Chapter 5

VASCULAR ACCESS AND INFUSION DEVICES FOR COMBAT ANESTHESIA

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INTRODUCTION

Establishing vascular access is of paramount importance for the successful resuscitation of the trauma patient. It is essential for administering intravenous (IV) fluids; it is the optimal route for administering anesthetic and other drugs; and it may be a useful adjunct for measuring physiological parameters both during primary resuscitation and subsequently in the postoperative period.

It is likely that some form of access will have been established prior to the first interaction with the anesthesia provider. Indeed, in civilian practice prehospital providers successfully establish IV access in approximately 90% of cases.[1] However, the anesthesia provider must be familiar with the entire spectrum of IV techniques in order to manage patients with either absent or suboptimal vascular access. Any IV access lines in situ on the patient's arrival must be checked thoroughly for function and adequate flow, and a plan made for the establishment of further access if required (Exhibit 5-1).

The patient's physiological status will dictate the urgency of the procedure and may direct the clinician toward one particular technique over another. Establishing or upgrading vascular access may be concurrent with other aspects of resuscitation, for example, airway control or surgical hemostasis. IV access should be a priority task assigned to a specified individual or individuals.[2,3]

The most suitable site and technique used will depend on several factors, including pattern of injury, the patient's current physiological condition, and the ability to physically access the proposed insertion site.

There must be a patent circulatory system proximal to the site of insertion. In the case of abdominal and thoracic trauma, IV access must be obtained in a tributary of the superior vena cava (SVC) because veins below the injury may not be in continuity with the central circulation as a result of inferior vena cava (IVC) injury. Insertion of IV devices in injured limbs should be avoided because there is no guarantee that infused fluid and drugs will reach the central circulation. Furthermore, extravasation of fluid may result in a compartment syndrome, thus exacerbating a preexisting injury.

CATHETER AND CANNULA SIZES

Currently two systems are in common use to describe the size of cannulae that may be used to secure IV access:

1. Smaller diameter cannulae tend to be expressed by a number based on either the US Birmingham wire gauge or the British Standard wire gauge. In this system as the diameter of the device increases the gauge number (G or Ga) decreases. The relationship between the gauge of the cannula and its actual measured diameter does not follow a linear relationship but rather is standardized by convention.
2. The diameter of larger cannulae tends to be expressed by reference to the French gauge (Fr or F). In this notation 1 Fr equals one third of a millimeter; therefore, the diameter in millimeters can be calculated by dividing the gauge size by 3. It follows that as the number increases, so does the diameter.[4]

PHYSICS OF FLOW

Traditional teaching is that flow in an IV cannula is governed by the Hagen-Poiseuille law, which relates flow (Q) to the pressure gradient (ΔP), viscosity of infusate (ϱ), and the length (l) and radius (r) of the catheter. In this relationship the primary determinant of flow is the radius, such that doubling the radius increases flow 16-fold.

PERCUTANEOUS CENTRAL VENOUS ACCESS

It may be difficult to establish early peripheral IV access in the critically hypovolemic patient with a collapsed circulation. In these cases early recourse to central access should be made. The ideal for managing massive hemorrhage in adults has been described as 8 Fr central access.[3] Large-bore central venous lines allow rapid infusion of resuscitation fluid. Therefore, once established, direct access to the central venous system provides the most effective route for resuscitating the profoundly hypovolemic patient.[5,6] Central access also allows the delivery of potent vasoactive drugs and irritating or hypertonic solutions, as well as routine blood sampling.

