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Ultrasound Guided Vascular Access

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1. Introduction

Vascular access is an important procedure for clinicians to master. Chronic medical conditions, intravenous drug use, and obesity can all make placements of vascular catheters in central and peripheral veins challenging and time-consuming. External landmarks have traditionally guided the placement of the needle for the performance of central venous catheterization. The proximity of such structures as the large arteries of the chest and neck as well as the apex of the lung results in a 6.2-11.3% rate of immediate mechanical complications when performing subclavian or internal jugular catheterization.¹ In recent years there have been significant improvements in portable ultrasound technology including the development of relatively inexpensive ultrasound machines with sufficient resolution to guide needle placement through tissues. These machines are now found throughout the house of medicine by the bedside of patients. Multiple studies have been performed demonstrating the benefits of ultrasound guidance of central venous catheter placement by multiple specialties, and the same technique has been extended to the placement of peripheral intravenous catheters.^{2,3,4,5,6} In this chapter, we describe the use of ultrasound for guidance of vascular access.

2. Use of ultrasound for vascular access

2.1 Transducer selection

Transducer characteristics, such as frequency and shape, determine ultrasound image quality. For the purpose of vascular access, it is ideal to use high frequency and small footprint transducers. The high-frequency linear array transducer provides higher resolution of the superficial areas of soft tissue including artery and veins. The flat and small footprint shape of the linear array transducer is less prone to slip off of the vessel of interest. Modern transducers are designed to generate a range of frequencies. For example, linear 5-12 MHz transducer can be used to adequately scan deeper targets if it used in lower range of frequencies. In general, transducers in the range of 5-12 MHz are preferred as the depths of target vessels for accesses are often limited to 2-4 cm below the skin surface.⁷

2.2 Modes

B-Mode and color Doppler are the main ultrasound modes used for the purpose of venous access. B-mode ultrasound produces recognizable two dimensional (2D) gray scale images.

Color Doppler is an application to characterize blood flow. The doppler effect occurs when blood flow of red blood cells move toward or away the ultrasound transducer. If the flow in a vessel is moving towards the transducer, the color displayed in the vessel is RED and when the flow is moving away from the transducer, the perceived frequency display is BLUE (BART – Blue Away and Red Toward). (Figure 1A, B) To clearly display the presence of a flow in an artery or vein, it is necessary to create an angle between the transducer and the direction of the flow. The color Doppler detection of flow is optimal when the transducer is parallel (0 degrees) to the flow and it is worst when the transducer is perpendicular (90 degrees) to the vessel, so in clinical practice, some angulations of the transducer are necessary to optimize color Doppler signal.

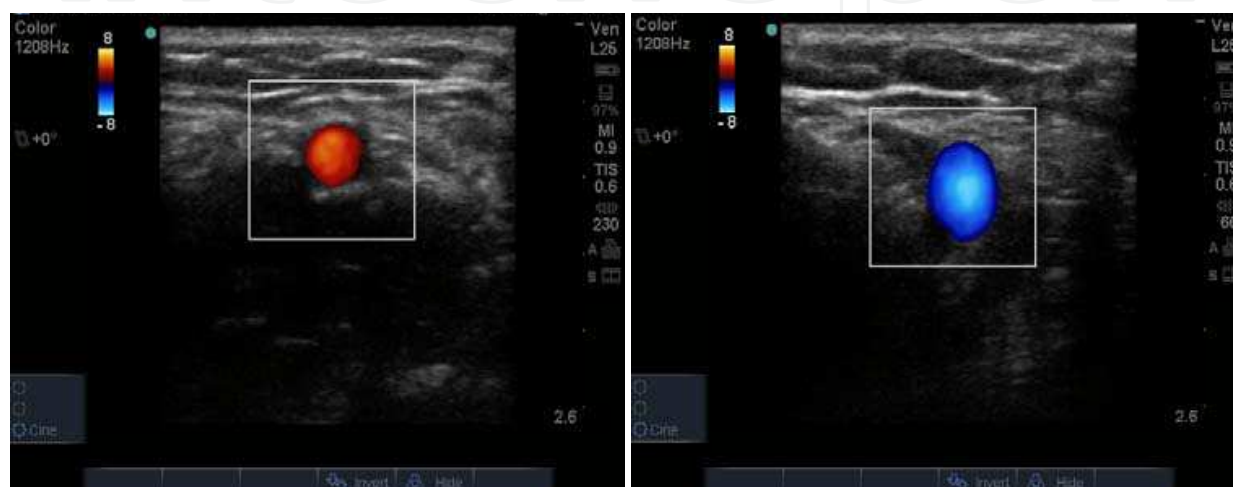


Fig. 1. (A) Transverse view, the brachial artery without compression with color flow TOWARD the transducer, (B) Transverse view, the brachial artery without compression with color flow AWAY from the transducer

