ULTRASOUND GUIDED CENTRAL VENOUS CANNULATION

Protocol of essay

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By

Raafat Abdel rahman Abdel rahman
M.B.B.Ch
Faculty of Medicine
Ain Shams University

Supervised by

Professor Doctor/ Omar Mohamad Taha Elsafty
Professor of Anesthesia and Intensive care
Faculty of Medicine
Ain Shams University

Professor Doctor/ Mostafa Kamel Reyad
Professor of Anesthesia and Intensive care
Faculty of Medicine
Ain Shams University

Doctor/ Ramy Mounir Wahba
Lecturer of Anesthesia and Intensive care
Faculty of Medicine
Ain Shams University

Faculty of Medicine
Ain Shams University
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الطبيب/ رأفت عبد الرحمن عبد الرحمن
بكالوريوس الطب والجراحه جامعة عين شمس

تحت إشراف

الأستاذ الدكتور/ عمر محمد طه الصفتي
أستاذ التخدير والرعايه المركزة
كلية الطب - جامعة عين شمس

الأستاذ الدكتور/ مصطفى كامل رياض
أستاذ التخدير والرعايه المركزة
كلية الطب - جامعة عين شمس

الدكتور/ رامي منير وهبه
مدرس التخدير والرعايه المركزة
كلية الطب - جامعة عين شمس

كلية الطب
جامعة عين شمس
القاهرة
٢٠١١

INTRODUCTION

Central venous cannulation (CVC) is routinely performed in operation theatres and intensive care units. The requirement of catheter in central vein is increasing as large numbers of extensive surgical procedures are being undertaken. In USA approximately 5 million central venous catheters are inserted annually ***(Raad, 1998).*** Any patient staying for more than few days in the intensive care units invariably needs central venous catheter for the purpose of central venous pressure monitoring, vasopressor infusion, parenteral nutrition, or haemodialysis.

Routinely, central venous catheters are inserted percutaneously as a blind procedure using anatomical landmarks. Due to underlying anatomical variations this may result in multiple punctures and injury to nearby arteries, nerves, and pleura. Life-threatening complications like pneumothorax and arterial bleeding are known to occur. Mechanical complications are reported to occur in 5 to 19% of patients ***(Merrer et al, 2001).*** In 1984, two-dimensional ultrasound and Doppler techniques were first reported for internal jugular vein (IJV) cannulation. The recent development of portable lightweight ultrasound machines designed specifically for central venous cannulations has made them practical for routine clinical use. The needle can now be inserted under ultra sound guidance, making the procedure extremely safe ***(Sherma et al, 2006).***

AIM OF THE WORK

The aim of this work is to throw light on ultrasound guided cannulation, especially the technique, equipment, advantages, disadvantages, contraindications and complications.

ANATOMY

Site selection

There are a number of approaches to the central venous system and with exception of the external jugular vein and Peripherally-Inserted Central Catheters (PICC) lines they are generally deep structures often running close to arteries and nerves as well as other structures (e.g. pleura). This requires good knowledge of the anatomy of the area and the surface landmarks to aid the blind technique. 2-D Ultrasound is becoming much more widely used and is well suited to the internal jugular, femoral and peripheral approaches allowing visualisation and identification of anatomical variation ***(Key and Duffy, 2009).***

The main veins accessed are ***(Key and Duffy, 2009).***

• Internal jugular
• Subclavian
• Femoral
• External jugular
• Peripheral / Antecubital veins (Basilic or Cephalic)

Factors determining choice (Fig. 1) ***(Key and Duffy, 2009).***

• **Patient:** How long is the catheter required, suitability of vein for technique chosen e.g. Central venous pressure (CVP) measurement tip must be in thorax
• **Operator:** Knowledge and practical experience of technique
•**Technique characteristics:** Success rate for cannulation and central placement, complication rate, ease of learning, puncture of visible/palpable vs, blind and landmark technique.
• **Equipment available:** Availability of suitable apparatus and cost.