Central venous access has been utilized extensively since the 1950s, when Swedish radiologist Sven Ivar Seldinger described the use of a flexible metal leader

EXHIBIT 5-1

VASCULAR ACCESS TASKS TO BE COMPLETED ON ARRIVAL OF PATIENT

- Identify vascular access devices in situ.
- For each device assess and record:
  - o Site
  - o Flow characteristics
  - o Security
  - o Current infusions
- Plan for further vascular access as required:
  - o Peripheral
  - o Central
- Discuss with operating surgeons whether cutdowns or direct atrial cannulation are required.
- Plan for arterial access if appropriate.

to exchange a needle for a catheter during arteriography.[7] However, early central venous catheters were long, small in diameter, and with a high resistance to flow, which proved ineffective in the volume resuscitation required in major trauma. Interest in their use in trauma increased during the 1980s, when it was recognized that percutaneous pulmonary artery catheter introducers could be used to deliver rapid volume replacement.[8,9]

Initial worries about the safety of central access in the trauma setting have been unfounded. Central access for the initial resuscitation of trauma patients has been demonstrated to be safe and quick to establish. Complications can and do occur with any route chosen; however, it is unclear if complication rates are increased in the trauma population.[10,11] It is recognized that complication rates are inversely related to the experience of the operator.[10,12] Therefore, central vascular access should be assigned to the most experienced individual. The central venous circulation is commonly accessed via the subclavian (SCV), internal jugular (IJV), and femoral veins.

Subclavian Vein

SCV access with a large-bore catheter has been described as the "gold standard" for fluid resuscitation in the military setting.[13] Venous access via the SCV is a useful technique in major trauma and cardiopulmonary resuscitation. It has a relatively constant anatomic position behind the clavicle, a large diameter of 12 to 25 mm, and has been shown to remain open even in critical hypovolemia.[14] As a tributary of the superior vena cava, the SCV is regarded by some as the method of choice in major abdominal trauma.[13] The area of insertion may remain available for line insertion during emergency airway management, cervical spine immobilization and resuscitative surgery.[15]

Patient Positioning

Optimal positioning of the patient may be compromised by the clinical situation. Use of a moderate Trendelenberg position may be useful.[16] With regard to the infraclavicular approach, anatomical studies have shown that arching the shoulders or turning the head may reduce the diameter of the vessel; however, these positions may be useful to reduce the incidence of arterial puncture. Caudal traction on the arm may facilitate needle entry to the vein.[17]

Techniques

An infraclavicular approach to the SCV was first described by Aubaniac in 1952.[18] The most often used technique describes the point of needle puncture as occurring just caudal to the junction of the medial and middle thirds of the clavicle. The needle is directed under the clavicle toward the sternal notch. To reduce the risk of pneumothorax, the needle should not be allowed to angulate below the coronal plane.[19]

Access to the SCV via a supraclavicular approach was described by Yoffa in 1965.[20,21] In this approach the needle is inserted 1 cm cephalad and medial to the midpoint of the clavicle. The needle should be directed to bisect the angle between the sternocleidomastoid muscle (SCM) and the clavicle, and be angulated 10° to 20° anterior to the coronal plane. This approach has been shown to be safe, with complication rates comparable to other methods of central access.[22,23]

Another typical method is a modified Seldinger technique. If a J-tip metal leader wire is used, the tip should be directed in a caudal direction to reduce the incidence of passing the wire and subsequent catheter into the IJV.[24]

The use of tandem large-bore subclavian catheters has also been described. In this technique the two guide wires are inserted into the chosen vessel before the catheters are inserted.[25]

Internal Jugular Vein

Catheterization of the IJV is a popular choice for central venous access. It is readily achieved with the operator standing at the patient's head; therefore, it may be the most readily accessible site once surgery has commenced. This technique has been readily adapted to ultrasound guidance. However, it also has several disadvantages. It may be difficult to achieve in patients with cervical spine immobilization as well as with concurrent advanced airway management. If IJV cannulation is undertaken during the management of a patient with major chest injury, as with SCV cannulation, it is advisable to perform the procedure ipsilateral to the injury.

Patient Positioning

The patient is positioned supine with the head rotated 30° to 40° degrees away from the side of puncture. Most commonly the right side is the site of first choice, which is usually more convenient for right-handed operators. The route from the right IJV to the SVC also follows a more linear course, making passage of the catheter more straightforward. Anatomical considerations may make complications more common with a left-sided approach.