2.3 Optimizing image quality

Best visualization of target vessels with ultrasound requires an optimal machine setting. In general, proper transducer selection and the selection of pre-programmed vascular ultrasound settings provide acceptable quality images. Additional controls that can further improve the image quality include gain, depth, focus and frequency.

Depth: Proper depth adjustment provides better target vessel imaging and facilitates tracking the needle through the tissues. By increasing the depth setting, the target vessel gets smaller and smaller. With too shallow a depth setting, important structures in the vicinity of the target vessel (such as a neighboring artery) may be lost off the far edge of the screen. It is therefore important to select the appropriate depth setting according to the target vessel location.

Gain: The brightness of the image on the screen is controlled by the gain setting of the ultrasound machine, and the quality of images displayed on monitor also depends on the selected gain. Increasing the gain makes the image brighter, while decreasing the gain makes the image darker. In addition to the overall gain, selected regions of the screen can be adjusted by selecting gain controls for the near field or far field. Inappropriately increased gain will add "noise" artifact to the image that adversely impact the quality of images.

Focus: The highest resolution of the displayed image is at the focal zone. Some machines automatically adjust the focal zone to the center of the screen, however, in systems with a manually adjustable focus, it is important to place the 'focus' at the level of the target vessel of interest.

3. Image orientation

Proper transducer orientation is an important step to accomplish a successful procedure. Most transducers have an indicator of some sort on one side of the probe that corresponds to a mark displayed on one side of the displayed image on the screen. (Figure 2A and 2B)



Fig. 2. (A) A high frequency linear transducer for vascular procedure, with orientation indicator (B) Localization and matching orientation indicator with ultrasound indicator on screen (green dot)

The aim is to keep the indicator on the side of the probe oriented in the same direction as the orientation mark side of the monitor. By default, the orientation mark is usually displayed at the left side of the image and keeping the indicator toward the left side of provider will largely prevent further confusion about the orientation. If there is any confusion about the orientation of the probe, a finger can be rubbed on one side of the transducer surface after gel application to produce an image on the screen and confirm the orientation.

3.1 Preparing a sterile transducer

Central venous access is a sterile procedure. In order to use ultrasound, the probe needs to become part of the sterile field. When preparing for the procedure a sterile ultrasound sheath should be placed on the sterile field. Ask your assistant to apply ample sterile or non-sterile gel into the sterile sheath. Place the ultrasound transducer inside the sterile sheath and ensure that gel is applied generously between the transducer and inside of the sheath covering. Smooth the sheath covering over the transducer surface to avoid any wrinkles or trapped air that could impede full contact. Wrap the sterile rubber band supplied with most commercially available probe covers around the transducer to avoid transducer movement inside the sheath during ultrasound scanning.^{8,9}

Alternatively, if a sterile probe cover is not available, a sterile glove can be used to cover the transducer surface, although this does not cover the cable of the ultrasound probe and care

must be taken during the procedure to prevent contamination of the sterile field by the cable. Applying generous amount of gel into the sterile glove and sliding the transducer into the glove's thumb may prevent air trapping or wrinkle on the contact surface. (Figure 3)

<ol style="list-style-type: none">1. Sterilize the skin surface thoroughly with an antiseptic solution2. Surround the CVC placement location with full body sterile fenestrated drape3. Using sterile technique, open the probe cover packet onto the sterile work field4. The gowned and gloved provider places ½ of the contents of the sterile gel inside the sheath5. Place the transducer inside the sheath, taking care to displace any air bubbles between the probe face and the probe cover6. Extend the sterile sheath to cover the cord completely7. Hold the sheath in place with a rubber band around the transducer head8. Place the transducer on the sterile field9. Use a package of sterile acoustic gel10. Apply sufficient amount of sterile gel over the site of scanning11. Place the transducer over the procedure site, identify target vessel, and proceed with cannulation
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Table 1. Preparing the ultrasound transducer for central venous catheterization