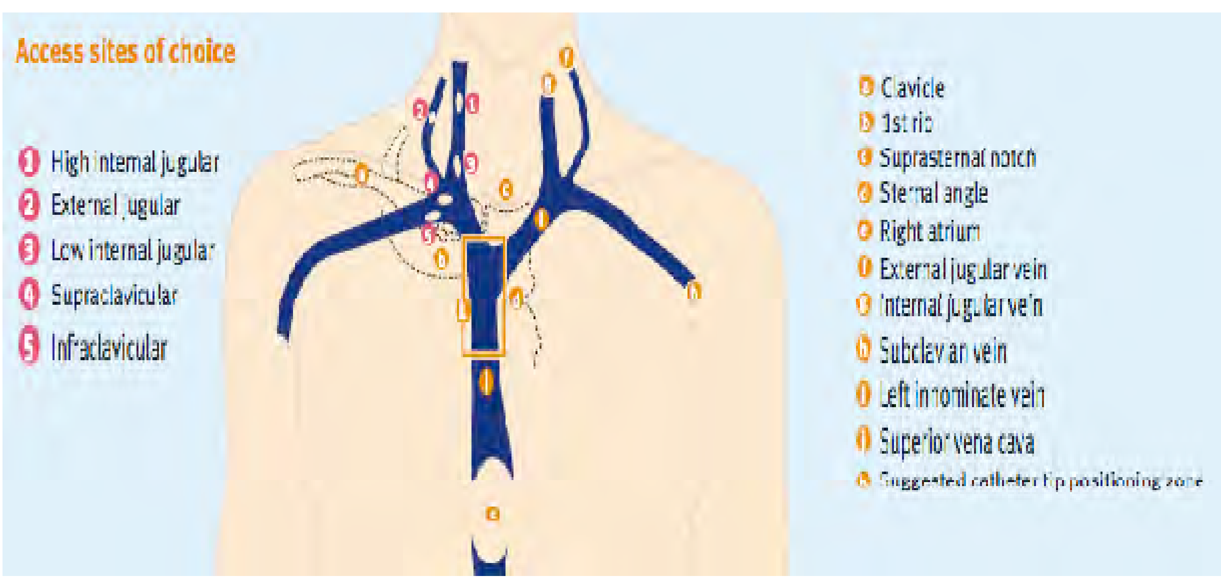

Fig 1. Access sites of choice ***(Key and Duffy, 2009).***

The Internal Jugular Vein

The internal jugular vein (IJV) is most frequently chosen site for Central venous cannulation (CVC) insertion. It is a potentially large vein with a lower risk of pneumothorax compared with the subclavian approach. Inadvertant arterial puncture can be easily controlled with manual compression. Many approaches have been described depending on the level of the neck at which the vein is punctured. A high approach reduces the risk of pneumothorax but increases the risk on arterial puncture. For lower approaches the converse is true.With experience this route has a low incidence of complications ***(Key and Duffy, 2009).***

Anatomy

The IJV arises from the jugular foramen at the base of the skull and is a continuation of the sigmoid sinus. It descends in the neck in the carotid sheath with the carotid artery and the Vagus nerve. It lies initially posterior to internal carotid artery before becoming lateral then anterolateral to the artery. Behind the medial end of the clavicle it joins the subclavian vein to form the brachiocephalic vein. The vein has dilatations at both ends, the superior and inferior jugular venous bulbs. Cannulation can be difficult in the morbidly obese as landmarks are often obscured and those patients with very short necks or limited range of movement can be ergonomically challenging. The IJV can be unilaterally absent in 2.5% of patients and is outside the predicted path in 5.5% of patients. The right IJV offers some advantages in that it tends to be larger and straighter than that on the left, it is more convenient for the right-handed practitioner and avoids the possibility of thoracic duct injury (fig.2) ***(Key and Duffy, 2009).***