A roll may be placed anywhere under the chest to facilitate extension of the neck. Use of a Trendelenberg position may increase engorgement of the neck veins and facilitate cannulation, although these effects must be moderated in the case of acute neurological injury.

Techniques

At least 13 approaches to the IJV have been described. They can broadly be divided into anterior, central, and posterior approaches, depending on their relationship to the SCM.

The anterior approach has a point of needle insertion at the midpoint of the anterior border of the SCM and aimed towards the junction of the middle and medial thirds of the clavicle. The angle of insertion should be 30° to 45°. It is important in this approach to retract the carotid artery medially to avoid inadvertent carotid puncture.

The most commonly used central approach has a site of puncture at the intersection of the clavicular and sternal heads of the SCM; this should be at the level of the cricoid cartilage. The needle is directed towards the ipsilateral nipple at an angle of 45° to the skin. Entry is made to the vein where it lies lateral to the pulsation of the carotid artery.

The posterior approach to the IJV has a needle puncture site at the lateral border of the SCM at the level of the thyroid cartilage or the superior border of the external jugular vein that crosses the muscle belly at this point. The needle is directed toward the contralateral nipple. At this point the IJV lies anterior to the carotid artery.

Femoral Vein

Cannulation of the inferior vena cava via the femoral vein is a well-documented route for fluid resuscitation in trauma. A technique for accessing the vein was first described in 1949.[26] Femoral cannulation is possible in trauma patients with neck immobilization and may be easily established in patients undergoing cardiopulmonary resuscitation or advanced airway management. This route may be unsuitable, however, in cases of severe lower limb injury and abdominal trauma when the continuity of the femoral vessels and the inferior cava may be questionable.[27]

Patient Positioning

Most commonly the patient is positioned supine with the legs slightly abducted. The chance of successful cannulation may be improved by externally rotating the leg.[28]

Techniques

When cannulated by a landmark technique, the femoral vein is located medial to the pulsation of the femoral artery as it passes from under the inguinal ligament. The point of needle insertion should be such that the needle does not pass superior to the inguinal ligament; typically insertion is made a few centimeters distal to the junction of the middle and medial third of the ligament.[29] The performance of a Valsalva maneuver can double the cross sectional area of the vein and may make location of the vessel easier.[30]

Ultrasound-Guided Central Venous Access

The use of ultrasound in central venous access has gained great popularity in recent years in anesthesia practice throughout the United States. In 2001 the Agency for Healthcare Research and Quality recommended the use of ultrasound for the placement of central venous catheters as one of eleven practices to improve patient care.[31] Many studies have favored the use of ultrasound-guided techniques in comparison to more traditional landmark techniques. A metaanalysis by Hind et al[32] revealed that in 18 trials comparing two-dimensional ultrasound-guided techniques with landmark methods, ultrasound-guided cannulation of the jugular vein in adults was associated with a significantly lower failure rate both overall and on the first attempt. The same study found limited evidence to support ultrasound guidance in placing femoral and subclavian catheters in adults. Additionally, Doppler-guided cannulation of the IJV was more successful than the landmark method.[32]

Extrapolation of such findings to trauma must be guarded given the fluid nature of the trauma experience and the time required to perform an ultrasound-guided technique. Additionally, the often limited space in the deployed field environment argues against ultrasound-guided techniques, especially when coupled with the goals of damage control surgery. Currently, trauma central venous access is conducted rapidly, often simultaneous with damage control surgery, and is done to facilitate the massive transfusion process. The traditional landmark technique for accessing the subclavian vein followed by the IJV is the current practice in combat trauma anesthesiology. Despite this practice, there may be a role for ultrasound-guided access of the internal jugular vein if theater CSHs continue to receive two-dimensional ultrasound capabilities.