Fig. 3. Probe position and needle insertion to approach internal jugular Central line access by using a sterile glove as an alternative to sterile probe cover

4. Planes and views

Transverse and longitudinal views are two main planes used for the purpose of vascular access. In transverse view, the transducer plane is in cross section of the target vessel and the vessel is displayed on the screen as a circle. In longitudinal view, transducer plane and vessel plane are parallel and the vessel is displayed on the screen as a long tube running across the screen. A longitudinal view allows visualization of entire vessel of interest, but it

requires that transducer beam, needle and target vessel be held parallel, which can be challenging for the novice user.^{10,11}

In general, we recommend starting with transverse view as it allows visualizing adjacent structures including artery and nerve in the area and is easier to visualize the tip of needle and its insertion. The provider can switch between the two views during the procedure as needed to track the progress of the needle moving toward the target vessel.

4.1 Differentiating artery and vein

Differentiating between artery and vein is essential to safely perform ultrasound guided vascular access. Compressibility of veins is the simplest way to distinguish artery from vein. Veins typically compress with minimal pressure applied from the probe, while arteries retain much of their original shape and appearance. When performing internal jugular vein placement one may visualize the influence of respiratory variation on the vein diameter. Valsalva maneuvers and trendelenberg positioning make the vein larger but have minimal affect on the carotid artery. The application of color Doppler is also very useful in differentiating artery from vein. Arteries have pulsatile flow visualized on color Doppler, while the vein has minimal flow. (Figure 4A and 4B)

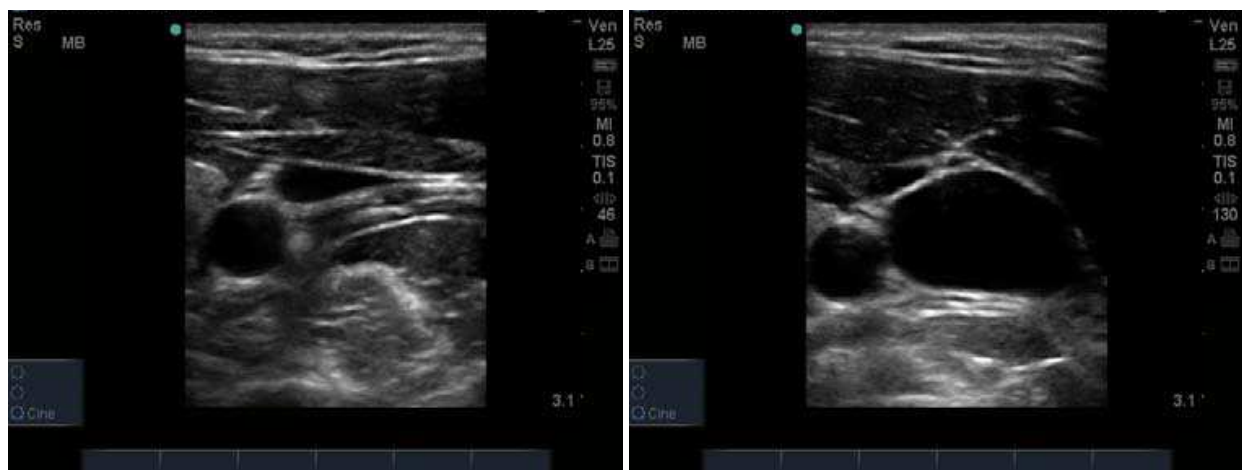


Fig. 4. (A) Transverse view of right internal jugular vein (with mild compression) and adjacent carotid artery (B) Transverse view of a distended right internal jugular vein during Valsalva maneuver and adjacent carotid artery

4.2 Scanning techniques

Static vs. Dynamic: The guidance of vascular access using ultrasound can be categorized as static or dynamic. In the static use of ultrasound, the provider would apply ultrasound to localize the vein and mark the site of needle insertion on the skin; after that the procedure will be performed much like a traditional landmark-based approach.