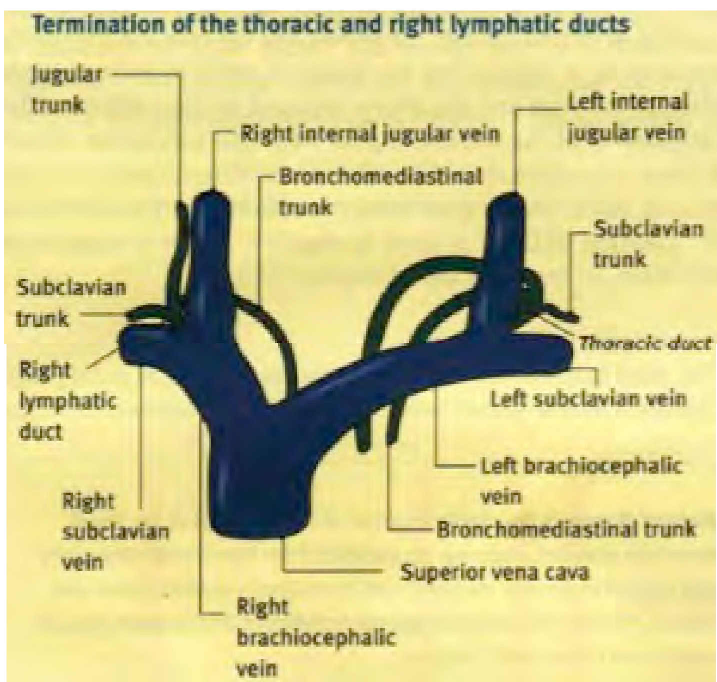

Fig 2. Termination of the thoracic and right lymphatic ducts ***(Key and Duffy, 2009).***

Positioning

The patient is supine, arms by their sides with a head down tilt to distend the veins and reduce the risk of air embolism. The head should be slightly turned away from the side of cannulation for better access (excessive turning should be avoided as it changes the relationship of the vein and artery and can collapse the vein). The patients neck can be extended by removing the pillow and putting a small towel under the shoulders ***(Key and Duffy, 2009).***

The Subclavian Vein

The subclavian vein (SCV) has a calibre of 1-2cm in adults and is thought to be held open by its surrounding tissues even in severe circulatory collapse. It is often preferred for long term central access as it is generally more comfortable for patients, can be easily tunnelled and has a lower risk of infection and other long term complications. This route may also be preferred in trauma patients with suspected cervical spine injury. This route is best avoided in patients requiring long term renal replacement as there is a significant risk of venous stenosis which cause problems for existing or future arteriovenous fistulae. It is also best to avoid in patients with abnormal clotting or bleeding diatheses as the vessels are inaccessible to direct pressure after inadvertent arterial puncture. Serious immediate complications are uncommon but occur more frequently than other routes. Pneumothorax is one of the most common major complications with an overall incidence of 1-2%. This figure increases to 10% if multiple attempts are made ***(Key and Duffy, 2009).***

Anatomy

The SCV is a continuation of the axillary vein as it reaches the lateral border of the first rib (fig.3). It ends at scalenus anterior where it joins the internal jugular vein to form the brachiocephalic vein behind the medial end of the clavicle. Its only tributary is the external jugular vein and it lies anterior and parallel to the subclavian artery throughout its course. Behind the artery lies the cervical pleura. Initially the vein arches upwards and across the first rib and then inclines medially, downwards and slightly anteriorly across the insertion of scalenus anterior ***(Key and Duffy, 2009).***

Positioning

The patient should be positioned as for the internal jugular approach with head down to fill the veins and reduce the risk of air embolism ***(Key and Duffy, 2009).***

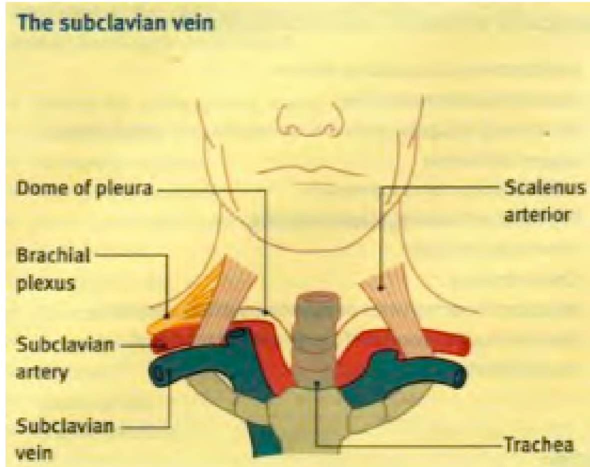

Fig 3: The subclavian vein ***(Key and Duffy, 2009).***

External Jugular Vein

As the external jugular vein (EJV) lies superficially in the neck it is often visible or palpable which negates many of the complications of the deep vein approaches. It is a useful when expertise is lacking, for emergency fluid administration and in cardiac arrests where no carotid pulse is palpable. However, due to the anatomy there is a 10-20% chance the catheter will not thread into the SCV and therefore CVP measurement will not be possible ***(Key and Duffy, 2009).***

