Femoral vascular access for endovascular resuscitation

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ABSTRACT: Endovascular resuscitation is an emerging area in the resuscitation of both severe traumatic hemorrhage and nontraumatic cardiac arrest. Vascular access is the critical first procedural step that must be accomplished to initiate endovascular resuscitation. The endovascular interventions presently available and emerging are routinely or potentially performed via the femoral vessels. This may require either femoral arterial access alone or access to both the femoral artery and vein. The time-critical nature of resuscitation necessitates that medical specialists performing endovascular resuscitation be well-trained in vascular access techniques. Keen knowledge of femoral vascular anatomy and skill with vascular access techniques are required to meet the needs of critically ill patients for whom endovascular resuscitation can prove lifesaving. This review article addresses the critical importance of femoral vascular access in endovascular resuscitation, focusing on the pertinent femoral vascular anatomy and technical aspects of ultrasound-guided percutaneous vascular access and femoral vessel cutdown that may prove helpful for successful endovascular resuscitation. (*J Trauma Acute Care Surg.* 2021;91: e104–e113. Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.)

KEY WORDS: Endovascular resuscitation; femoral vascular access; ultrasound-guided percutaneous needle insertion; femoral vessel cutdown; cardiac arrest.

Endovascular resuscitation is a rapidly evolving area for managing severe traumatic hemorrhage, nontraumatic sources of acute blood loss, and acute medical illnesses characterized by hemodynamic decompensation leading to circulatory collapse, cardiac arrest, and death.[1–7] Broadly speaking, endovascular interventions include hemorrhage control, support of intrinsic hemodynamics, extracorporeal perfusion support, core temperature modulation, infusion of blood, oxygen-carriers, and other fluids, as well as intra-arterial drug delivery. Resuscitative endovascular balloon occlusion of the aorta (REBOA),[8–13] extracorporeal membrane oxygenation (ECMO),[14–17] emergency preservation and resuscitation,[18–20] selective aortic arch perfusion (SAAP),[21–24] and intravascular axial flow pump (Impella)[25,26] are all endovascular therapies presently being used or proposed for resuscitation in a variety of clinical settings.

The critical first step for endovascular resuscitation is vascular access itself. For the therapies previously noted, femoral arterial (and venous, when applicable) access is the most practical approach. Vascular access is also the step with the greatest time variability, and failure to achieve prompt vascular access precludes effective endovascular therapy. Time-critical endovascular interventions can be lifesaving, and the time required for initial vascular access can significantly impact outcome. Therefore, practitioners of endovascular resuscitation must be knowledgeable and experienced with rapid femoral vascular access, including both percutaneous and surgical techniques.

Emergency vascular access is particularly challenging due to several factors. The urgency of endovascular resuscitation limits time flexibility for ultrasound (US) assessment of vascular anatomy, setup, and procedural execution. Loss of pulses makes arterial localization difficult and US verification less apparent due to vasoconstriction and loss of pulsations. During cardiopulmonary resuscitation (CPR) chest compressions, resultant torso movement presents an additional challenge. Anatomical distortion due to a hematoma or edema can obscure US visualization. Vascular calcifications or other anomalies may require technical adjustments. As advanced procedures extend to the prehospital setting, environmental factors require additional consideration. Endovascular procedures on the ground, in an ambulance or in confined spaces of evacuation platforms with potentially limited lighting are physically and technically more challenging than in-hospital.[27–33]

This review covers key aspects of femoral vessel anatomy and vascular access techniques that should be mastered by practitioners of endovascular resuscitation to facilitate rapid, time-critical femoral vascular access that affords the ability to perform optimal endovascular resuscitation.

FEMORAL VASCULAR ANATOMY

Understanding the position, dimensions, contour, and course of the femoral vessels, as well as the superficial and deep fascial structures, is essential for vascular access procedural competence.[34–38] For endovascular resuscitation interventions, the common femoral artery (CFA) is the proper site of arterial cannulation. The CFA begins as a continuation of the external iliac artery at the inguinal ligament passing just under the ligament at approximately the midpoint between the anterior superior iliac spine (ASIS) and the ipsilateral

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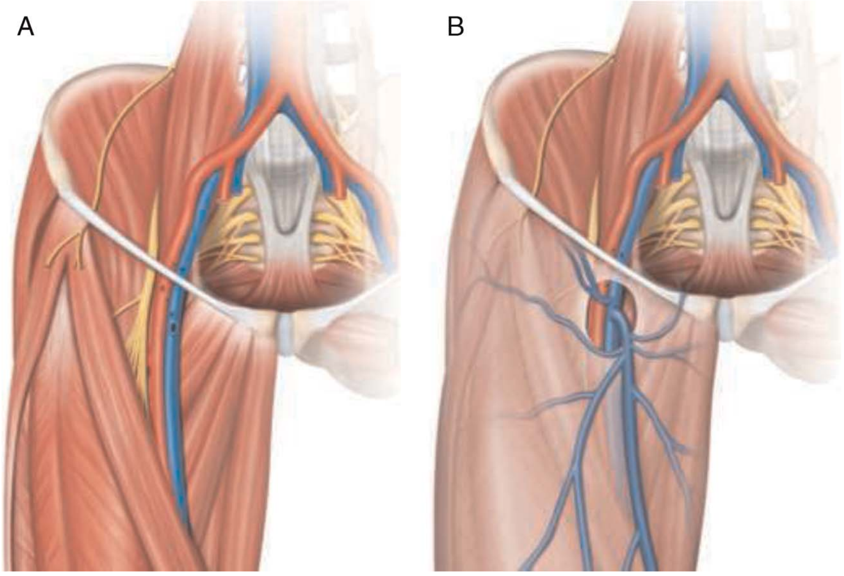

