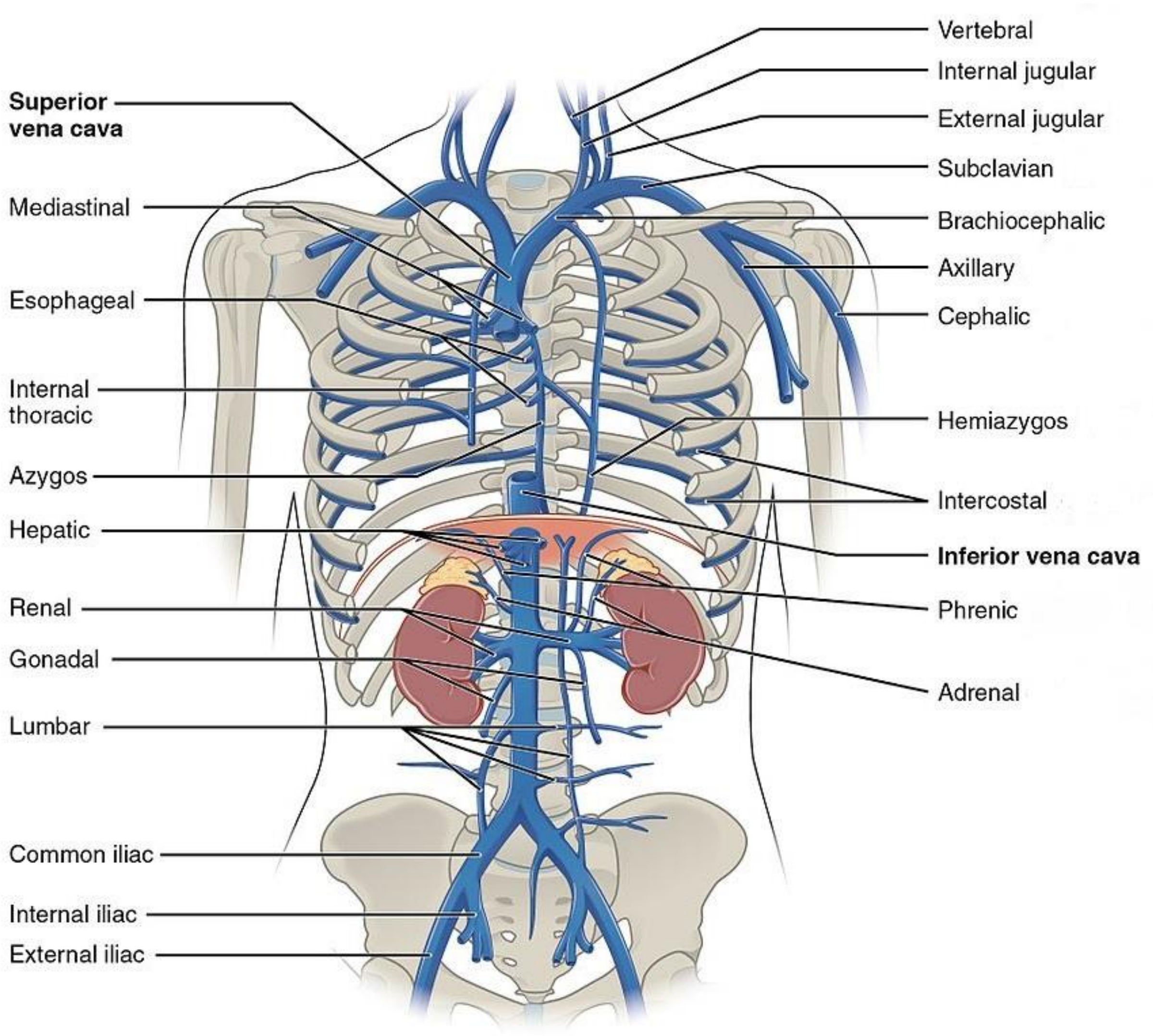

Figure 1 The major veins of the abdomen and trunk.

Taking a breath

The lungs themselves are located within the ribcage in the pleural cavity and extend all the way down to the diaphragm, slightly further down on the dorsal side. They are lined with visceral pleura, and the inside of the pleural cavity is lined with parietal pleura. Between these sheaths of pleura exists the intrapleural space which is more of a theoretical space in a healthy individual.

The intrapleural space is lined with a thin layer of pleural fluid that helps lubricate the lung as it slides against the ribcage. There is also a negative pressure in the intrapleural space compared to atmospheric pressure, which keep the lungs inflated. When at rest at the beginning of inspiration, this negative pressure is roughly -3.6 mmhg. As inspiration proceeds, this negative pressure increases to around -5.5 mmhg. Inspiration is accomplished chiefly by the diaphragm and external intercostal muscles.

When the intrapleural pressure increases, the lungs expand and a slight negative alveolar pressure of around -0.73 mmhg draws around 500ml air into the lungs in a normal breath. The pressure difference between alveolar pressure and intrapleural pressure is called the transpulmonary pressure. It is this transpulmonary pressure that keep the lung inflated. The lung is also very elastic, and these elastic forces are mainly elastic fibers and collagen fibers along with the surface tension force. The surface tension force makes up roughly two thirds of the lungs elasticity, this is however increased tremendously with the absence of pulmonary surfactant.

Pneumothorax

A pneumothorax is a condition where air has been trapped within the intrapleural space. The pressure in the intrapleural space is as previously mentioned negative, at around -3.6 to -5.5 mmhg in a healthy individual.

If air is present in the intrapleural space, one or more of the following events must have occurred: communication between the intrapleural space and the outside atmosphere, communication between the alveoli and the intrapleural space or presence or gas-producing organisms in the intrapleural space.

Clinically, pneumothorax is classified as either spontaneous or non-spontaneous. Spontaneous pneumothorax can further be divided into primary spontaneous pneumothorax and secondary spontaneous pneumothorax.

Primary spontaneous pneumothorax is a condition where there is no apparent underlying cause. These patients are usually tall and thin males. Smoking is common a risk factor (18). These patients often report a sudden ipsilateral chest pain. Dyspnea is also a common symptom.

The exact mechanism of primary spontaneous pneumothorax is unknown however one hypothesis for the cause is rupture of sub pleural blebs (19, 20). Pulmonary blebs are small sacs of air between the visceral pleura and the lung, usually located in the apex of the lungs. The formation of these blebs may be associated to distal airway inflammation, hereditary predisposition, anatomical abnormalities, apical ischemia and low caloric intake among others (20).