In dynamic guidance, the provider uses the ultrasound in “real time,” with continuous visualization of the needle insertion throughout the procedure. The authors highly recommend the dynamic approach on performing central venous access considering the possibility of changes due to patient movement in the time interval between marking and needle insertion in the static approach. The success rates for dynamic guidance as compared

with the static technique is significantly higher. Direct ultrasound guidance gives the opportunity of visualizing the needle in real time to puncture the vein and avoid puncturing adjacent artery and nerves but it is more technically demanding because it requires significant eye-hand coordination and it requires a sterile probe cover throughout the procedure.

One-provider vs. Two-provider: The dynamic use of ultrasound can be conducted by a provider operating alone, or by two providers. In the one-provider method, the provider holds the ultrasound transducer with the non-dominant hand and the needle with the dominant hand. In the two-provider method, a sterile assistant will hold and control the probe while the provider performs the needle insertion under real-time ultrasound guidance. We recommend the one-provider method, as it not only allows for more flexibility and the ability to perform the procedure independently, but also enables the provider to make very small movements of the ultrasound probe in conjunction with the needle to enhance localization of the needle tip. In a small study among 44 cases focusing on the specific question of whether single- vs. two-provider technique was advantageous revealed no significant differences.^{12,13}

Out-of-Plane vs. In-Plane Approach: Needle insertion can be performed in either in- plane (longitudinal) or out-of- plane (transverse) in relation to the ultrasound transducer. During the in-plane insertion, the needle is placed parallel to the transducer and the full length of the needle shaft and tip are visualized. In the out-of plane approach, the needle is placed perpendicular to the transducer and either the needle shaft or the tip is visualized as a hyperechoic dot on monitor. In this method, needle, vein, adjacent artery or vein and tissue movements are observed. The choice of these two methods depends on the location of the vessel, provider experience, and anatomic relationships. In a study by Blaivas et al. they reported that the technique utilizing a transverse, short-axis view of the needle in vascular access was easier for novices to learn than a technique using longitudinal scan.¹¹

5. Ultrasound - guided catheter insertion techniques

5.1 Internal jugular vein

Anatomy and ultrasound technique: The internal jugular vein (IJ) is typically located anterior and lateral to the carotid artery; however, there is a significant anatomic variation where the vein can overly the artery and even be medial to the artery. As described above, the IJ vein and carotid artery can be differentiated by the fact that the vein is compressible, non-pulsatile, and distensible by the Trendelenberg position or the Valsalva maneuver.¹⁴ (Figure 4A and 4B)

Contralateral rotation of the head significantly affects the relative anatomy of the IJ vein and carotid artery. Extreme contralateral head rotation can decrease IJ vein diameter and increase overlap on the carotid artery.^{8,14}

In longitudinal view, the IJ vein can be followed inferiorly, down to the level of the sternoclavicular joint where it joins the subclavian vein on each side and drains into the superior vena cava.⁸

Positioning and preparation: Proper positioning of the patient significantly affects the likelihood of a successful procedure. For the IJ cannulation, patient's head should be rotated

slightly contralaterally, with the neck extended. Extreme rotation of the neck may increase the amount of overlap of the carotid artery and IJ vein. The patient should be placed in Trendelenburg position in order to maximally distend the IJ vein. The ultrasound machine should be placed by the same side of the bed and directly in front of the provider to provide a direct line of vision that is ergonomic and efficient.

An initial examination of the surrounding areas and the target vessels should be performed to confirm the patency of the IJ vein and absence of thrombosis prior to applying the sterile probe cover and prepping the patient. Following this important step, the procedural areas of the neck and upper chest should then be prepared in the usual manner, and full barrier precautions should be used to maintain sterility of the procedure.^{2,8,9} A sterile probe cover should be applied as discussed in Table 1. The CVC catheter should be set up per normal routine. The catheter ports should be flushed to remove air and to check for their patency. The equipment needed for catheter insertion, including the CVC kit should be set and place within an easy reach. Local anesthetic should be applied at the site of puncture.