Complications of Central Venous Access

Pneumothorax is the most common complication of central venous access. Several anatomical considerations related to this complication should be used to help guide the operator. The dome of the pleura is higher in the left hemithorax than the right, and both may rise higher during positive pressure ventilation. Care should therefore be taken to minimize tidal volumes during SCV puncture. It is unclear whether this complication is more common with IJV or SCV catheter insertion.[33] Pneumothoraces may develop quickly or many hours after line insertion[34] and will most likely require the insertion of a chest drain. Some authors suggest it is prudent to insert IJV and SCV lines ipsilateral to preexisting chest injuries.[13,15]

Vascular injuries may occur with all access routes. Arterial puncture is more common with IJV (the carotid artery is at risk) than SCV cannulation. Carotid puncture is usually well tolerated; however, it is recognized that the SCV artery is difficult to compress behind the clavicle, so an injury may be more likely to be clinically significant. A hemothorax may develop after arterial puncture in these areas. Pressure to control a developing carotid hematoma has been associated with cerebrovascular accidents and death. The most severe complications of femoral vein access arise from inadvertent femoral or iliac artery puncture. Above the inguinal ligament, arterial puncture may result in a hemoperitoneum or retroperitoneal hemorrhage (such a complication may be more likely in severe hypovolemia in the absence of a palpable femoral pulse).[27] If either complication is followed by coagulopathy, the result can be severe. Other vascular injuries may involve the aorta and any of the great vessels; injuries to the walls of the cardiac chambers. Overall, femoral access carries the highest complication rate.[35] Other complications of central venous access include line malposition, air embolism, cardiac dysrhythmias, chylothorax, and peripheral plexus or nerve damage. With all routes, the strongest predictor of complications is the number of insertion attempts.[36]

INTRAOSSEOUS ACCESS

Access to the circulation via the bone marrow was first described in the 1920s by Drinker and Doan and the technique gained widespread support during the Second World War. Subsequently, with the development of more reliable and robust IV cannulae, it fell out of favor. However, the technique came back into use in the 1980s, especially in the pediatric population. Intraosseous (IO) vascular access is increasingly recognized as a valuable tool in the initial resuscitation of combat-injured patients.[13,37–39]

Several commercial kits are available to achieve IO access quickly and safely. These can be grouped into manual needles, impact-driven needles, and power-driven needles. It is essential that operators be familiar with the particular devices they may encounter in their practice.

Potential sites for IO access, dictated by the device to be used, include sternum, proximal and distal tibia, humeral head, and iliac crest. Other sites that have been described include the medial clavicle and calcaneum[40]; however, these are used much less frequently. Correct placement may be indicated by the aspiration of bone marrow and the ability to infuse fluid without subcutaneous extravasation. Extra care should be taken with sternal insertion because of the potential for rare complications including mediastinal injury and pneumothorax.

IO access has been shown to be significantly quicker to establish than central venous access.[41] However, it is recognized that maximum infusion rates are not comparable and that fluids must be infused under pressure. Most currently available devices use a 15-G cannula and provide flow rates comparable to a 20-G peripheral cannula.[41]

It is possible to infuse all commonly used anesthetic drugs via the IO route, and bioequivalence with the direct IV route has been demonstrated.[42,43] In addition to drugs, blood, crystalloids, and artificial colloid-containing solutions may be infused. Blood samples drawn from an IO needle demonstrate hemoglobin, electrolyte, and blood gas analysis results comparable to peripheral venous blood.[44,45]

Complications of IO access are rare (the overall rate is less than 1%[43]) and can be mitigated by familiarity with equipment. Patients commonly experience pain on infusion, which can be relieved by local anesthetic administered into the medullary cavity.[46] Fluid extravasation may occur with an improperly sited cannula, which can cause a compartment syndrome.[47] Osteomyelitis has been reported, with an incidence of approximately 0.6%, usually associated with prolonged infusions.[43] Iatrogenic fractures have been reported in children. A rare reported complication is retention of the cannula, necessitating surgical removal.[48] Long-term follow-up has shown that bone deformity due to needle insertion is not a problem.[49]