Secondary spontaneous pneumothorax occurs due to an underlying lung disease. Categories of diseases which are known to cause secondary spontaneous pneumothorax include airway diseases such as asthma, cystic fibroses and chronic obstructive pulmonary disease. Many infections may cause secondary spontaneous pneumothorax, interstitial lung diseases, connective tissue diseases and malignancies. Because of the underlying disease these patients often cope worse than those with primary spontaneous pneumothorax (20).

Nonspontaneous pneumothorax can be divided into traumatic non-iatrogenic pneumothorax and traumatic iatrogenic pneumothorax. Traumatic non-iatrogenic pneumothorax commonly occurs in major chest trauma (21). A feared kind of pneumothorax commonly occurring in major chest trauma is tension pneumothorax, a condition where a high positive pressure compress the lungs as well as the major veins.

One common cause for iatrogenic pneumothorax is insertion of a central venous catheter, this will be discussed further.

The effects of pneumothorax

When air, for whatever reason, has entered the intrapleural space, the negative pressure that keeps the lungs inflated is turned into positive pressure. How much the pressure change is depends greatly on the amount of air and thus the extent of the pneumothorax. This has the opposite effect compared to normal lung; the lung is compressed. The main physiologic effect of this is a reduction of arterial oxygen saturation in the blood flowing through the effected lung, this may be because a part the blood is effectively shunted past the lung and not saturated with oxygen in the alveoli. The reduced oxygen saturation may also be due to hypoventilation of the alveoli. The vital capacity is also decreased because the positive pressure in the intrapleural space is compressing the lung.

The reduced arterial pressure is because part of the blood flowing through the lung is not saturated with oxygen, the PaO2 will consequently never reach 99-100% until the pneumothorax is treated, no matter the amount of oxygen the patient receives. In one study 12 patients with spontaneous pneumothorax were evaluated in regards to their PaO2. Nine of the patients had a PaO2 ≤ 80 mmHg. Two of the patients were diagnosed with secondary spontaneous pneumothorax and had a PaO2 ≤ 55 mmHg (28).

Symptoms usually associated with pneumothorax are sudden ipsilateral chest pain, along with dyspnea. Clinical findings include hypersonic breath auscultation, tachypnea and in large pneumothorax; tracheal deviation to the unaffected side. In patients with primary spontaneous pneumothorax, the pain and dyspnea usually resolve within 24 hours. In patients with primary spontaneous pneumothorax, when the pneumothorax encompasses less than 25% of the pleural cavity they do not seem to develop hypoxemia easily. However, patients with pulmonary emphysema fare far worse and even a small pneumothorax can cause serious hypoxemia (29).

Central venous catheter

A central venous catheter is a catheter placed in one of the major venous vessels. Usually the right or left subclavian vein or the internal jugular veins are used. The femoral vein may also be used. There are several indications for a central venous catheter. These include injection of potent vasoactive drugs, such as dopamine or other vasopressors. The injected substance might be irritating to the vessel, such as potassium chloride or chemotherapeutic agents. In these cases, the injected substance might cause local inflammation, thrombophlebitis or even localized necrosis of the vessel. A central venous catheter might also be used when long-term need for vascular access is expected. Other indications might be an inability to find a peripheral vein, for measuring the central venous pressure, and acute hemodialysis among others. In acute settings, a large bore central venous catheter may be used for extremely rapid infusion of fluids in a hemodynamic instable patient (1, 2).

Because a central venous catheter can be lifesaving in certain situations, no direct contraindications exist. Rather the need for central venous access should exceed the risk for complications, and this must be decided in each case by the clinician. In difficult cases a more experienced clinician should perform the procedure. Studies have shown that clinicians with experience in central venous line catheterization (>50 cannulations) have a significantly lower risk of complications, compared to inexperienced clinicians (<50 cannulations) (3, 4).

The choice of catheter depends on the clinical needs, there are catheters with multiple lumens and there are single lumen catheters. Multiple lumen catheters are useful in day-to-day clinical practice while single lumen catheters are preferable in trauma situations where large quantities of fluid might need to be injected in a short time span. According to Poiseulle's law, when the radius of the tube is doubled, the flow rate is quadrupled. However, no matter if it is a single or multi lumen catheter, the complication rate is unaltered.

Cannulation technique

Prior to cannulation, the patient should be connected to monitoring equipment such as electrocardiograph and a pulse oximetry device. The skin is cleaned using chlorhexidine. A sterile technique is used with sterile drapes, gown, hand-wash and gloves help decrease catheter-related infections (10).

The technique that has been in use since the 1950s is the modified seldinger technique. The clinician identifies relevant anatomical landmarks, sometimes the vein is localized using ultrasound. When the internal jugular vein is cannulated, the ultrasound is also used during the cannulation process for visual guidance. For cannulation into the internal jugular vein, this has been proven to be advantageous and associated with increased rate of success (5-7). There are however mixed results regarding the use of visual ultrasound guidance during cannulation into the subclavian vein (6, 8, 9).

After sterile precautions are taken, and the cannulation site has been determined, the clinician anesthetizes the skin and underlying tissue with 1% lidocaine. Then the catheterization needle, usually 16-18 gauge, is inserted through the skin. A suction is applied to the syringe by the clinician, so that once cannulation into the vessel occur, a stream of venous blood will immediately be sucked into the syringe. After this, the syringe is removed and a guidewire is fed through the catheterization needle. When the guidewire is fed through the needle, minimal or no resistance should be met. Once the guidewire is in place, the needle is withdrawn. Sometimes a dilator is used before the catheter is advanced into the vessel. Once the catheter is in place, the guidewire is withdrawn. Free flow through the catheter into the vessel lumen is then confirmed using saline. Catheter lumens are flushed through with saline beforehand to prevent any air embolism from forming. After the catheter is in place and free flow through the catheter is established, it is secured to the skin by sutures and a sterile dressing is applied. After catheterization is complete, a chest radiograph is performed to rule out any complications such as pneumothorax and to verify catheter position.

Subclavian cannulation

As previously noted, the most commonly used veins are the right and left internal jugular and the right and left subclavian. For cannulation into the subclavian vein, an infraclavicular approach is regularly used. This begins with the patient placed in Trendelenburg position, that is; the bed is tilted downward 15 degrees to facilitate increased venous flow.