Catheter Insertion: Provider should use the dominant hand to handle the needle and the non-dominant hand to hold and handle the transducer. If prefer to start with transverse view, the needle is placed perpendicular to the transducer directly underneath the middle of the transducer while jugular vein placed in the center of the screen. The needle insertion site should be 0.5-1 cm proximal to the transducer. In this approach, the needle tip and the shaft are visualized as a hyperechoic dot on monitor. If the needle tip cannot be visualized, indenting the tissue overlying the vein or moving the transducer along the axis of the vein while “agitating” the needle may enhance the image of the needle and tip. If consider longitudinal plane, the needle is placed inline with and parallel to the transducer in which the entire length of the needle and the tip are visualized as puncture the vein. Once the vessel has been successfully punctured, the transducer can be set aside and the procedure can proceed normally with wire and catheter placement. The wire should be advanced slowly with no pressure at the length of the needle plus 5-6 cm. considering the short distance of the puncture site and superior vena cava to the right jugular vein extreme precaution should be used not to advance the catheter too far to prevent right atrial or ventricular wire insertion. After wire placement, the needle is removed and a small incision is made around the wire insertion to facilitate dilator insertion. After removal of the dilator, the catheter is then advanced to the desired distance that is 4-5 cm shorter in the right jugular vein compare to the left IJ vein.^{8,9} Once the line is in place, it should be properly flushed in all ports, secured, and dressed. Post procedure chest X ray is required to confirm proper catheter placement and the lack of complications including pneumothorax to start using the central catheter.

5.2 Subclavian vein

Anatomy and ultrasound technique: Subclavian vein is a continuation of the axillary vein at the lateral border of the first rib that crosses over the first rib and passes in front of the anterior scalene muscle that separates the vein from subclavian artery. The subclavian vein (SC) continues in main length behind the medial third of clavicle which makes it less available for ultrasound scanning. At the junction of Sternoclavicular joint in each side SC veins join to the IJ veins and form the innominate vein to the left and brachiocephalic vein to the right side.¹⁵

To visualize the Subclavian vein, the ultrasound transducer is placed at the supraclavicular space posterior to the long axis of clavicle to obtain a longitudinal view of the SC vein. At this level it is critical to differentiate SC vein from the SC artery as they pass in parallel along side of each other. The SC vein can be distinguished from the artery by the fact that the SC vein is in a more medial and superficial than artery and by following its path medially it can be traced to IJ vein. The SC vein is not pulsating and affected by Valsalva maneuver similar to IJ vein.

SC vein can be visualized at the infraclavicular region by placing transducer at the mid third of clavicle while the half of the footprint covering the cross section of the clavicle and the lower half investigating the infraclavicular region.

Catheter insertion: The SC vein access with ultrasound guidance can be performed through either supraclavicular or infraclavicular approach. In supraclavicular approach while the vein is visualized the probe will be adjusted toward the medial end of the vein near the junction of IJ vein to provide sufficient space for the needle placement under real time ultrasound guidance. Following the puncture site identification, the area is prepped and draped sterilely and the ultrasound transducer sterile cover should applied as described previously. Furthermore, the ipsilateral IJV area should be prepped in case of possible catheter misplacement required proper ultrasound guided repositioning. While the needle gains access to the SC vein the guide wire would advance and the transducer can be set aside and proceed with a normal procedural steps according to the Seldinger's technique.

Typically, the subclavian vein is more difficult to visualize by ultrasound due to its position under the clavicle, which requires significant angulations and manipulation of the transducer to acquire and maintain sufficient imaging during real time procedure. Therefore, it is less ideal procedure compare to ultrasound guided IJ CVC access.

5.3 Femoral vein

The proximal femoral vein is medial to the femoral artery, deep to the fascia iliaca and superficial to the iliopsoas muscle. At the lower level the vein gradually descend posterior to the femoral artery that would be deeper in ultrasound scanning. For the purpose of CVC placement provider should consider more proximal (cephalad) puncture site where the vein is medial to the artery. Minimal pressure on the vein can totally compress the vein confirming the lack of thrombosis. Often, inguinal lymph nodes also appear as hyperechoic structure in the region that need to be distinguished by scanning proximally and distally in this region. The femoral vein should be distinguished from the artery by the fact that the vein is in a more medial and deeper than artery and by examining its compressibility and lack of pulsatile doppler.