Anatomy

The EJV drains blood from the superficial facial structures and scalp and passes down in the neck from the angle of the mandible, crosses the sternocleidomastoid muscle obliquely and terminates behind the middle of the clavicle where it joins the SCV. The vein is variable in size and contains valves which may prevent the passage of the guidewire and catheter. There is a wide range in EJV size and prominence due to natural variation and disease states ***(Key and Duffy, 2009).***

Positioning

As for IJV ***(Key and Duffy, 2009).***

The Femoral Vein

The femoral vein (FV) may be cannulated with low risk of serious short-term complications and for this reason is preferred by less experienced operators. This route is also useful in urgent situations when the patient is coagulopathic and is perhaps the safest central vein in children requiring resuscitation where peripheral access has failed. The large diameter of the FV allows large volumes to be removed and infused, and because of this, it is commonly used in the Intensive Care Unite (ICU) for placement of short-term heamofiltration catheters. Femoral catheters are better suited to ventilated, sedated patients as excessive movement can cause kinking of the catheter and mechanical complications. The CVP measurement from a femoral catheter can be affected by intra-abdominal pressure although in ventilated patient values correlate well with thoracic veins. Arterial puncture or femoral nerve damage are both possible if insertion is too lateral. The risk of infection in the medium and long-term is higher with femoral catheters compared with most other routes because of the greater degree of bacterial colonisation found in the groin compared to other sites. There is also an increased risk of thromboembolic complications compared with internal jugular and subclavian approaches. For these reasons femoral catheters should be removed within 48-72 hours of insertion ***(Key and Duffy, 2009).***

Anatomy

The FV starts at the saphenous opening in the thigh and runs alongside the femoral artery to the inguinal ligament where it becomes the external iliac vein. In the femoral triangle the FV lies medial to the artery in the femoral sheath ***(Key and Duffy, 2009).***

Positioning

The patient should be supine with a pillow under the buttocks to elevate the groin.
The thigh should be abducted and externally rotated ***(Key and Duffy, 2009).***

<u>The Antecubital Veins</u>

The superficial, palpable veins of the antecubital fossa provide a very safe route for central access. Risk of infection is lower than other routes and lines can be used for longer periods (e.g. TPN, prolonged antibiotic courses or chemotherapy). A long catheter is required (around 60cm) to thread the tip into the central veins and for this reason flow rates are low with large dead space making them less useful for resuscitation and inotropes. Tip position is important as migration can occur with movement of the arm (up to 7cm in cadaveric studies but around 2 cm in vivo) ***(Key and Duffy, 2009).***

Anatomy

Two main veins are available but the more medial basilic vein has a smoother, more direct route to the SCV. The more lateral cephalic vein turns sharply to pass through the clavipectoral fascia and also has valves at its termination. These factors frequently cause difficulty in advancing the catheter ***(Key and Duffy, 2009).***

The basilic vein ascends along the medial side of the forearm before moving anterior to the medial epicondyle where it is joined by the median cubital vein. It then runs along the medial edge of the biceps muscle to the middle of the upper arm where it pierces the deep fascia and runs along side the brachial artery becoming the axillary artery ***(Key and Duffy, 2009).***

The cephalic vein ascends on the front of the lateral side of the forearm to the front of the antecubital fossa where it communicates with the basilic vein via the median cubital vein. It ascends along the lateral edge of the biceps muscle until it reaches pectoralis major where it pierces the clavipectoral fascia to pass beneath the clavicle where it usually terminates in the axillary vein (occasionally it may join the EJV) ***(Key and Duffy, 2009).***