The skin is punctured approximately one cm caudal to the clavicle, on the lateral portion of the clavicle. The needle is then angled towards the sternal notch, and advanced to a depth of 3 – 5 cm depending on patient’s anatomy and size. The needle is advanced parallel to the frontal plane, and should never dip down too far towards the sagittal plane in order to avoid pneumothorax.

Jugular cannulation

For jugular cannulation, there are two approaches, a central and a posterior approach. The central approach for cannulation into the internal jugular vein begins in Trendelenburg position. The right internal jugular vein is often preferred because of the relatively straight pathway down to the superior vena cava, compared to the left internal jugular vein that joins the left subclavian vein at a somewhat right angle which can sometimes hamper the insertion of the guidewire. The patients head is rotated toward the opposite side, and the insertions of the sternocleidomastoid muscle are located. The insertions of the sternocleidomastoid muscle along with the clavicle bone forms a triangle through which the internal jugular vein might be accessed. The clinician might also locate the communal carotid artery which is located medially and more profoundly compared to the internal jugular vein. The skin is punctuated at the apex of the triangle with the needle in a 45 degrees' angle aimed caudally and somewhat lateral toward the ipsilateral nipple. The needle is then advanced 3-5 cm depending on patient's size and anatomy (1).

The posterior approach also begins in the Trendelenburg position, with the patient's head rotated toward the opposite side. The internal jugular vein is visualized through ultrasound and distinguished from the carotid artery. It is located medially of the sternocleidomastoid muscle, approximately 6 cm rostral of the clavicle. Sterile conditions apply as described above. While the vein is being visualized through ultrasound, a needle is inserted through the skin, and proceeds to cannulate the vein.

After CVC insertion, patients at Sahlgrenska Universitetssjukhus are ordered a chest radiograph to ascertain CVC tip location as well as rule out any mechanical complications. A routine chest radiograph after CVC insertion is also common practice in most hospitals.

CVC complications

There are a number of complications associated with central venous catheterization. The most common of which are arterial puncture, catheter malposition, bloodstream infection, hematothorax, pneumothorax and vessel occlusion. The risk for each complication varies with location.

Pneumothorax in the internal jugular vein is described as less than 0.1-0.2% compared to 1.5% - 3.1%. Frequency of mechanical complications can be seen in table 1.

Table 1 (11). Mechanical complications from central venous catheterization.

	Internal jugular	Subclavian
Arterial puncture	6.3-9.4	3.1-4.9
Hematoma	<0.1-2.2	1.2-2.1
Hemothorax	NA	0.4-0.6
Pneumothorax	<0.1-0.2	1.5-3.1
Total	6.3-11.8	6.2-10.7

Pneumothorax incidence at Sahlgrenska University

At Sahlgrenska Universitetssjukhus in a previous student project based on 531 CVC insertions on patients receiving CVC in order to administer cytostatic drugs, the pneumothorax rate was found to be 1.1% (34).

Traumatic pneumothorax due to central venous cannulation

Pneumothorax as a result from central venous catheterization commonly occur with the subclavian approach or the central approach for the internal jugular vein. Some of the most important factors that might influence the mechanical complication rate are; unusual anatomy, either a normal variant or due to injury or surgical intervention, compromised procedural settings; i.e. trauma situations, experience of the physician among others.

What actually happens when a iatrogenic pneumothorax occurs during central venous cannulation is that the needle used to cannulate the vessel pierces first the parietal pleura and later the visceral pleura, thereby causing a connection between lung tissue and the intrapleural space. Since the pressure in the intrapleural space is negative at around -4 mmhg depending on the lung cycle, and the alveolar pressure is slightly negative during inspiration and slightly positive during expiration, a pressure difference will occur that will push air through the damaged lung wall and into the intrapleural space until the pressure difference is equalized at the injury location.

Lung Ultrasonography

Ultrasonography has been in medical use since the 1950s, when Ian Donald introduced the technique and used ultrasound to measure the fetal head. Commercial use dates back to 1963 when "B –Mode" ultrasound devices were made available. From then on, the use of ultrasound has become widespread and used in a variety of fields in medicine such as anesthesiology, cardiology, emergency medicine, gastroenterology, gynecology, neonatology, pulmology and urology to name a few.

In recent years, ultrasound to evaluate the lungs has gathered more attention. In 1986, the use of ultrasound to diagnose pneumothorax was first described in a veterinary medical journal (22).

In short, medical ultrasound requires three steps in order to create an image; sending out soundwaves, receive the sound wave echoes and interpret the echoes.

To be able to perform, interpret and evaluate any findings from ultrasound, it is of importance to understand a little surrounding the general principles of ultrasound mechanics. Dense materials such as bone prevent the soundwaves from penetrating through it, while the ultrasound waves have no issue penetrating soft tissues. The presence of air will also stop the ultrasound waves from penetrating through it since air simply does not produce an echo wave to be registered by the ultrasound machine.

Concerning lung ultrasonography, there are a few terms which need to be explained in detail. The different pulmonary abnormalities visible on lung ultrasonography depends greatly on the status of the lungs just as an ECG can look vastly different depending on the current condition of the heart.

The following terms will be discussed in order to give the reader a basic understanding surrounding the findings on a lung ultrasound examination; B- and M-mode, pleural line, lung sliding, lung point, comet tails, seashore sign, barcode sign, A-lines, B-lines and Bat sign.

One important thing to mention is the fact that many of these signs are artifacts that might be filtered out when using newer ultrasound machines with sophisticated software to enhance the image. In order to properly evaluate the lungs in a lung ultrasound exam, the ultrasound machine needs to be “dumbed down” so that these artifacts are no longer filtered out. Some machines already have this feature, so the clinician simply needs to turn on a “lung mode”, in other cases these settings needs to be changed manually.

B-mode is most commonly used by anesthesiologists and stands for brightness mode. B-mode provides a two-dimensional image of any visible structures in real time. The image is a composition of bright dots where the brightness of each dot is determined by the amplitude of the returned echo signal. In this mode, structures might be assessed, cannulation into vessels may be assisted and flows may be measured among other things.