Catheter insertion: Before applying sterile procedures, we recommend to perform a systematic anatomical survey from medial to lateral and superficial to deep, distinguishing vein from artery and investigating the presence of thrombi. The groin area should be exposed while patient is in supine and the leg is in natural position. After area and transducer preparation in a sterile manner (table 1), transducer should be placed along the inguinal crease. If the femoral artery and nerve are deep, the machine imaging capability should be adjusted appropriately by increasing the depth and adjusting the gain. Starting with a short axis view will provide a sufficient image of adjacent structure and facilitate a

proper needle insertion. However, transducer can be rotated 90 degree while the femoral vein image keep in the center of screen and it provide a longitudinal view of the vein. While the venous puncture confirmed, the procedure should be proceed identical to the SC and IJ vein access considering the Seldinger's technique.

6. Ultrasound - guided peripheral venous access

Intravenous (IV) access is a basic and critical procedure, which routinely performs, in medical community. IV access usually uses to administer medication, IV fluid, obtaining blood sample and it is one of the necessary actions for patients who need to be admitted in hospital. This procedure usually performs by medical technician or nurses, but sometimes they are unable to obtain access and this could delay patients' care. This section will discuss important key features regarding peripheral IV access and pitfalls to enhance success rate to insert IV access without any invasive procedure.



Fig. 5. Transverse probe position to approach peripheral IV access with orientation indicator toward to right side of patient

6.1 Anatomy

The upper extremity consists of two types of veins, superficial and deep. These 2 sets of veins have several communications, known as anastomose. The deep veins accompany the arteries. They are connected to the superficial system by perforating veins. The depth of vein is measured by distance from skin. The superficial veins start on the back of the hand as a dorsal arch. Cephalic and Basilic veins are example of superficial veins. Dorsal veins of the hand empty into the cephalic vein on the lateral aspect and into the basilic vein on the medial aspect of the forearm. The cephalic vein ascends in the radial (lateral) aspect of wrist and courses laterally upward around the anterior surface of the forearm. Under the front of the elbow it divides to some branches, which receives a communicating branch from the deep veins of the forearm and passes across to join the basilic vein. In the upper arm, the cephalic vein terminates in the infraclavicular fossa, and empty into the axillary vein. The