Positioning

Apply a torniquet to the upper arm and select the best vein. The medial side of the arm is best for the reasons mentioned above. Lie the patient supine with the arm abducted at 45° to the patient and the head turned towards the ipsilateral arm (this may help prevent the catheter passing into the IJV) ***(Key and Duffy, 2009).***

ULTRASOUND GUIDED DEVICES

Physics and principles of Ultrasound devices

Sound wave:

Sound wave is a mechanical disturbance that is propagated through solid, liquid, or gas medium. Sound waves don't propagate in vacuum. Sound waves are produced by vibrating sources which produces vibration of the adjacent molecules in the medium, which push against more dense molecules and so forth. The resulting mechanical disturbance travels away from the source at the speed of the sound ***(Sobbagaha, 1994).***

Sound energy behaves according to the principle longitudinally propagating waves with alternating compress and refraction of the transmitting medium ***(Miller, 1994).***

When a sound wave propagates through a medium, particles in the medium are displaced in the direction that is paracentral to the direction of travel of sound wave. This is called longitudinal wave, diagnostic ultrasound transducers are designed to produce longitudinal sound waves, because only longitudinal sound waves can be transmitted through soft tissues. It is possible in some media such as quartz and aluminum to generate sound waves in which the direction of the vibration of particles is perpendicular to the direction of travel of the wave. These are called transverse waves. In the body they can propagate through bone ***(Sobbagaha, 1994).***

Ultrasound:

The normal range of sound that human can perceive is 20,000 Hz. A sound wave with frequency higher than 20,000 Hz is called ultrasound ***(Higaashi et al, 1991).***

Frequencies between 1 and 40 MHz are used for medical purposes ***(Rolandi et al, 1993).***

Sound is characterized by the frequency (f) off the waves in the cycles per second or Hertz (Hz) and by wavelength (λ). These terms are related to the velocity of the sound (ν) as follows $\lambda = \nu/f$ ***(Davis et al, 1995).***

Ultrasound production:

When electric current is applied to each side of a piece of quartz coated with silver, the quartz expands or contracts from its original thickness, depending on the polarity of the current applied. This phenomenon is called a piezoelectric effect, and a substance with this polarity is called a piezoelectric element. This piezoelectric element returns its original shape with the removal of the current, and the energy produced is propagated to the surrounding media as ultrasound fig (4) ***(Collins and skorton, 1986).***

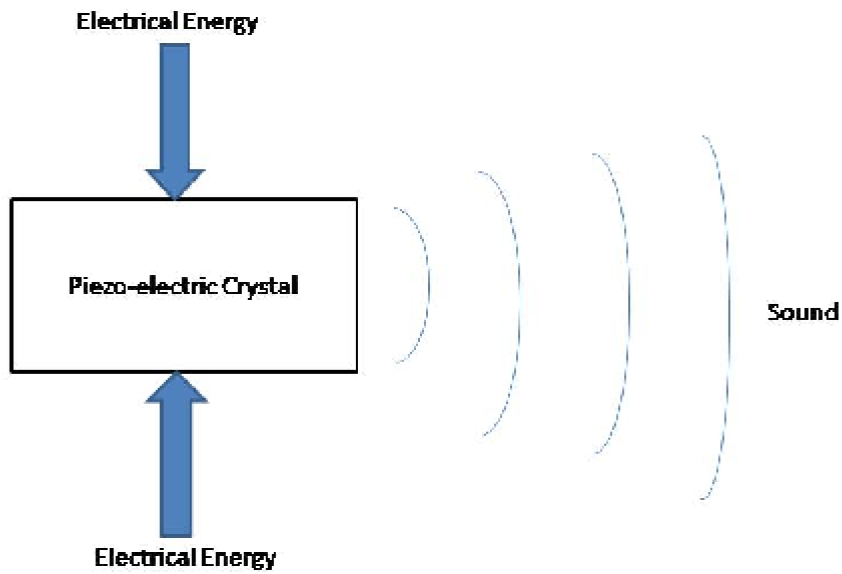

Fig 4: The production of Ultrasound waves relies on transformation of electrical energy into sound energy by a piezo electric crystal ***(Collins and skorton, 1986).***