PERIPHERAL VENOUS CUTDOWN

Peripheral venous cutdown had been a popular route for fluid resuscitation in critically ill patients with shock since the first reported use in 1940.[50] However, the technique declined in popularity with the increased use and familiarity of the Seldinger technique for percutaneous access. Although setting up and starting IV resuscitation via venous cutdown techniques has been shown to take significantly longer to infuse fluids with by percutaneous femoral vein cannulation,[51] a cutdown remains a viable option in cases where percutaneous access proves impossible.

Popular sites for cutdown to be performed are the great saphenous vein, in the groin and distally at the ankle, and the basilic vein proximal to the elbow. At these sites it is usually possible to insert an 8.5-Fr catheter. If IV tubing is used, insertion is made easier by shaping the end of the tubing with a 45° bevel.[52] Exposure and cannulation of the great saphenous vein at the groin is the preferred technique. At the groin, the classic technique involves a transverse skin incision through superficial subcutaneous tissue in the proximal thigh.

A technique for rapid access to the femoral vein has been described utilizing a skin incision from a point inferior and lateral to the pubic tubercle, directed toward the medial epicondyle of the femur. Manual distraction of the subcutaneous tissue allows visualization of the vein at the base of the incision.[53] In all cases the vein is then identified, and a venotomy is performed and cannulated using either a modified Seldinger technique or classic technique without a guidewire. The line is then usually secured with sutures.

A contraindication for the technique is trauma to the ipsilateral extremity. Infection at the intended site and anatomical variance are relative contraindications.

The most common complications include cutaneous nerve damage and damage to vascular structures. If vascular structures are disrupted during attempted insertion, the site should be packed and explored in the operating room. Rates of infection rise significantly with duration of infusion, so lines inserted using cutdown techniques should be removed as soon as practical.[52]

DIRECT ATRIAL CANNULATION

Performing an emergency resuscitative thoracotomy may afford a further option for vascular access. Direct infusion of fluid to the heart is possible.[54] A technique has been described utilizing a 16-Fr or larger Foley catheter passed into the right atrial appendage via an atriotomy incision.[55] However, a number of complications may result from this procedure. First, air may be entrained into the cardiac chambers. The small amount of air that may enter at the time of the initial incision is considered to be of no consequence; however, care should be taken to ensure a good seal between the inflated balloon of the catheter and the atriotomy. This seal will also help to limit the leakage of blood from the heart.

A second complication is cardiac distension, which may occur if the technique is utilized in conjunction with proximal aortic occlusion. Manual and visual examination of the contracting heart should be used to guide fluid resuscitation along with other hemodynamic parameters.

ARTERIAL ACCESS

Once the anesthesia team is satisfied with the adequacy of the venous vascular access, access to the arterial system for rapid blood gas measurement and beat-to-beat blood pressure measurement can be conducted. Although venous blood gases may be used in extremis and utilized for base deficit determination for trauma,[56] using arterial blood for analysis is ideal. Arterial blood gas determination of base deficit is the best indicator for determining the adequacy of resuscitation for a combat trauma patient who is receiving a massive blood transfusion. Additionally, beat-to-beat blood pressure measurements are ideal for large-volume trauma resuscitations. The mere presence of systolic pressure variation can provide real-time information about intravascular volume status during resuscitation.

Again, due to the massive nature of injuries and diffuse injury pattern caused by IEDs, considerable yet rapid consideration must be given to the site for arterial cannulation. A review of the literature published between 1978 and 2001 on the most common arterial cannulation sites (radial, femoral, and axillary) revealed that major complications occurred at a rate of less than 1%, with similar rates for radial, femoral, and axillary arteries.[57] The location of the arterial site during combat anesthesia operations is often dictated more by the location of injury than an individual anesthesia provider's particular preference. Femoral arterial cannulation may be necessary if the soldier has injury to the bilateral upper extremities. Traumatic amputation of the upper extremity is a devastating injury, yet not uncommon because of the high velocity of IED projectiles. In these cases placement of a femoral line by a trauma surgeon would facilitate arterial blood gas analysis as well as rapid preparation for damage control surgery.