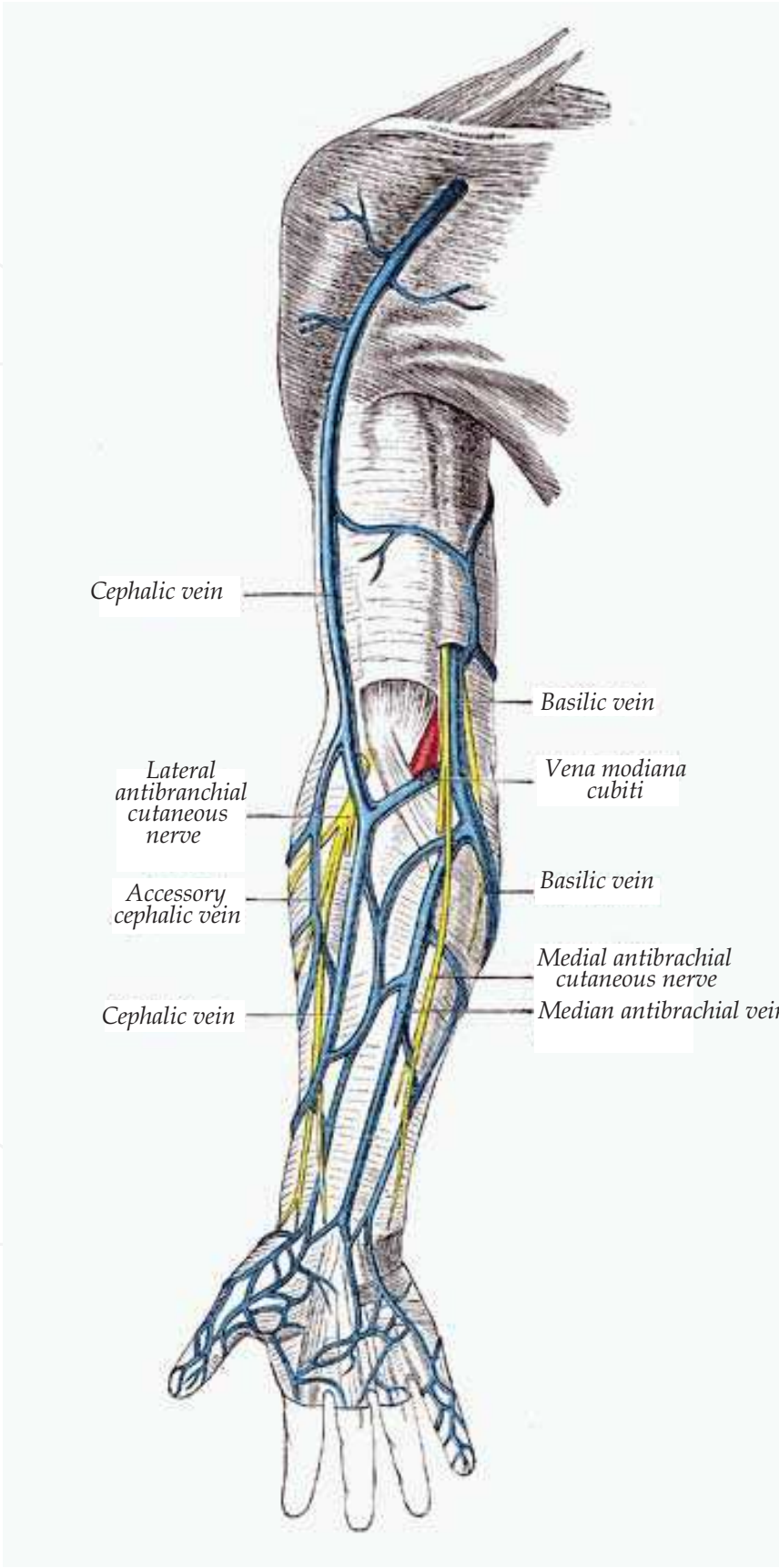


Fig. 6.

basilic vein runs medially along the ulnar part of the forearm and penetrates the deep fascia as it courses past the elbow in the upper arm. It then joins with the deep brachial veins to become the axillary vein. The median cubital vein joins the cephalic and the basilic veins on the ventral surface of the elbow. The axillary vein becomes the subclavian vein at the lateral border of the first rib. At the medial border of the scalenus anterior muscle, the subclavian vein joins with the internal jugular vein to become the brachiocephalic vein, with the subclavian vein coursing anterior to the scalenus anterior muscle. The left and right brachiocephalic veins join to become the superior vena cava, which empties into the right atrium.^{16,17}

6.2 Preparation

The ability to obtain US guided IV access is a skill that combines knowledge of peripheral IV access and US. Provider should collect necessary equipment prior to start the procedure at the bedside. Provider should consider contraindication to start IV access in upper extremities such as burn, cellulitis, end stage renal disease access, scar from previous trauma or surgery, and breast cancer on dependent arm. Provider should explain the procedure to patient and request permission to start IV access. Basic equipment at bedside should consist of appropriate angiocatheter size, tourniquet, skin cleaning instrument (alcohol or betadine swab), 2x2 gauze, tape, band-aid, sterile transparent dressing, blood tube, iv tubing and extensor, vaccutainer, normal saline flush, sharp container, biohazard bag, gloves, sterile lubricant and of course ultrasound machine.

6.3 Procedure

This procedure can be done as one or two person procedure. Usually one-person procedure is a routine and acceptable procedure. In this procedure provider can have a control of probe and can change angle, depth or approach instead of asking the second person to manage probe. The high frequency, linear probe is appropriate for peripheral IV access. Using high frequency probe will show superficial structure. The vascular structure consists of vein and artery. Veins will be anechoic structures and easily compressible with probe pressure. Arteries are anechoic structures, which they could be compressible but they have a pulse and will pulsate under probe pressure. There is another way to distinguish between veins and arteries using color Doppler flow. In this scenario, arteries will have central red color flow pulsating compare with veins that there is a blue non-pulsating color.