When a piezoelectric element is physically compressed by externally applied ultrasound, it produces a current. Hence the piezoelectric element serves a dual function as both transmitter and receiver ***(Higashi et al, 1991).***

Because the sound is propagated by oscillations of the conducting medium, part of its energy is lost in this process. The degree of this attenuation of ultrasound is directly proportional to its frequency. This is tends to limit the maximum distance the higher frequency ultrasound can penetrate before it is completely absorbed. Since the intensity of ultrasound decreases as it travels through the medium, the echo apparatus incorporates a mechanism to amplify echoes from greater depth. This mechanism is called time gain compensation ***(Higashi et al, 1991).***

The principle characteristic of ultrasound that forms the basis of its use in imaging is its reflection from surfaces incountered in its path. A surface can be defined as the interface between two media of different acoustic impedence (z), which is determined by density and velocity of sound conductance of individual materials ***(Collins and skorton, 1986).***

The majority of body tissues are not homogeneous and the sound wave strikes a series of interfaces. These may be macroscopic, e.g. the wall of a blood vessel, or microscopis, e.g. the internal structure of the renal cortex. At each interface the wave can be reflected or refracted. Refraction occurs as the wave is transmitted through the interface. The angle of refraction is usually insignificant. However, if multiple refractions occur these can significantly degrade the image. The method of reflection depends upon whether the reflecting surface is large and smooth (specular) or small and irregular (non-specular). ***(Taylor, 2003)***

When the wave strikes a specular surface, for example the gall bladder wall, the angle of reflected sound is equal to the angle of the incident sound wave. In contrast, non-specular reflectors such as the liver parenchyma, scatter the sound wave is crucial to the production of the ultrasound images. Those which are refleceted back to the transducer strike the piezoelectric crystal. The sound energy is the converted by the crystal into electrical energy. By calculating the time taken for the sound to travel from, and to, the transducer the distance of the reflector can be calculated. Similarly the amplitude of the reflected sound can be used to calculate the reflectivity of the object. These calculations assume that the velocity of sound is constant in all body tissues ***(Taylor, 2003).***

In order to prevent interference between the transmitted and reflected sound waves the waves are transmitted in pulses. The further the sound has to travel the longer the delay between pulses and the lower the pulse repetition frequency (PRF). Typical PRFs are between 10 and 20 cycles per second (10-20Hz). Each pulse produces a new image (frame) and this is displayed on the monitor of the ultrasound system to produce a moving "real-time" image ***(Tylor, 2003).***

The proportion of sound reflected or transmitted at an interface depends upon the difference in acoustic impedance between the tissues forming the interface. The acoustic impedance measured in Rayls, is the product of the density of the tissue and the velocity with which it propagates sound. It can be seen from table 1 that many body tissues have similar acoustic impedances and that only a small proportion of the sound is reflected. However air and bone have radically different values to other tissues and as a consequence at such interfaces the majority of sound is reflected. This means that not only do these interfaces appear intense on the monitor but they cast a shadow as the reflected sound is not transmitted to the deeper structures. The practical implication is that ultrasound cannot be used to image deep to bone or air interfaces. One of the rationales for using ultrasound gel is to avoid a layer of air causing sound reflection between the ultrasound transducer and the skin ***(Taylor, 2003).***

Material	**Acoustic impedance (Rayls)**
Air	400
Fat	1 380000
Water	1 430 000
Soft tissue	1 630 000
Bone	7 800 000

Table1. Acoustic impedance of different materials. ***(Taylor, 2003).***

Resolution:

It is the ability to discriminate two points that are placed close to each other. For ultrasound systems this can be measured in two planes, the axial and transverse. Axial resolution is measured along the axis of the ultrasound beam in its direction of propagation. It is directly proportional to ultrasound frequency. Transverse resolution is measured at 90° to axial resolution. The quality of transverse resolution depends upon the probe design, in particular the number of crystals, the narrow the ultrasound beam, the better the resolution becomes. Axial is always superior to transverse resolution (fig.5) ***(Taylor, 2003).***