M-mode, as one might guess, stands for motion mode. This is similar to an ECG strip, and from M-mode activity occurring over a period of time can be viewed. The actual image is made up of returned ultrasound waves which are stacked next to each other. The lines on top represents echo of structures closer to the probe, while the lines at the bottom represents echoes from structures further from the probe. When discussing lung ultrasonography, two terms are useful to know about, these are the seashore sign and the barcode sign.

Pleural line

The pleural line is visible as a hyperechoic (bright white) shimmering line on ultrasound when examining a healthy individual. It is viewed in B-mode and anatomically represents the parietal pleura and the visceral pleura, both and indistinguishable from each other on ultrasound in a healthy individual. The pleural line is the most essential anatomic finding concerning lung ultrasound and should be the first task to locate when examining the lungs by ultrasound. This is normally very easy but can be complicated in obese individuals.

Bat sign

The bat sign refers to the appearance of a "bat" on the sonographic screen when the probe is oriented in a rostral-caudal position on the chest wall. The "bat" is made up of an upper rib, pleural line and a lower rib, in this analogy the upper and lower ribs make up the bats wings. It is easily identified in most patients, even for novices.

Lung Sliding

Lung sliding is the ultrasound representation of visceral pleura sliding alongside parietal pleura. It may be seen in spontaneous breathing as well as when patients are mechanically ventilated, large tidal volumes make it easier to see lung sliding. The presence or absence of lung sliding should be the first thing evaluated after finding the bat sign and subsequently identifying the pleural line. It is of utmost importance to identify the real pleural line, which in certain cases might be difficult for novices. Lung sliding, or "ants marching" as it is also sometimes called cannot occur when a pneumothorax is present, there for the presence of lung sliding is highly specific for ruling out pneumothorax. When a patient is intubated and ventilated by a machine, checking for pleural sliding is useful to reveal main-stem bronchus intubation.

Lung point

The lung point is the sonographic term used to describe the sonographic representation of the edge of the pneumothorax, where normal lung sliding ends and the pneumothorax begins. When observing the edge of a pneumothorax with ultrasonography, the clinician may observe how the edge of the pneumothorax oscillates in relation to the patient drawing breath. This is in fact the visceral pleura sliding back and forth, like a zipper being pulled up and down. When there is no observable lung sliding and a lung point can be located, diagnosis of pneumothorax is confirmed.

In order to even see a lung point, some parts of the visceral pleura must still be in contact with parietal pleura. This means that in large pneumothorax, or tension pneumothorax, searching for a lung point might be difficult or even impossible.

Lung pulse

The lung pulse is a phenomenon which can be observed in B-mode during lung ultrasound when the parietal pleura and the visceral pleura are touching and there is no pneumothorax present. It is in fact the vibration from each heartbeat. Therefor it is a sure sign to exclude pneumothorax in the current area as well as a way to monitor heart rate.

Lines

When talking about lines in ultrasonography, one is actually talking about the different artifacts in the lung parenchyma that occur for different reasons. There are three principal lines which will be discussed. These are the A-lines, B-lines and Z-lines. They are all viewed in B-mode.

A-lines are horizontal hyperechoic lines. They are essentially repetitions of the pleural line, and the first A-line will be the same distance from the pleural line, as the pleural line is from the ultrasound probe. The same distance applies to further A-lines as well until the echo depletes itself. The presence of A-lines indicates subpleural air, or mostly subpleural air, i.e. normal lung tissue. The presence of A-lines does not say anything about pneumothorax (27).

B-lines

A variety of B-lines are described in the literature, however only the basics will be covered here. B-lines appear as vertical cones of light, or "comet-tails". B-lines always arise from the pleural line. They move with pleural sliding, are hyperechoic and erase the A-lines. The B-lines are also well defined, and extend to the edge of the screen, or at least far enough to erase A-lines. B-lines are generated by pathologic conditions and are not a consequence of frequency, geometry or the probe. Instead the artifact appears when there is a difference in acoustic impedance between an object and its surroundings in other words; when there is a combination of fluid and air which causes the ultrasound beam to reverberate between the probe and the liquid dense alveoli multiple times (25, 27).

A single B-line may be a normal variant and without pathologic meaning, sometimes a representation of a lung fissure. The number of B-lines increases when there is pulmonary edema, and are an indicator of pulmonary edema and pulmonary artery occlusive pressure (26). Since the B-lines arise from the lung parenchyma, the presence of B-lines rules out pneumothorax at that location.

Z-lines

Z-lines are similar to B-lines, they are hyperechoic, vertical “comet-tail” artifacts and are viewed in B-mode. However, they differ from B-lines in that Z-lines are smaller, diminish distally from the pleural line, not as clear and do not break up A-lines. Z-lines can occur in normal lung and are thought to be devoid of meaning.

Seashore sign

The characteristic sign of pleural sliding while using the M-mode. The name comes from the appearance of a shore line next to the sea. The sea part represents the parietal pleura, its echo gives a straight line in M-mode. The shore part represents the visceral pleura and the lung that is sliding back and forth.

Barcode sign

As the name implies, this has the appearance of a barcode. Visible in M-mode when a pneumothorax is present. Only echoes from the parietal pleural line echoes back which gives straight lines, indicating no movement.

Figure 2 B-mode as well as M-mode below, the pleural line is clearly visible and the seashore sign seen in M-mode indicates normal lung.