Figure 1. (A) The CFA passing underneath the inguinal ligament at the midpoint between the anterior superior iliac spine and ipsilateral pubic tubercle. (B) Greater saphenous vein and its branches lying superficial to the fascia lata and passing through the saphenous hiatus to join the common femoral vein. The fascia lata is translucent in this illustration to show the underlying anatomy, whereas it is thicker and not translucent in real life.

pubic tubercle (Fig. 1A). The CFA lies lateral to the common femoral vein (CFV) and medial to the femoral nerve at the level of the inguinal ligament and these structures course distally in the area known as the femoral triangle, formed by the medial border of the sartorius muscle, the inguinal ligament, and the medial aspect of the adductor longus muscle. The pneumonic “NAVEL” (nerve, artery, vein, empty space, lymphatics) may be helpful to remember the lateral to medial order of these key relationships. Identifying the medial sartorius muscle below the midpoint of the inguinal ligament helps orient the clinician to the proximate location of the femoral vessels.

The CFA, CFV, and femoral nerve are contained within the femoral sheath, a caudal extension of fascial tissue continuous with the intra-abdominal transversalis fascia. Overlying the femoral sheath and vessels at the femoral triangle is the fascia lata, a broad layer of deep fascia that encases the entire thigh and constitutes the anterior aspect of the femoral sheath containing the key femoral neurovascular structures. The fascia lata/femoral sheath is interrupted only by the saphenous hiatus (or fossa ovalis), an opening through which the greater saphenous vein, coursing cephalad and superficial to the deep fascia, passes underneath the fascia lata to join the CFV (Fig. 1B). The lateral aspect of the saphenous hiatus is a discrete margin formed by a fascial fold referred to as the falciform margin. Beneath this lateral margin and the saphenous hiatus itself lie the CFA and CFV. Thus, it is important to recognize that the CFA and CFV are not visible after the initial incision and spreading of the subcutaneous fat during a cutdown. These deep fascial layers must be identified and negotiated (by sharp dissection or blunt separation) to visualize the femoral vessels for cannulation. Identifying the discrete lateral falciform margin of the saphenous hiatus and the greater saphenous vein diving deep toward the CFV identifies the location of the femoral vessels visually hidden by the fascia lata. In hypovolemic patients the greater saphenous vein may be flat (empty) but should be recognizable. The greater saphenous vein can be mistaken for the femoral vein by the inexperienced practitioner. If one has not dissected through the fascia lata, the femoral sheath has not been opened and the femoral vessels should not be visible. The greater saphenous vein joins the CFV at about the level of the CFA bifurcation into the superficial and profunda femoral arteries, but the saphenofemoral junction can be variable.

The iliofemoral vessels form an arc from the pelvis to the thigh as the external iliac vessels ascend from deep within the pelvis to their most superficial point transitioning into the femoral vessels as they traverse underneath the inguinal ligament and descend more deeply again into the thigh (Fig. 2). The shape of this arc can be variable from patient to patient and has implications for both percutaneous and surgical techniques used to obtain vascular access, such as the angle of needle insertion.[39]

The CFA overlies the femoral head extending from the inguinal ligament to its bifurcation into the superficial femoral artery (SFA) and profunda femoral artery (PFA).[40,41] Arterial dimensions vary substantially. Common femoral artery length can be 2 cm to 8 cm, but typically 4 cm to 5 cm.[42,43] At the bifurcation, the CFA diameter (6–10 mm) tapers to a smaller diameter SFA (3–7 mm) as the PFA branches off posterolaterally and courses deeper into the thigh[44–46] (Fig. 3). This vessel diameter transition may help distinguish CFA from SFA, particularly during cutdown because the PFA may be difficult to visualize given its posterolateral position. However, arterial vasoconstriction in the setting of severe blood loss or cardiac arrest may minimize this taper in vessel diameter. The smaller caliber of the SFA places it at increased risk of occlusion or thrombosis if cannulated. The SFA supplies the distal leg, whereas the PFA does not extend past the thigh. Thus, cannulation of the SFA instead of the CFA increases the risk of distal limb ischemia. If US guidance can be used, it is important to identify the bifurcation and direct needle puncture proximal to the bifurcation into the CFA.

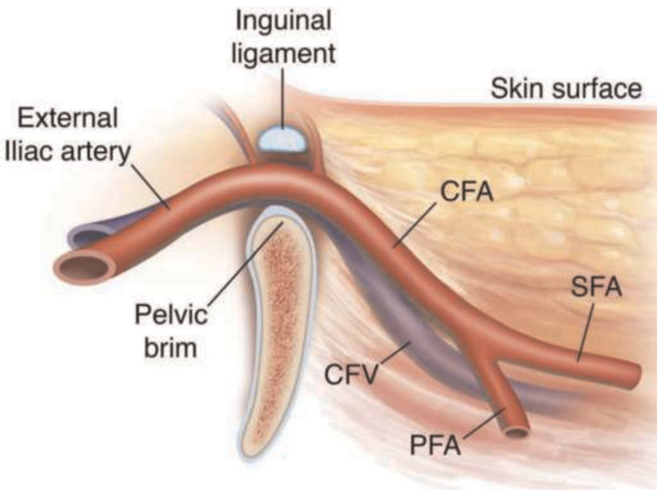

Figure 2. The arc formed by the external iliac vessels as they transition into the CFA and CFV underneath the inguinal ligament and then course deeper into the proximal thigh. The CFA bifurcates into the SFA and PFA. Needle entry into the CFA, above this bifurcation, is desired.