After having equipment ready for IV access and explain procedure to patient, skin needs to be clean with cleansing agents, and then tourniquet should be applied to upper arm. Ultrasound probe with orientation marker should be facing to right side of patient this will correlate with an indicator on the left side of US monitor and left side of probe. The next step is to use sterile gel to locate vascular structure. As mentioned above, veins are easily compressible with transducer pressure and should be located in the middle of screen. The depth key should be adjusted to make sure veins are in an approachable depth. Vascular structure on short axis should be circular versus long axis. Using short axis approach, the vein should be in the middle of screen. In this situation, middle of transducer is compatible with middle of US screen. Appropriate angiocatheter size

should be use and clean 3cm above the antecubital area, then introduce angiocath with 45 degree and cannulate skin. You should see the tip of needle as a hyperechoic structure and you should approach the vein. You will stop advancing your needle as soon as you get blood flush back. Now remove introducer and advance plastic angiocatheter all the way in. You need to attach extensor and apply sterile dressing to accomplish your procedure. (Figure 5)

6.4 Complication

There are several complication related to peripheral IV access. These complications are divided to vascular, infectious, and neurological. Vascular complication include arterial puncture and formation of hematoma, local infiltration or extravasations of fluid, superficial or deep vein thrombosis. The most common infectious complications with US guided IV access are phlebitis and cellulitis. Soft tissue swelling and superficial vein thrombosis can mimic the infection at IV site. Paresthesia due to nerve irritation and local infiltration is the most common complication. There is no long-term nerve damage was reported.

7. US guided arterial line

The radial artery is the extension of the brachial artery. It is originating inferior to elbow along the lateral side of forearm along the radius bone. The main part of focus is radial artery in wrist.

Arterial line placement is an invasive procedure, which it requires skill and expertise to perform it. It is painful procedure and needs a lot of preparation. Preparation is already discussed in aforementioned section, but arterial line kit is additional equipment that we need for this procedure.

7.1 Indication

There are several indications for arterial line placement. Reliable and frequent blood pressure measurements in patients who are hemodynamically unstable, access to arterial blood for frequent acid-base, or blood gas sampling.¹⁸

7.2 Procedure

US guided arterial line requires fewer attempts and more success rate. After prep and drape in sterile fashion, and cover US probe with sterile cover, arterial line should be located. The characteristic of artery as mentioned above is pulsating in nature with special color Doppler and non compressible. US probe should be in radial side of wrist with orientation indicator facing to right side of patient. After anterior surface of the artery is punctured with the bevel of the angiocatheter facing up and pulsatile blood return, this indicates an intra-arterial position. The rest of procedure is the same as described in peripheral IV access.

The arterial line complications include arterial puncture and hematoma, thrombosis, and infection.

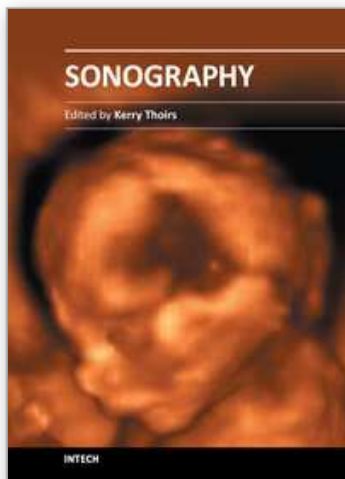
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Sonography

Edited by Dr. Kerry Thoirs

ISBN 978-953-307-947-9

Hard cover, 346 pages

Publisher InTech

Published online 03, February, 2012

Published in print edition February, 2012

Medical sonography is a medical imaging modality used across many medical disciplines. Its use is growing, probably due to its relative low cost and easy accessibility. There are now many high quality ultrasound imaging systems available that are easily transportable, making it a diagnostic tool amenable for bedside and office scanning. This book includes applications of sonography that can be used across a number of medical disciplines including radiology, thoracic medicine, urology, rheumatology, obstetrics and fetal medicine and neurology. The book revisits established applications in medical sonography such as biliary, testicular and breast sonography and sonography in early pregnancy, and also outlines some interesting new and advanced applications of sonography.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Hamid Shokoohi, Ali Pourmand and Keith Boniface (2012). Ultrasound Guided Vascular Access, Sonography, Dr. Kerry Thoirs (Ed.), ISBN: 978-953-307-947-9, InTech, Available from:
<http://www.intechopen.com/books/sonography/ultrasound-guided-vascular-access>

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