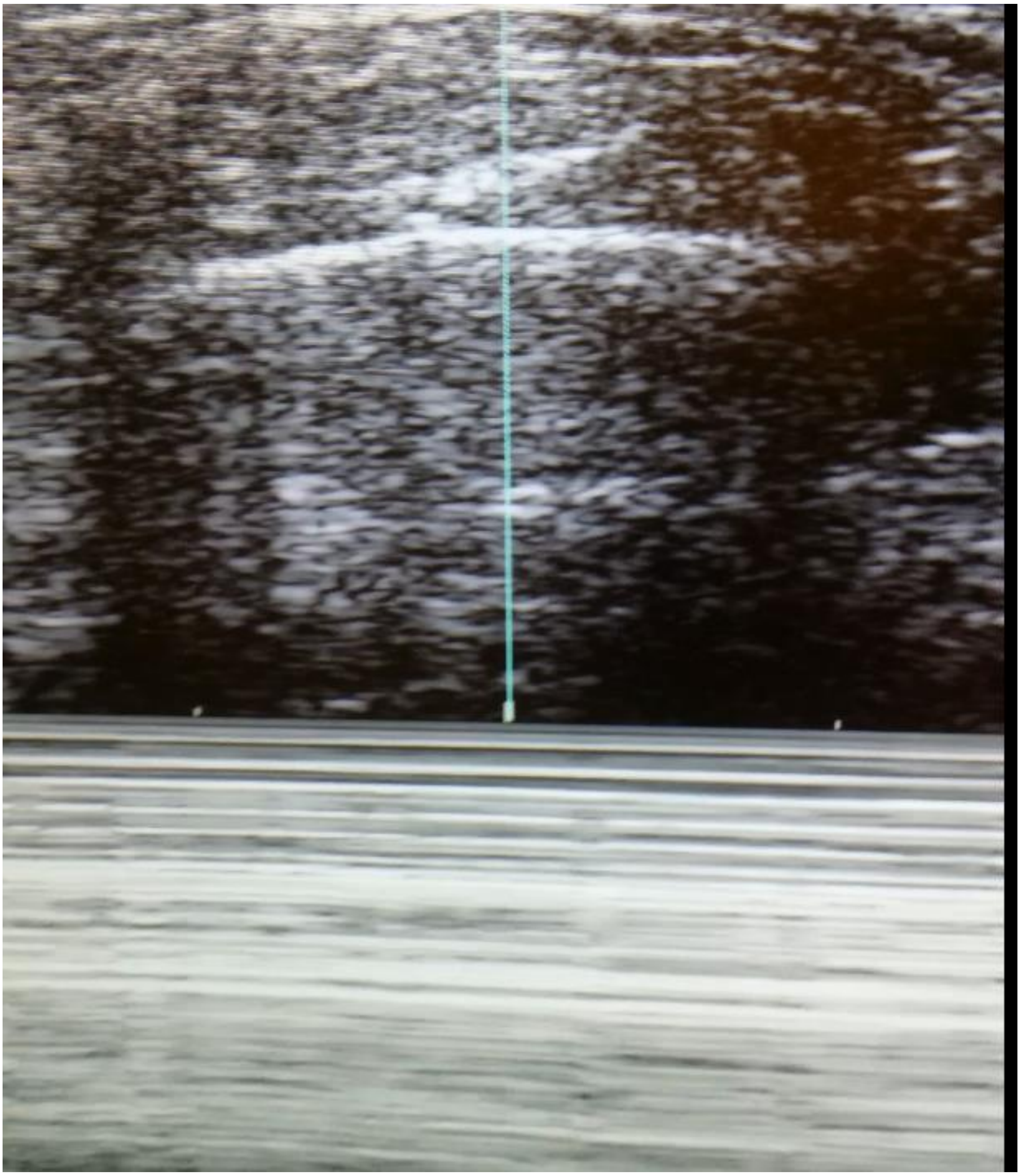

Figure 3 Pneumothorax as seen on ultrasound. M-mode clearly shows the barcode sign, indicating absent sliding.

Detection of pneumothorax by lung ultrasound and chest radiography

To best detect a pneumothorax with chest radiography, the patient should be standing or sitting up straight when the chest x-ray is taken. This is because the pneumothorax gas rises to the highest point in the intrapleural space and this makes identification of a pneumothorax much more sensitive in the anteroposterior projection. In a supine patient lying on his back, a less impressive pneumothorax is difficult to detect in the anteroposterior projection and also difficult in the lateral projection.

According to a meta-analysis from 2011, pooled sensitivity and specificity for chest radiography is 0.52 and 1.00 respectively (31). However, in trauma patients who are unable to stand or sit up for the anteroposterior projection, the sensitivity for identification of pneumothorax ranges between 0.28 – 0.75. The specificity is 1.0 in these patients as well (23).

Lung ultrasound has been reported to have close to 1.0 specificity in most studies (23). It is less sensitive however, with a sensitivity of around 0.86-0.98 (23). If a lung point can be located, the presence of pneumothorax can be confirmed (24). The presence of a lung point also gives an indication of the pneumothorax size.

Purpose

The purpose of this pilot study was to elucidate whether lung ultrasound performed both immediately and within 24 hours after central venous cannulation is a viable, sensitive and effective tool to use to rule out pneumothorax.

Method

At first I learned the theoretical basics of ultrasonography, as well as gathered a deeper understanding surrounding lung ultrasonography. A literature search was performed via Gothenburg University – University library medical database in order to gather the most relevant published studies surrounding lung ultrasonography and pneumothorax. Information was also gathered from an ultrasonography seminar at Sahlgrenska Universitetssjukhus which I attended. I learned how to operate the ultrasonography machine from an experienced clinician at Sahlgrenska Universitetssjukhus.

The data collection was gathered by myself at Sahlgrenska Universitetssjukhus using a Flex Focus 400 machine. A high frequency linear probe was used, with a predetermined lung filter. The purpose of this filter, as previously discussed, is to keep the artifacts that might appear and not have these filtered out by the machine's software.

The patient selection consisted of patients receiving or had recently received a central venous catheter. These patients were admitted to post-operative intensive care unit ward 22 as well as preoperative ward 4, where data collection was also performed. Patients who were too ill to be examined were excluded, as well as patients who did give verbal consent. In general, almost all available patients were examined.

There were two patient groups, group one included patients from post-operative patients at ward 22. These patients were more often than not treated surgically for malignancies and received a central venous catheter peroperatively for this reason.

Group two included patients from preoperative ward 4, these patients generally received a central venous catheter in order to administer intravenous cytostatic drugs.

After a patient with central venous catheter was identified, verbal consent was acquired. After this I followed a predetermined scan protocol made up by myself and my supervisor and strongly influenced by established methods, such as the BLUE-protocol (30) as well as other published data (27).

On the ipsilateral side of the patient in comparison to the CVC location, the ultrasound probe was placed just below the clavicle in the midclavicular line. The probe was oriented in a vertical fashion and the left side of the monitor always pointing in the direction of the patient's head, the reason for this was to stay oriented and perform a similar exam in all patients.

After placement of the probe, the "bat sign" was identified. As mentioned, this is the ultrasound representation of an upper rib, pleural line and a lower rib. Once the pleural line was identified, the presence or absence of pleural sliding was evaluated. The patient was asked to take deep breaths in and out in order to make this extra clear. The presence of artifacts was also noted, such as A-lines, B-lines or Z-lines.