Just as arterial puncture too distally into the SFA increases the risk of distal ischemic complications, arterial access too proximally, that is, above the level of the inguinal ligament, also poses a significant risk. If needle puncture of the artery is at or above (cephalad) the level of the inguinal ligament, there is a risk of the needle passing through the external iliac artery above the level of the pubic ramus. This area is not amenable to direct pressure and could result in noncompressible hemorrhage with retroperitoneal hematoma formation.[47,48] The variable, and often short, length of the CFA mandates that the arterial anatomy be accurately defined either by US for percutaneous vascular access or careful visualization for cutdown vascular access to limit the risk of serious vascular complications. The time-critical nature of endovascular resuscitation interventions makes this an important step.

The relative position of the CFA and CFV changes as these vessels progress more distally. But this can also occur with lateral or medial positioning of the US probe at the CFA level. At the inguinal ligament, the femoral artery is consistently lateral to the femoral vein. However, as these vessels course into the thigh, they become deeper and the femoral vein tends to shift into a more posterior (or dorsal) position relative to the femoral artery (Fig. 4A). Thus, from an anterior approach at the inferior portion of the femoral triangle (by US or cutdown), the femoral artery can be positioned directly on top of the femoral vein. This poses a challenge if access to both vessels is required, such as for venoarterial ECMO. In a state of severe shock or cardiac arrest, there is a risk of passing a needle through both the anterior and posterior walls of the femoral artery into the femoral vein (Fig. 4B). A lack of sufficient arterial pressure to maintain arterial distension can make complete arterial collapse more likely. This can lead to the inadvertent insertion of the endovascular resuscitation catheter into the venous system (inferior vena cava) rather that into the arterial system (aorta). Such a misplacement of the endovascular resuscitation catheter would preclude the intended therapeutic effect and could potentially worsen hemodynamic status, such as by diminishing venous return rather than limiting arterial hemorrhage with a balloon catheter.

The location of the inguinal ligament should not be assumed based on the position of the inguinal skin crease. It is important to recognize that the inguinal skin crease usually lies distal (caudal) to the inguinal ligament with substantial individual variation that is influenced significantly by the thickness and laxity of the overlying subcutaneous tissue and skin layers.[41,43,49] Careful palpation to identify the inguinal ligament or US identification is crucial to attempt a proper vascular access approach. Thus, in an obese patient, it is helpful to have an assistant elevate the pannus. An adage to keep in mind is that "the inguinal ligament and CFA are higher than you think" in almost every case.

PERCUTANEOUS VASCULAR ACCESS

Initial Vascular Access Strategy

Vascular access is the rate limiting step in endovascular resuscitation procedures. Percutaneous vascular access can be attempted by using landmarks for blind needle insertion or by US-guided techniques.[50–59] Although skilled practitioners with years of experience can be proficient with blind vascular access using landmarks, the availability of US in the present day strongly supports vessel visualization to increase success rate and limit complications. For time-critical CFA catheterization (and CFV, if needed) to allow endovascular resuscitation, the use of US guidance is highly recommended and considered paramount for success by the authors (Fig. 5). Percutaneous access can use standard Seldinger technique with an 18G needle and 0.035 in. guidewire-catheter introducer kit that will allow for insertion of endovascular resuscitation catheters. Alternatively, micropuncture technique uses a smaller needle (21G), guidewire (0.018 in.), and 18G arterial catheter that can subsequently be exchanged,

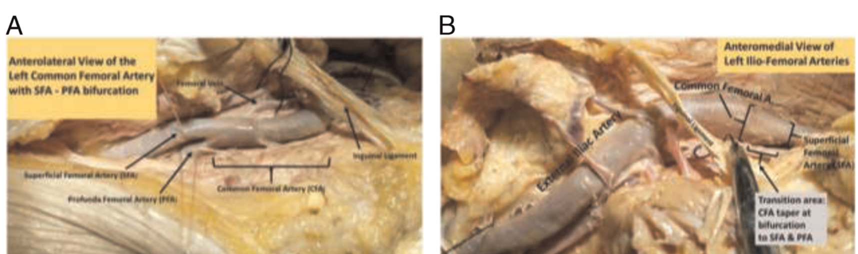

Figure 3. Anatomic dissection of the external iliac and femoral vessels. (A) The CFA passing underneath the midpoint of the inguinal ligament and the bifurcation into the SFA and PFA. (B) The arc formed by the external iliac and femoral vessels and the decrease in diameter of the SFA at the CFA bifurcation as the PFA takes off posteriorly.