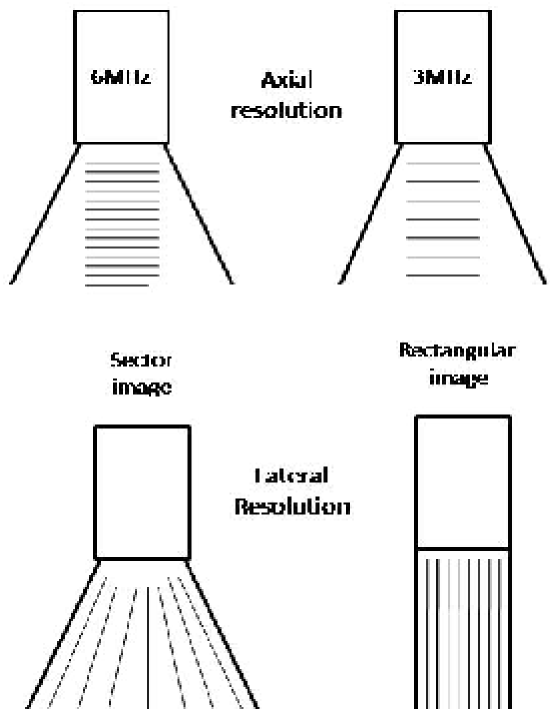

Fig 5: Axial resolution, along the axis of sound propagation, is proportional to the frequency of sound. Lateral resolution, at 90° to the direction of propagation, depends upon the geometry of the transducer. Lateral resolution is always inferior to axial resolution and, in the case of transducers which produce sector image declines with increasing depth ***(Taylor,2003).***

As mentioned before, the amount of attenuation of ultrasound is directly proportional to its frequency.Thistend to limit the maximum distance that higher frequency ultrasound can penetrate before it is completely absorbed. On one hand, the higher frequencies allow better resolution of the details of internal organs of the human body ***(Higashi et al, 1991).***

Imaging modules:

Medical ultrasound uses sound frequencies in the range 3–15MHz (the upper limit of human hearing is 20 kHz). The piezoelectric effect is used to generate soundwaves and the probe acts as both transmitter and receiver. Tissue penetrance is inversely related to probe frequency. Thus, high frequency probes (7.5–10 MHz) are most useful for CVC. There are various modes of ultrasound. B-mode (brightness mode) provides real-time two-dimensional images; most clinicians are familiar with this. Many machines can combine B-mode with Doppler imaging (duplex scanning) ***(Hatfield and Bodenham, 2005).***

Quantitative assessment of blood flow is possible because moving red blood cells reflect sound waves producing a Doppler shift. Audible Doppler-only machines provide no image and are of limited value in CVC. Soundwaves are attenuated as they pass through body. Fluidfilled structures appear black as fluid transmits sound well and there is no reflection. Sound is reflected off bone and air as they do not transmit sound well. This generates a bright echo (seen as white) on the image; it also results in an acoustic shadow (black) in which no structures can be seen. In normal patients, imaging intrathoracic structures is limited by air-filled lungs ***(Hatfield and Bodenham, 2005).***

A (Amplitude) mode:

It provides display of the amplitude of the echo signals in relation to the distance from the probe along a single observation direction. The height of a peak is influenced not only by the difference in the media that define the particular surface, but also by the distance of the object from the transducer. This points to the importance of time gain compensation to correct for ultrasound attenuation ***(Miller, 1994).***

B (brightness) mode:

B mode display converts A mode peaks to dots of an intensity that is proportional to the amplitude of the signal ***(Miller, 1994).***

M (Motion) mode:

The first echocardiograms “motionor” (M-mode) studies were one-dimensional views of cardiac structures produced by single crystal transducers with the results traced on moving photosensitive paper. Today, M-mode transducers can produce up to 1,000 images per second. However, M-mode images reveal only a small portion of the heart at one time, making orientation of spatial relationships difficult ***(Cahalan, 1996).***

2-D (two-Dimentional) scanning:

2-D ultrasound scanning represents a significant advance in ultrasonography, because it provides a recognizable image of the objects being examined ***(Oka and Goldiner, 1992).***

By using multiple crystals (linear or phased array transducers) or by rapidly moving a single crystal (mechanical transducer), multiple views can be obtained and collected into a 2-D image. Although 2-D techniques produce only 30 images per second, definition in 2