If pleural sliding was noted, the probe was moved to the second intercostal space and a similar scan was conducted. In this manner, the anterior chest wall was scanned with the patient in a supine position if possible.

If no pleural sliding was noted, B-lines were looked after. The presence of B-lines per definition rules out pneumothorax. M-mode was also used when sliding was absent in order to determine if either the stratosphere or barcode sign was visible.

On some cases where pneumothorax was ruled in by ultrasound, a video of the positive findings was recorded.

After each patient was examined, an improvised chart was filled out for each patient with information concerning the CVC and ultrasound exam. The chart information included; date and time for cannulation, weather the cannulation was complicated or not, the amount of needle penetrations, any suspected or verified complications, the location of the CVC, any recent ventilator treatment, any other treatments or surgery or note, any ultrasonographic findings and radiologic findings.

The patient chart was read after ultrasound examination was performed on all patients in order to compare lung ultrasound results to chest x-ray. On patients absent sliding, a review of any recent surgery or any other procedures or trauma which might cause pneumothorax or otherwise explain the pneumothorax was performed.

The patient data were later compiled in an excel file and analyzed.

Figure 4 The probe is placed in the midclavicular line and in a rostrocaudal orientation.

Results

155 patients were examined through lung ultrasound after CVC insertion of whom 99 were examined at preOp 4 and 56 at ward 22. Patient characteristics are shown in Table 2.

Table 2. Positive ultrasound finding referrers to absent lung sliding. CVC; Central venous catheter, CXR; Chest X-ray.

	preOp 4	Ward 22
Total, N	99	56
Number of woman, N (%)	62 (63)	24 (43)
Age, years	57 (47 - 66)	50 (43 - 58)
Number of subclavian CVC, N (%)	87 (88)	24 (43)
Average number of cannulations	1 (1 - 2)	1 (1 - 1)
Average time to ultrasound	15min (10-20min)	23h (19h - 25h)
Positive ultrasound findings, N (%)	4 (4)	5 (9)
Ptx according to CXR, N (%)	2 (2)	5 (9)

Five patients with absent lung sliding were found in the post-operative group at ward 22 while four patients absent lung sliding were found at preoperative ward 4. The nine patients absent lung sliding are presented in detail in Table 3.

Chart review on the five patients at post-operative ward 22 after lung examination was performed revealed two diaphragmatic tears during surgery, one previously known pneumothorax, one pneumothorax due to extensive esophageal surgery.

Four patients absent lung sliding were found at preoperative ward 4. Of these; two patients turned out to have large invasive lung carcinomas while chest x-ray showed no appearance of pneumothorax. The other two patients with absent lung sliding at preoperative ward 4 did have a pneumothorax which was also confirmed by chest x-ray.

In one of the two patients with pneumothorax at preoperative ward 4, no symptoms were noted. However, lung ultrasound detected absent lung sliding in the apical lung field at intercostal spaces 1 – 2 and M-mode had the appearance of the barcode sign. No clear lung point was noted. In the other patient, the lung ultrasound examination showed absent sliding and no lung pulse at intercostal spaces 1 – 4. When M-mode was turned on, it had a clear barcode sign.

Table 3 Characteristics of patients with absence of lung sliding.

CVC; Central venous catheter, US; ultrasound, CXR; Chest X-ray.

Patient no.	Age	Sex	Surgery Yes/No	Type of surgery	Time CVC to US	Ultrasound findings	CXR	Probable cause of absent sliding
1	67	M	Yes	Liver resection	20h 35min	No sliding i1, lung point at i2 dx	Apical ptx 1.5cm	Diaphragm tear
2	70	W	No		16h	No sliding i1 dx	Apical ptx 1cm	Ptx existed before CVC insertion
3	55	W	Yes	Thyroid resection	24h 30min	No sliding at i6 sin	Probable ptx i6 sin	Surgery or CVC-insertion
4	38	W	Yes	Suprarenal resection	31h 30min	No sliding i3-i5 dx, no lung pulse	Apical ptx 0.5cm	Diaphragm tear
5	80	W	No		15min	No sliding on right lung field	Large lung tumor	Pleurodesis due to lung tumor
6	57	W	No		10min	No sliding i1-i2 dx	Small ptx dx	CVC insertion
7	75	M	Yes	Esophageal surgery	34h	No sliding i1-i2 sin	Ptx 2cm sin	Thoracothomy
8	79	W	No		15min	No sliding i1-i3 dx	Large lung tumor	Pleurodesis due to lung tumor
9	59	M	No		15min	No sliding i1-i3, no lung pulse	Ptx 7cm sin	CVC insertion

No pneumothorax was missed by ultrasound examination, hence a sensitivity of 1.0 Specificity was 0.98. The positive predictive value of having a pneumothorax if lung sliding was absent was 0.78, negative predictive value was 1.0.

Discussion

In this pilot study, lung ultrasound was used to rule out pneumothorax after central venous cannulation. 155 patients were examined in total. Lung ultrasound was performed both immediately after CVC insertion as well as after roughly 24-30 hours. Two pneumothoraces were likely caused by the CVC insertion and there were seven pneumothoraces in total. All patients with pneumothorax had a positive lung-ultrasound, as measured by absence of lung sliding.

In both groups, there were no pneumothoraces missed. This gave us a sensitivity of 100% which is consistent with the literature. Furthermore, the specificity as well as the positive predictive value was high. The excellent sensitivity with a high specificity suggest that lung ultrasound is a good screening tool for ruling out pneumothorax after CVC insertion. There have been reports of pneumothorax not being detectable at or immediately after CVC insertion (32).

Notably, in the two patients with pneumothorax attributed to CVC-insertion examined within minutes after the cannulation, lung ultrasound confirmed the possibility of pneumothorax. Thus, this support the notion that lung-ultrasound can be performed instantly after the insertion of CVC for exclusion of pneumothorax.

In one of the patients with absent sliding at preoperative ward 4, while ultrasound examination was being performed, the patient began experiencing ipsilateral chest pain as well as dyspnea. The ultrasound examination quickly revealed a large pneumothorax of at least 7 cm on the patients left side where the CVC was inserted. During the examination, the patient was in an upright position to alleviate breathing. Due to the patient’s urgent symptoms, no time was spent searching for a lung point in order to verify the diagnosis, rather the patient was rushed to radiology where a chest x-ray confirmed an apical pneumothorax. In the other patient with absent sliding at preoperative ward 4, no symptoms were recorded after CVC insertion. In this patient chest x-ray suggested an apical pneumothorax on the side of CVC insertion.