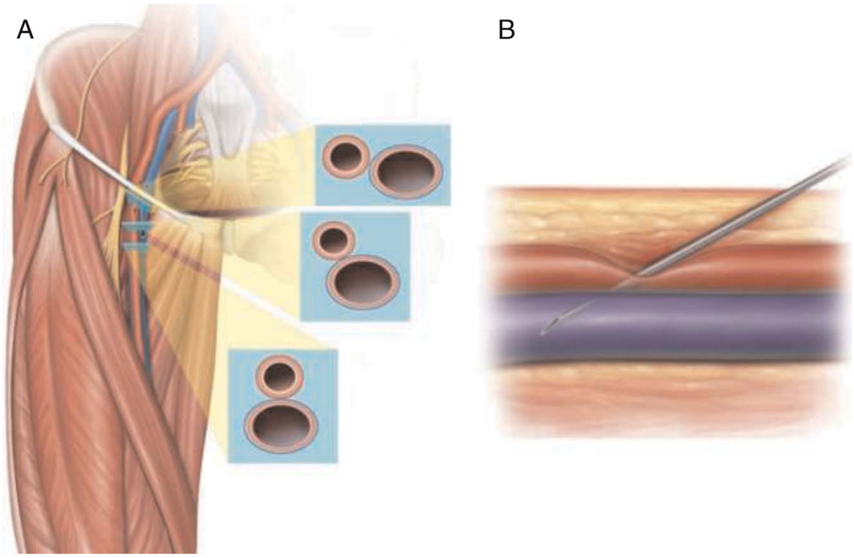

Figure 4. (A) The relative position of the femoral artery and vein as the vessels course distally with the femoral vein shifting to be more posterior to the femoral artery. (B) How a needle can pass through the anterior and posterior walls of the femoral artery in a hypotensive, hypovolemic patient and inadvertently puncture into the femoral vein is shown.

if needed, for a larger introducer catheter using a 0.035 in. guidewire for endovascular resuscitation catheter placement.

Micropuncture technique is optimally used to secure CFA access in a patient with moderate hemorrhagic shock who may eventually, but not immediately, need endovascular resuscitation. There are technical limitations to micropuncture that make it less desirable with advanced shock.

Due to the fragile needle, a 3 mm skin incision at the anticipated needle entrance point will limit resistance as the needle traverses the subcutaneous adipose tissue. With micropuncture needles, the arterial flashback dribbles rather than squirts, as is typically seen with larger needles. This is particularly true with severe hypotension or during cardiac arrest. As opposed to elective utilization, among hypotensive trauma patients, the use of a

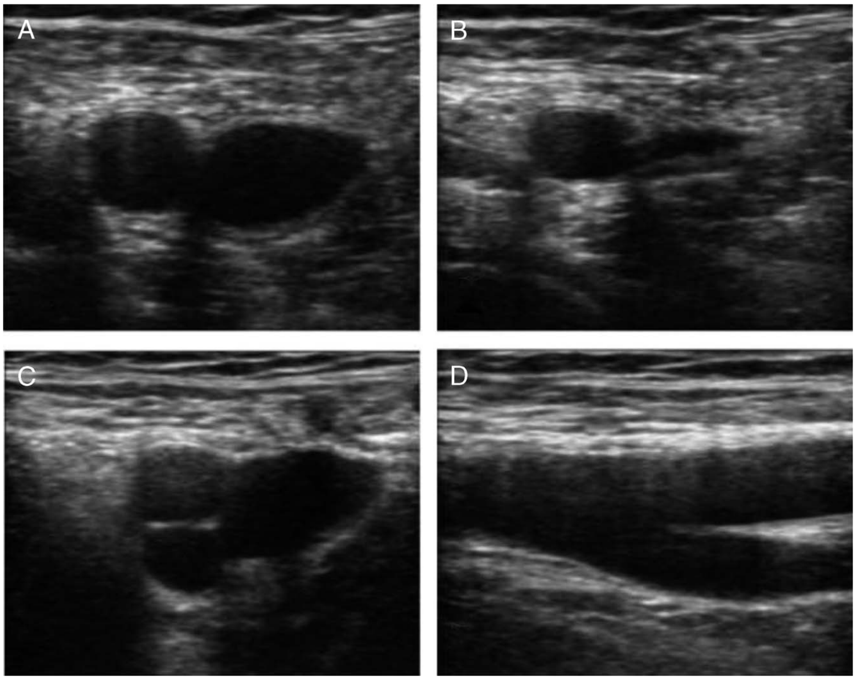

Figure 5. Shows US images of the right femoral vessels of a healthy human. (A) The short-axis (out-of-plane, transverse) view of the CFA and CFV without compression. (B) The compression with the transducer causing collapse of the CFV. (C) The short-axis view of the SFA and PFA just caudal to the CFA bifurcation seen in panel A. (D) The long-axis (in-plane, longitudinal) view of the CFA and its bifurcation into the SFA and PFA.

syringe to confirm aspiration of blood and confirm arterial puncture may be needed. The smaller needle can also become occluded in patients who are hypercoagulable or if the guidewire is not inserted promptly. Furthermore, the more flexible 0.018 in. wire may more easily passes into smaller arterial branches, such as the superficial iliac artery or circumflex branch of the femoral artery, increasing the risk of subsequent malposition or arterial injury with access upsizing.[60]

Femoral arterial access is more easily accomplished and less time-pressured when the patient has pulsatile blood flow. Once cardiac arrest has occurred, lack of pulsations and arterial vasoconstriction make CFA access a more challenging task. The initial insertion of a small femoral arterial catheter, by either standard or micropuncture technique, allows blood sampling for arterial blood gases, continuous arterial pressure monitoring during the initial resuscitation phase, and more accurate assessment of hemodynamic trends toward either stabilization or decompensation that guide decision-making. If the patient stabilizes, the small arterial catheter can be removed without risk of a pseudoaneurysm. If extracorporeal perfusion support is being considered (i.e., ECMO or SAAP), placement of a small CFV catheter can also be performed.