The femoral arterial route may be less desirable with intraabdominal or groin-penetrating injuries; in these cases a more traditional route may be preferred. Most anesthesia providers have a high comfort level with the radial arterial site given its use in routine practice. Despite this familiarity, it is sometimes difficult, if not impossible, to obtain the radial artery pulse with traditional palpation techniques and cannulate the radial artery. Often severely traumatized combat patients present with profound tachycardia, hypotension, and peripheral vasoconstriction, which makes palpation of a radial arterial difficult, particularly with systolic blood pressures below 60 mm Hg. Hypothermia and hypovolemic shock may result in peripheral vasoconstriction. This also makes radial arterial access and monitoring difficult. Although the use of ultrasound to obtain a radial arterial line is possible, the equipment is often impractical in the cramped and chaotic field environment.

An attractive alternative to the traditional radial artery site is the cannulation of the axillary artery. Adler was the first to describe the use of the axillary artery for intravascular monitoring in 1973.[58] Obviously this line is precluded in the presence of an upper extremity injury, but it is an invaluable technique for the severely traumatized combat soldier. The axillary vessel has a relatively larger caliber compared to the radial artery, so it is less likely to be affected by vasoconstriction. The more central location of the axillary is also advantageous for more accurate central pressure measurements. Additionally, the axillary arterial line is very durable and is in an ideal position for patient transport to higher levels of care.

The axillary artery is easily accessed with the aid of ultrasound[59]; again, however, the use of ultrasound for vascular access may be limited in the field environment. If ultrasound is unavailable, the axillary artery can easily be accessed from the head of the bed by placing the patient's hand behind the head and flexing the upper extremity at the elbow. By doing this the anesthesiologist can place the axillary line at the same time as the surgeons are performing damage control surgery.

The brachial artery should be cannulated with care during trauma. The brachial artery is an end-artery, and the presence of a vascular access line may result in ischemia of the forearm and hand on the side of arterial cannulation. The axillary artery is not an end-artery and when appropriately managed does not pose the same risk of ischemia as the brachial artery catheter.

EXHIBIT 5-2

POST-ANESTHESIA CARE OF VASCULAR ACCESS DEVICES

- For each device assess:
  - o Site
  - o Flow characteristics
  - o Security
- Reassess circumstances of insertion of each device.
- Plan for removal of devices no longer required.

BEYOND THE FIRST 24 HOURS

IV access lines should be removed as soon as they are no longer needed. Complications relating to duration of insertion, particularly infection, may affect subsequent recovery. Infective complications may be more common than in lines placed electively because they may have been placed in less than ideal circumstances; indeed, some may remain from the prehospital phase. Thorough handover to the next role of care must include discussion of current vascular access devices (Exhibit 5-2).

SUMMARY

In summary, vascular access in combat trauma anesthesia is done in the context of damage control surgery and often with the requirement for massive transfusion. It is critical for the anesthesia team to work in concert. The anesthesia team must attack the lethal triad of acidosis, hypothermia, and coagulopathy by performing targeted intravascular line placement with appropriate escalation to central venous access. This must be done simultaneously with damage control surgery and never delay the combat trauma patient from reaching the operating room. Intravascular access should augment the overarching goal of damage control surgery to stop the bleeding, and at times should be delayed to allow a more hypotensive strategy, especially when vascular injury is suspected. Obtaining good vascular access is a priority task in the early management of the injured. It will facilitate subsequent therapeutic maneuvers and is essential for the optimal resuscitation of the critically injured patient. A sound knowledge of the options available to access the circulation and familiarity with the commonly used equipment will allow anesthesia providers to quickly optimize this aspect of patient management.

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