Regarding the patients at post-operative ward 22, it is difficult to determine the cause of the pneumothoraces. In some cases, the operating physician described a cause such as accidental tear of the diaphragm and some patients had thoracotomy during surgery. This makes it impossible to tell whether the pneumothorax was caused by the CVC-insertion or by other causes. However, all these pneumothorax of uncertain origin were also found. Thus, this suggest that lung-ultrasound can exclude pneumothorax in the postoperative setting, regardless cause.

The data in the present study suggests ultrasound was equally effective at detecting pneumothorax after CVC insertion. In studies performed comparing the sensitivity of chest radiograph with lung ultrasound, lung ultrasound was proven more sensitive than chest radiograph (23). The reason for this discrepancy between the current study and previous work is most likely the relatively small size of this pilot study.

There are many potential benefits to be had from lung ultrasound. Pneumothorax is a rather unusual complication after CVC-insertion. In different studies, the incidence of pneumothorax after CVC insertion is described as 1.5-3.1% (11). Thus, chest x-ray is performed unnecessarily. Lung-ultrasound is a fast method, in the current study, examination time was in all cases less than five minutes. It also provides immediate and accurate bedside information to the clinician concerning the cannulation. This might be especially important for patients with cardiovascular or pulmonary diseases, where the treating clinician might be able to immediately confirm and treat the pneumothorax. There is also a monetary gain to be had, today all patients receiving a CVC normally undergo chest x-ray after which they are also obliged to stay for four hours of observation. Lung ultrasound could possibly be used instead of chest x-ray on certain patients in order to rule out mechanical complications. There are also studies done where the CVC position is confirmed by ultrasound only (33), however that is quite beyond the scope of this study.

Limitations of this study include small number of positive findings, i.e. few pneumothoraces were found. This makes conclusions from this study limited.

The present study implies that lung ultrasound is a fast and effective method to rule out pneumothorax after CVC insertion and was in the present study equally as effective as chest radiograph. As previously mentioned the pooled sensitivity for detecting pneumothorax with chest radiograph is 0.53 compared to 0.92 using ultrasound. To prove non-inferiority between the two methods with 90% power, a significance level of 5% as well as non-inferiority of 5%, at least 15 pneumothoraces would need to be found. This would mean a study group consisting of around 1500 patients. The potential benefits to be had are in our opinion great, not only sparing patients from unnecessary radiation, but also sparing resources.

In conclusion, this pilot study suggests that lung ultrasound is a fast, sensitive and effective method to use to rule out pneumothorax and might possibly be used as such in a clinical setting. Further studies with larger material are necessary before any definitive conclusions may be drawn.

Ethics

Permission was given from the head of the anesthesiology department to perform this pilot study. All patients gave verbal consent prior to examination.

Populärvetenskaplig sammanfattning

En central venkateter (CVK) är en plastslang som förs in genom huden in i en av kroppens större vener, vanligtvis placeras CVK slangen på höger sida under nyckelbenet eller på halsen. Detta görs i steril teknik, dvs diverse åtgärder vidtas för att undvika införsel av bakterier. Rent praktiskt så sker detta genom att en lång nål sticks in genom huden och sedan in i venen, därefter så förs en ledare in genom nålen, nålen dras ut och en plastslang förs in i venen trädd ovanpå ledaren varefter ledaren dras ut. En CVK läggs in i lokalbedövning och det finns många olika indikationer, vanligtvis så är det för att kunna ge patienten kärlretande läkemedel då mindre vener inte tolererar detta.

En pneumothorax är en kollapsad lunga, hos friska individer så hålls lungan uppspänd av ett undertryck jämfört med atmosfärstrycket. Detta undertryck existerar mellan lungan och bröstkorgsväggen. Vid trauma mot bröstkorgsväggen så kan det uppstå en passage mellan detta utrymme samt antingen lungan eller miljön utanför, i båda fallen så kommer luft att sugas in i utrymmet på grund av undertrycket. Detta kollapsar delvis lungan beroende på hur allvarlig skada som uppstår, i vissa fall så kan en akut livshotande situation uppstå.

En sådan skada kan ske vid inläggning av en CVK om nålen sticks något för djups och in i lungan.

Lungultraljud fungerar på precis samma sätt som vanligt ultraljud, dvs ljud med en vågfrekvens av vanligtvis 1 – 18 megahertz skickas ut och maskinen mäter sedan vågorna som studsar tillbaka vilket ger en uppfattning om föremålet dem studsat mot. En barriär med luft kommer att stoppa dessa vågor från att färdas i kroppen, varför lungultraljud ej använts mycket tidigare. Dock så uppträder olika fenomen vid lungultraljud vilka kan antyda hur lungornas tillstånd är, trotts att lungultraljudet inte ger en reell bild av dem.

Rutin på alla svenska sjukhus är att göra en radiologisk undersökning av patienten efter CVK inläggning. Nyligen så har ett intresse för lungultraljud blossat upp och man har kunnat visa att lungultraljud har en nära till 100% förmåga att utesluta pneumothorax om undersökningen sker på rätt område på bröstkorgsväggen.

Denna studien ämnade alltså undersöka huruvida lungultraljud kan användas för att hitta pneumothorax direkt efter inläggning av CVK samt efter ca 24h. 155 patienter undersöktes, 7 pneumothorax hittades av både röntgen samt lungultraljud. Två av dessa misstänkts starkt bero på CVK inläggningen varav en krävde omedelbar behandling. Således missades inga pneumothorax, dock hittades två falskt positiva fall som visade sig bero på stora lungtumörer. Dessa resultat är i linje med tidigare forskning och antyder att lungultraljud möjligtvis kan användas efter CVK inläggning istället för röntgen för att utesluta pneumothorax.

Acknowledgements

I would like to thank my supervisor Jonatan Oras for his invaluable help, continued support and insights. I would also like to thank Carl Hallgren for showing me how to use the ultrasound machine. Lastly I would like to thank the staff at preoperative ward 4 as well as the ICU staff at ward 22 for their help and assistance.