A prudent strategy for initial CFA access in a patient with uncontrolled hemorrhage is to insert a 5-Fr catheter for sustained systolic blood pressure (SBP) < 100 mm Hg, insert a 7-Fr introducer for SBP < 90 mm Hg, and proceed to REBOA catheter insertion for SBP < 80 mm Hg.

US-Guided Percutaneous Vascular Access

Distinguishing the CFA from the CFV is essential for endovascular resuscitation (Fig. 5A). As described in the anatomy section, the CFA is normally lateral to the CFV at the level of the inguinal ligament, but more distally the CFA tends to be more anterior to the CFV, often overlying the vein when viewed by US from the anterior proximal thigh. If the US probe is positioned laterally over the vessels, the US image may show the CFA overlying the CFV. Collapse of the femoral vein relative to the femoral artery with surface compression using the US probe is commonly used to help distinguish artery from vein (Fig. 5B).[61–63] Normally, the intrinsic arterial pressure prevents arterial collapse with surface compression that easily collapses the vein. Compression of the femoral artery requires much greater surface compression force. The pulsations of the femoral artery also help distinguish it from the femoral vein during normal spontaneous cardiac contractions and are enhanced with slight compression. In a cardiac arrest state, the intrinsic arterial pulsations will be absent, and the arterial diameter will be smaller than during spontaneous cardiac activity due to vasoconstriction without any opposing distending pressure generated by the heart.

One of the challenges to femoral arterial access in true cardiac arrest or severe hemorrhagic shock with impending cardiac arrest is that the femoral artery will be vasoconstricted. The smaller diameter of the femoral artery makes percutaneous needle access and cannulation more difficult. In this situation US-guidance is particularly valuable since blind percutaneous needle insertion into a constricted femoral artery is much more difficult without US imaging. In cardiac arrest, there is equivalence of arterial and venous pressures waveforms with CPR chest compressions. Thus, pulsations during CPR do not reliably differentiate artery from vein. The loss of normal arterial pressure can also make the arteries more collapsible with surface compression. Furthermore, the movement caused by CPR makes US imaging technically much more difficult and needle cannulation of a moving artery more problematic.

There are two fundamental US views used to guide percutaneous vascular access: (1) the short-axis or transverse or out-of-plane view, and (2) the long-axis or longitudinal or in-plane view.[61–64] The choice of view orientation is the personal preference of the practitioner although the short-axis view for vascular access is generally recommended, particularly for those with less US experience. Adjusting the depth and gain settings to optimize vessel visualization is also important.

The technique using the short-axis view is to identify the vessel and position the US probe such that the vessel is in the center of the image. The hollow tip of the needle is easily seen as a bright signal on the US image, whereas the needle shaft only creates a faint shadow that can be difficult to distinguish. The recommended technique is to follow the needle tip as it passes through the subcutaneous tissue until it enters the vessel lumen (the US probe is moved to follow and guide the needle tip toward the vessel). This can be accomplished by short-axis sliding the US probe over the surface of the skin as the needle is being advanced (Fig. 6A and Fig. 7A) Alternatively, the US probe can be progressively tilted along its short-axis with the surface contact point being held steady (forming an arc), as the needle is advanced. Experienced practitioners often combine sliding and tilting movements to follow the needle tip into the vessel, a technique mastered with practice.

The technique using the long-axis view involves identifying the vessel along its longitudinal orientation with the vessel lumen visible across the entire US image field, and then holding this fixed position, so the vessel is constantly visible (Fig. 6B and Fig. 7B). The needle is then inserted so it remains visible in the US image field as it passes through the soft tissue and into the vessel lumen (the US probe is stationary, and the needle position is adjusted).

The short-axis and long-axis views each have advantages, and both can be used during a vascular access procedure. For example, the short-axis view may be used for the initial insertion through the subcutaneous tissue until the needle is at the vessel wall and then switched to the longitudinal view to watch the needle (or guidewire that follows) pass into the vessel lumen.

Insertion of the needle at a 45° angle from the plane of the vessel is commonly used. A steeper angle may lead to some difficulty passing a guidewire. The skin insertion point is chosen based on the depth of the intended vessel entry point. For example, if the vessel is 3 cm deep, the skin needle puncture should be 3 cm to 4 cm away from the US probe (caudally for femoral vessels) with the needle directed toward the center of the probe positioned such that the vessel is in the center of the US image. If using the short-axis view, follow the needle tip and try to enter the vessel at its most superficial point (at the top or 12 o'clock position on the US image). If using the long-axis view, position the US probe stationary with the vessel at its widest diameter along the entire course of the image and adjust the needle trajectory such that the needle tip remains clearly visible in the US image field.

Stabilizing both hands on the patient's body may help minimize unwanted movements that either alter the optimal

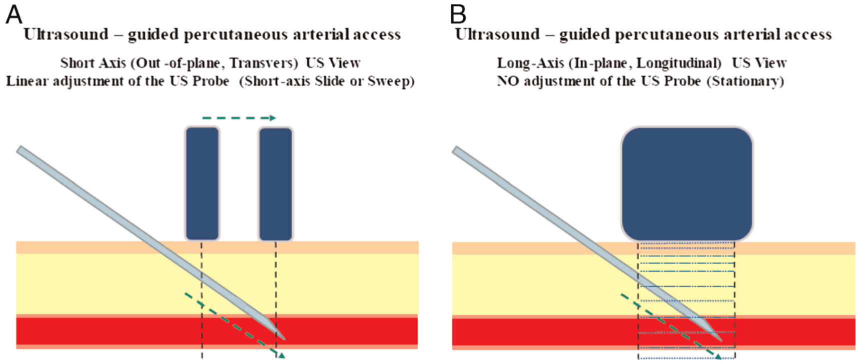

Figure 6. Vascular US probe over an underlying vessel in the short-axis (out-of-plane, transverse) orientation in panel A and in the long-axis (in-plane, longitudinal) orientation in panel B. Using the short-axis view, the US probe is moved to maintain visualization of the needle tip as it is advanced into the vessel lumen. Using the long-axis view, the US probe is held stationary as the needle is advanced, and the practitioner adjusts the needle trajectory to keep the needle tip in the US image field.

direction of the needle or the optimal positioning of the US probe, although this may not be helpful in the presence of CPR chest compressions. Once the needle had entered the vessel, focus on holding the needle position very still and try to not take your eyes off the needle, or alternatively, have an assistant secure the needle. This is when minor movements can cause the needle to be pulled out of the vessel or advanced through the posterior wall. Have the guidewire in the field so it can be retrieved without taking your eyes off the needle.

If the US image shows that the femoral artery is directly above the femoral vein, the US probe can be shifted a bit more medially and the US beam angled accordingly. When the femoral artery is centered in the US image it will appear a little more lateral with this probe adjustment. In a nontrauma patient, the relative position of the vessels may also be improved by gentle external rotation of the hip joint. This maneuver will tend to move the femoral artery into a more lateral position relative to the femoral vein. This is also a situation in which checking the needle position using the long-axis US view is recommended to assure that the needle and guidewire have been properly placed in the femoral artery lumen and not through the posterior femoral artery wall into the femoral vein.

Ultrasound-guided percutaneous vascular access is the preferred method if it can be successfully performed in a time-critical manner. If percutaneous access is problematic, clinicians must have the discipline to limit percutaneous attempts (e.g., three attempts). Practitioners proficient in US-guided percutaneous access must also have the capability to perform a cutdown should US-guidance be unsuccessful. Endovascular intervention should not be abandoned due to inadequate technical skills to perform a cutdown.

CUTDOWN VASCULAR ACCESS

Cutdown for rapid femoral vascular access to initiate endovascular resuscitation requires adequate training and technical skill.[65,66] It is important to understand the anatomy previously described and frequently practice cutdown vascular access techniques (clinically, or on relevant models) to be optimally facile with rapid arterial cannulation. This may be particularly true in the setting of CPR chest compressions because percutaneous vascular access in a moving body can be both an exercise in futility and a needlestick risk to personnel.

The first step in the cutdown procedure is defining the location and orientation of the skin incision. The incision can be longitudinal (vertical) or transverse (Fig. 8). The trauma/vascular surgery authors of this review strongly recommend a longitudinal incision for endovascular resuscitation interventions (such as REBOA) in

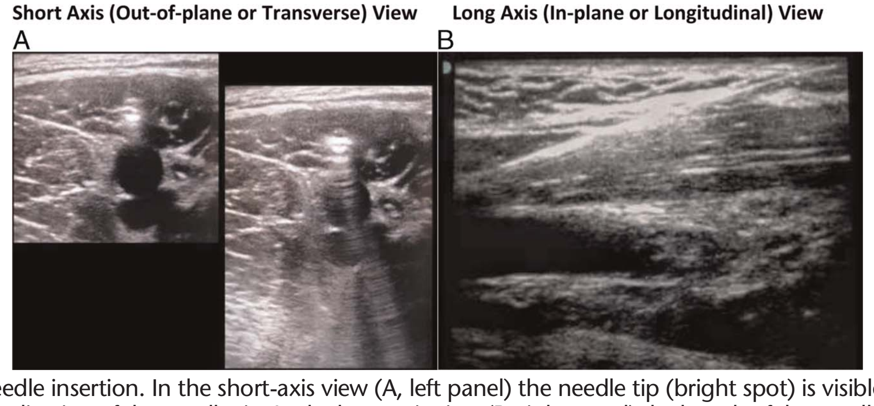

Figure 7. US-guided needle insertion. In the short-axis view (A, left panel) the needle tip (bright spot) is visible and the US probe is adjusted to maintain visualization of the needle tip. In the long-axis view (B, right panel) the length of the needle (bright line) is visible in the US image and the needle direction is adjusted to keep the tip visible in the image field.