References

1. Robert W. Taylor, MD; Ashok V. Palagiri, MD: Central venous catheterization. Crit Care Med. 2007 May;35(5):1390-6.
2. Vardhandboken: Central venkateter. Revised 2016-05-30.
3. Sznajder JI, Zveibil FR, Bitterman H, et al: Central vein catheterization: Failure and complication rates by three percutaneous approaches. Arch Intern Med 1986; 146:259–261
4. Fares LG II, Block PH, Feldman SD: Improved house staff results with subclavian cannulation. Am Surg 1986; 52:108–11
5. Teichgraber UK, Benter T, Gebel M, et al: A sonographically guided technique for central venous access. AJR Am J Roentgenol 1997; 169:731–733
6. Randolph AD, Cook DJ, Gonzales CA, et al: Ultrasound guidance for placement of central venous catheters: A meta-analysis of the literature. Crit Care Med 1996; 24:2053–2058
7. Sabba JA, Hedges JR: Ultrasonographic guidance for internal jugular vein cannulation: An educational imperative; a desirable practice alternative. Ann Emerg Med 2006; 48:548–550

8. Lefrant JY, Cuvillon P, Benezet JF, et al: Pulsed Doppler ultrasonography guidance for catheterization of the subclavian vein: A randomized study. Anesthesiology 1998; 88:1195–1201

9. Bold RJ, Winchester DJ, Madary AR, et al: Prospective randomized trial of Doppler-assisted subclavian vein catheterization. Arch Surg 1998; 133:1089–1093

10. Raad I, Hohn DC, Gilbreath BJ, et al: Prevention of central venous catheter-related infections by using maximal sterile barrier precautions during insertion. Infect Control Hosp Epidemiol 1994; 15:231–238

11. David C. McGee, M.D., and Michael K. Gould, M.D: Preventing complications of central venous catheterization. N Engl J Med 2003; 348:1123-33.

12. Merrer J, De Jonghe B, Golliot F, et al. Complications of femoral and subclavian venous catheterization in critically ill patients: a randomized controlled trial. JAMA 2001; 286:700-7.

13. Sznajder JI, Zveibil FR, Bitterman H, Weiner P, Bursztein S. Central vein catheterization: failure and complication rates by three percutaneous approaches. Arch Intern Med 1986; 146:259-61.

14. Mansfield PF, Hohn DC, Fornage BD, Gregurich MA, Ota DM. Complications and failures of subclavian-vein catheterization. N Engl J Med 1994; 331:1735-8.

15. Martin C, Eon B, Auffray JP, Saux P, Gouin F. Axillary or internal jugular central venous catheterization. Crit Care Med 1990; 18:400-2.

16. Durbec O, Viviand X, Potie F, Vialet R, Albanese J, Martin C. A prospective evaluation of the use of femoral venous catheters in critically ill adults. Crit Care Med 1997;25: 1986-9.

17. Timsit JF, Bruneel F, Cheval C, et al. Use of tunneled femoral catheters to prevent catheter-related infection: a randomized, controlled trial. Ann Intern Med 1999;130: 729-35.

18. Bense L, Wilman LG, Hedenstierna G: Onset of symptoms in spontaneous pneumothorax: correlations to physical activity. Eur J Respir Dis 1987; 71: 181–186

19. Bradley M, Willams C, Walshaw MJ: The value of routine expiratory films in the diagnosis of pneumothorax. Arch Emerg Med 1991; 8: 115–116.

20. Marc Noppen et al: Pneumothorax. Respiration 2008;76:121–127.

21. Kenneth G. Bridges et al: CT DETECTION OF OCCULT PNEUMOTHORAX IN MULTIPLE TRAUMA PATIENTS. The Journal of Emergency Medicine, Vol 11, pp 179-186, 1993.

22. Wernecke K, Galanski M, Peters PE, Hansen J. Pneumothorax: evaluation by ultrasound-preliminary results. J Thorac Imag. 1987; 2:76–8.

23. R. Gentry Wilkerson, MD, and Michael B. Stone, MD, RDMS. Sensitivity of Bedside Ultrasound and Supine Anteroposterior Chest Radiographs for the Identification of Pneumothorax After Blunt Trauma. Acad Emerg Med. 2010 Jan;17(1):11-7.

24. Lichtenstein D, Meziere G, Biderman P, Gepner A. The ‘‘Lung Point’’: an ultrasound sign specific to pneumothorax. Int Care Med. 2000; 26:1434–40.

25. http://www.criticalecho.com/content/tutorial-9-lung-ultrasound

26. Lichtenstein DA, Meziere GA, Lagoueyte JF, Biderman P, Goldstein 1, Gepner A. A-lines and B-lines: lung ultrasound as a bedside tool for predicting pulmonary artery occlusion pressure in the critically ill. Chest. 2009;136(4):1014-1020

27. Jonathan P. Kline et al. Detection of Pneumothorax with Ultrasound. AANA Journal • August 2013 • Vol. 81, No. 4.

28. Norris RM, Jones JG, Bishop JM. Respiratory gas exchange in patients with spontaneous pneumothorax. Thorax 1968;23:427-33

29. Won-Il Choi, M.D., Ph.D. et al. REVIEW Pneumothorax. Tuberc Respir Dis (Seoul). 2014 Mar; 76(3): 99–104.

30. Daniel A. Lichtenstein. BLUE-Protocol and FALLS-Protocol Two Applications of Lung Ultrasound in the Critically Ill. Chest. 2015 Jun;147(6):1659-70.

31. Ding W Et al. Diagnosis of Pneumothorax by Radiography and Ultrasonography: A Meta-analysis. Chest. 2011 Oct;140(4):859-66.

32. Nermin Kelebek Girgin et al. Delayed pneumothorax and contralateral hydrothorax induced by a left subclavian central venous catheter: a case report. Clinics (Sao Paulo). 2010 May; 65(5): 562–565.

33. T Saul et al. The Ultrasound-Only Central Venous Catheter Placement and Confirmation Procedure. J Ultrasound Med 34 (7), 1301-1306. 7 2015.

34. Lovisa Ehrencrona. Förekomst av komplikationer vid användning av centrala venkatetrar hos cancerpatienter.

35. Daniel A. Lichtenstein et al. Ultrasound diagnosis of occult pneumothorax. Crit Care Med. 2005 Jun;33(6):1231-8.