emergency situations, as has long been the practice for open femoral artery access for thrombectomy or bypass reconstruction. The inguinal ligament, specifically at the midpoint between the anterior superior iliac spine and the ipsilateral pubic tubercle, is the most consistent anatomical landmark for identifying the location of the CFA. The authors recommend a longitudinal incision beginning above this defined midpoint with about one third of the incision above the inguinal ligament and two thirds below. The length of the incision needs be generous to allow adequate visibility and maneuverability to accomplish rapid dissection, identification, and access to the femoral vessels. A 6-cm to 8-cm incision is typical but may need to be longer based on body habitus. Although this may be considered a long incision, these patients are in critical condition and rapid, adequate exposure of the CFA is essential. An advantage of the longitudinal incision is the ability to extend the incision, if needed. If a transverse incision is chosen, it should be 6 cm to 8 cm over the anteromedial thigh about 2 cm to 3 cm below the inguinal ligament, remembering that the inguinal crease lies variably a few centimeters below the inguinal ligament. Patient factors and prior experience of the clinician may influence the choice of incision. The subcutaneous tissue can be easily spread apart down to the deep fascia using gauze-covered fingers. An assistant or a self-retaining retractor is helpful.

The femoral vessels (as previously noted) descend more deeply as they course from the inguinal ligament through the femoral triangle of the anteromedial thigh. They will be deeper than one might initially expect, especially if there is a lot of overlying adipose tissue. The first large vessel that is seen may be the greater saphenous vein. It is important not to mistake this for the CFV. However, following the greater saphenous vein to the saphenous hiatus, and the falciform margin, in the fascia lata where it dives deep to the CFV can quickly orient you to the area where the deep fascia needs to be separated to expose the common femoral vessels for cannulation. The overlying deep fascia can usually be separated with blunt finger dissection, but if the fascia is thick, a pair of blunt-tipped surgical scissors (Metzenbaum), a right-angled clamp, or a scalpel could be used with care taken to remain superficial to the large femoral vessels underneath. With the fascia separated, identify the CFA and CFV while trying to discern the position of the CFA bifurcation into the SFA and PFA. The CFA to SFA tapering may be seen to help define the bifurcation. At this level, the femoral artery may be anterior to (directly on top of) the femoral vein.

Once the femoral artery and vein have been identified, needle puncture of the femoral artery and insertion of a guidewire can be performed in a manner generally consistent with standard percutaneous Seldinger technique. A direct femoral arteriotomy using a scalpel could also be performed but carries a greater risk of complications. This choice may be influenced by the size of the endovascular device that will be inserted (e.g., REBOA catheter vs. ECMO cannula). Remember that if the femoral artery is overlying the femoral vein, it is possible to pass a needle through the anterior and posterior walls of the femoral artery and then into the femoral vein, just as noted previously with percutaneous technique. Just because you have done a cutdown to the femoral artery and are looking at it directly does not mean this inadvertent misplacement cannot occur.

Although the etiology of the cardiac arrest or shock/hemorrhagic shock episode leading to the true or impending cardiac arrest will influence the appearance of the blood, the color of the blood from the arterial puncture is still likely to have a brighter red appearance than venous blood if the lungs have been functioning properly to oxygenate the blood passing through them up to the point of cardiac arrest or impending cardiac arrest. However, if the etiology of the cardiac arrest involves acute hypoxemia related to some ventilatory failure (airway/pulmonary pathophysiology), the blood may be darker in appearance and not be distinguishable from the femoral venous blood.

If a femoral arteriotomy is performed directly with a scalpel, the size of the arteriotomy should be just large enough to allow insertion of the distal tapered end of the endovascular device dilator or obturator, such that when the endovascular device has

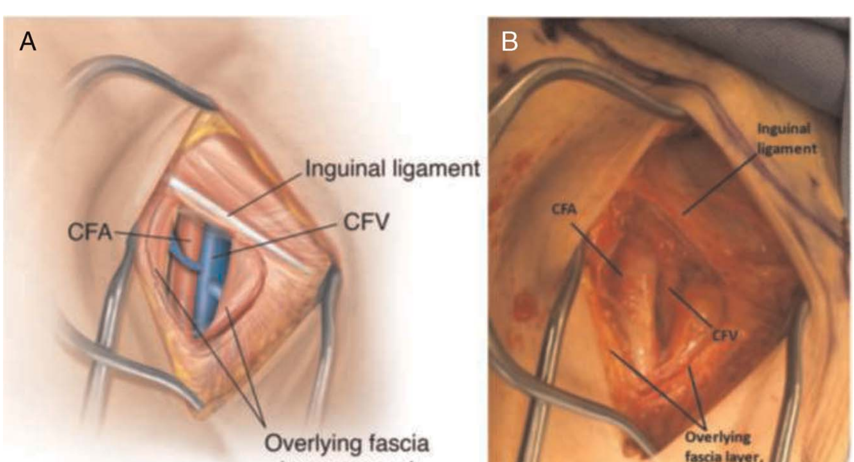

Figure 8. Vertical (longitudinal) incision to access the femoral vessels. The authors recommend an incision that is approximately one third above (cephalad) and two thirds below (caudal) to the palpated midpoint of the inguinal ligament (A). Note that the inguinal crease is typically a few centimeters below (caudal) to the inguinal ligament. This incision allows for identification of the striations of the external oblique fascia, the lower margin of the inguinal ligament, and the location of the common femoral vessels just caudal to the ligament. With the fascia layer opened, the CFA and CFV are exposed. Panel B shows the exposure of the CFA, CFV, inguinal ligament and fascia in a surgery patient.

been inserted there will be minimal or no blood leak around the endovascular device at the arteriotomy site. This is a potentially significant disadvantage of cutdown vascular access.

As with percutaneous technique, if the femoral artery overlies the femoral vein there is a risk of inserting a needle through both walls of the artery and into the vein. A technique to help avoid this problem is to approach needle puncture from the medial or lateral side of the femoral artery such that passing through the opposite wall of the artery will have the needle pass into the surrounding tissue and not into the femoral vein (this may or may not be visible but would prevent aspiration or return of venous blood that could be mistaken for arterial blood).

If bleeding occurs at the vessel insertion site, packing with gauze would be the most appropriate temporary management. The SFA and PFA should remain open to preserve lower extremity blood flow whenever possible. Placement of a Rumel tourniquet or vascular loop around the femoral artery should not be done unless deemed absolutely necessary since this would render the leg ischemic. If done, it should be for the shortest time possible with clear recognition that this must be dealt with urgently.

As with percutaneous technique, the femoral artery should be entered at the level of the CFA proximal to the bifurcation. It may be possible to identify the transition from the CFA to SFA at the bifurcation by a tapering of the vessel size (with the PFA taking off posteriorly and potentially not visible), but this transition in vessel diameter may be less noticeable in the hypovolemic or cardiac arrest state. For reasons as noted with percutaneous femoral arterial access, accessing the femoral artery more proximally at the level of the inguinal ligament is not advisable to avoid posterior arterial wall puncture above the level pubic ramus where hemorrhage cannot be controlled with direct pressure, thus risking a noncompressible retroperitoneal hemorrhage and hematoma.

"HYBRID" TECHNIQUE FOR VASCULAR ACCESS

A "hybrid" vascular access technique that combines both cutdown and percutaneous techniques has been described by the SAMU de Paris prehospital ECMO team to cannulate both the CFA and CFV to initiate extracorporeal perfusion CPR in cardiac arrest patients in the field. This technique involves a cutdown using a transverse incision with soft tissue dissection to identify the femoral vessels at the level of the CFA. Percutaneous needles are then passed through the skin on the distal/caudal side of the incision with direct visualization of the needle puncturing the CFA and CFV sequentially. With each needle puncture, an ECMO cannula guidewire is inserted followed by serial dilation steps before insertion of the ECMO cannulas. The lower extremity perfusion catheter can also be inserted through the skin on the proximal/cephalad side of the incision into the SFA in a similar fashion under direct visualization. The incision is subsequently closed with no catheters protruding through the incision. This "hybrid" technique could potentially also be used for the placement of introducer catheters for other endovascular resuscitation catheters.

CHOICE OF VASCULAR ACCESS APPROACH

The choice of vascular access technique used is dependent on several factors, including: prior training and experience, available equipment, factors related to the specific patient's body habitus, history of vascular disease, surgical history, and the environment where the procedure is being performed (prehospital or in-hospital). The endovascular resuscitationist should have facility with both percutaneous and surgical vascular access using the best technique for the presenting circumstances.

POTENTIAL COMPLICATIONS AND POSTVASCULAR ACCESS CONSIDERATIONS

Catheters should be carefully secured as soon as possible to avoid inadvertent displacement. Potential complications include insertion site bleeding and hematoma, arteriovenous fistula, arterial wall dissection, pseudoaneurysm, catheter misplacement, and distal limb ischemia or arterial thrombosis.[67–73] Emergency procedures are fraught with complications. Therefore, a low threshold for imaging or surgical exploration is prudent. Duplex Doppler examination (q4hr $\times$ 6) is recommended following catheter removal.

If the patient requires transfer to a higher level of care after definitive endovascular hemorrhage control, consider leaving the introducer sheath in place. There is controversy as to whether transport teams should be trained in the use of advanced endovascular hemorrhage control modalities. However, maintaining vascular access for the receiving facility to easily use endovascular resuscitation techniques for a decompensating patient would save time, additional arterial cannulation, and risk for traumatic vascular complications. If the introducer sheath is left in place, the sheath should be flushed every 15 minutes to 30 minutes with saline. In addition, arterial pressures can be monitored during transport to identifying ongoing resuscitation needs.

SUMMARY

Endovascular resuscitation in life-threatening situations requires that clinicians have a detailed knowledge of femoral vascular anatomy and adequate training in both percutaneous and cutdown vascular access techniques, as well as the endovascular resuscitation interventions to be used. Regular practice, both simulated and actual, is crucial for reinforcing anatomical knowledge and sharpening procedural skills to be adequately prepared to successfully perform femoral vascular access for endovascular resuscitation.

AUTHORSHIP

J.E.M., E.E.M., J.J.M., R.F.L., J.J.D., and J.D.R. discussed the concept of the review and contributed ideas. J.E.M. performed a literature review and wrote the first draft with substantial input from E.E.M., J.J.M., R.F.L., and J.J.D. J.E.M., E.E.M., and R.F.L. contributed images for the figures. All authors participated in critical review and revision of the subsequent drafts until the current version was deemed ready for submission.

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DISCLOSURE

J.E.M. is the inventor on expired patents for selective aortic arch perfusion that were assigned to the University of North Carolina at Chapel Hill, and is co-founder of Resusitech, Inc., a medical device company developing endovascular resuscitation technologies. The remaining authors declare no conflicts of interest.

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