13 Vascular Access

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Securing vascular access for a child is very gratifying but can also be challenging to the point of severe frustration. Pediatric surgeons should strive to be the best vascular access experts available anywhere in the hospital or clinic. Children who need a lifeline in an emergency, for comfort, for nutrition, or for long-term care, depend on us to make sure the access is placed safely and that it works reliably and painlessly. Any surgically created line should be inserted under general anesthesia or deep sedation while peripheral lines, depending on the age and maturity of the child, usually require only mild sedation. Sterile precautions should be followed with meticulous attention to detail and the safety of the patient should always be optimized. Complications from central access procedures can be very serious and, in some cases, potentially lethal.

Short-Term Access

Peripheral venous access should be considered first for most children who need intravenous access and surgeons should be skilled and experienced in their placement. In the current era of *intravenous access teams*, it is unfortunately fast becoming a lost art, but it need not be. Surgical residents should learn how to place peripheral IVs and practice placing them in the OR every chance they get, not only because it is a valuable skill to have but also because it teaches them a great deal about the handling of tissue and improves their manual dexterity.

One cannot learn to place a PIV by reading about it; hours of practice is really the only way. However, there are a fewer pearls to pass along: learn to do it with gloves on; do not apply the tourniquet too tight; be patient when looking for a suitable vein; wipe with alcohol from proximal to distal (toward the patient's fingertips) to avoid pushing blood up past the tourniquet; stretch the skin by pulling it distally with your non-dominant hand; when you get a flash of blood, push the entire needle–catheter unit in a little bit deeper before trying to slide the catheter over the needle; learn how to gauge the depth of the vein (which is more difficult than it seems); and have the line to attach to the catheter ready, primed, and close at hand. One should also develop a short list of favorite sites—the vein on the ulnar aspect of the back of the hand and the saphenous vein at the ankle (just superior and anterior to the medial malleolus) are excellent choices. Always place a catheter of sufficient size for the child and its intended use, typically one size larger than you think will fit. Except in times of desperation, one should generally avoid the abominable and ironically named *interns'* vein as it is actually very difficult to access and patient hate it. Likewise, the antecubital location should be avoided—it is difficult to secure it properly as it lies so close to the elbow joint, it should be saved for other purposes (phlebotomy), and an IV placed here is the hallmark of the inexperienced and insecure.

In the heavily sedated or critically ill child with very difficult access, a saphenous vein cutdown at the ankle is an excellent option. A small transverse incision anterior and superior to the medial malleolus using sterile technique and a fine mosquito clamp should allow isolation and control of the saphenous vein. Placing the catheter itself through a separate skin puncture just distal to the incision allows the incision to be sutured neatly without having a catheter in the way. Traditionally, the vein was ligated distally, but this is not always necessary if the vein is punctured with the needle (rather than by venotomy) and if back-bleeding is minimal.

Percutaneous non-tunneled central venous catheters are useful alternatives in patients who are seriously ill and have either very poor peripheral access or who need short-term (<7 days) central access for central venous monitoring, parenteral nutrition, or vasoactive drugs. Most are made of relatively stiff polyurethane and are therefore prone to infection, breakage, and vascular or atrial erosion. Antibiotic-coated

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catheters seem to be less prone to infection. They are placed using Seldinger's technique, often under circumstances that are less than ideal. The three most accessible veins are the internal jugular, subclavian, and femoral. The right internal jugular vein is ideal for most critical care needs given its ease of access and straight course. US should be used whenever available (surgeons should be trained and practiced in its proper use), though one should also be prepared to gain RIJ access using only anatomic landmarks for those rare situations when a US is not available. The vein is superficial and often palpable anteriorly, between the two heads of the sternocleidomastoid muscle. The needle is inserted almost perpendicular to the skin and above the level of subclavian artery, which in most children arches slightly above the level of the clavicle and is more at risk than the carotid artery. The pressure needed to puncture the skin can be significant, but the subsequent overshoot usually results in the tip of the needle residing within the lumen of the vein, which becomes obvious when the needle is lifted to tent up the anterior wall of the vein. Common complications include arterial puncture, hematoma, and vein thrombosis; rare complications include pneumothorax, Horner syndrome, and phrenic nerve injury.

Percutaneous access to the subclavian vein is also a fading art as more institutions mandate open access at the deltopectoral groove or internal jugular vein, presumably out of fear of litigation for pneumothorax and other complications. Nevertheless, it is a useful and safe technique when performed properly. A small rolled towel between the scapulae is all that is necessary to slightly exaggerate the normal angulation of the clavicles—a large roll is not necessary and can allow the patient to rock back and forth. Live fluoroscopy is critical when available. The vein is easier to access in the sulcus just lateral to the first rib, palpable in most anesthetized children. Here, within the middle third of the clavicle, the vein is superficial (1–3 cm deep) and the risk of inadvertent arterial puncture is lower than with the more lateral approach we were taught to use in adults. Trendelenburg position probably helps very little to distend the subclavian vein, but it does not hurt. We also routinely ask the anesthetist to hold positive pressure ventilation while we try to access the vein as this might minimize the risk of injury to an inflated lung. One needs to angle the needle along an imaginary line that intersects the cricoid cartilage rather than the sternal notch. It is helpful to place your non-dominant middle finger in the sternal notch and use your thumb to push the shaft of the needle downward so that the needle is always parallel to the chest wall, never angled sharply downward in a way that places the apex of the lung at risk. Except perhaps in children who are the size of a large adult, the vein will be entered just under the clavicle—it is almost never necessary to bury the full length of the needle, which can cause puncture of the subclavian or carotid artery, the internal jugular vein, trachea, or the endotracheal tube balloon. The entry of the lumen of the vein might not be obvious until the needle is withdrawn slowly. There must be a robust flash and good blood flow or the wire will not pass easily. Once the vein is entered, turn the needle slightly so the open end of the beveled end is facing proximally, hold the needle extremely still, and pass the wire until cardiac ectopy is noted or most of the length of the wire has passed.

It is very common in children for the wire to travel up the internal jugular vein or opposite subclavian vein, the first clue usually being the fact that only a third or half of the length of the wire passes until an obstruction is encountered. A standard IV catheter (18 or 16 gauge) can be used as a sheath while the wire is manipulated under fluoroscopy. The right brachiocephalic vein origin can be gently compressed by pressing down on the head of the right clavicle while passing the wire from the left subclavian side. Likewise, one can use a finger to compress the internal jugular vein, which prevents the J-tip from passing cephalad and allows a loop of wire to go down into the atrium, dragging the tip with it.

The femoral vein should always be considered the central venous access of last resort. It is difficult to access because of its proximity to the femoral artery and the fact that it is not directly medial to but rather also slightly posterior to it. Catheters in this location are also prone to infection and kinking.

Surgeons should be trained and certified in the use of US guidance for the placement of central venous lines. It has been shown to reduce the incidence of complications and improve the accuracy of placement of catheters in the internal jugular vein. It is considered the standard of care in most institutions but is probably of little benefit for subclavian vein access. A more practical reason to become experienced in US guidance is that due to the widespread use of PICC lines and the availability of interventional radiologists to place central lines, the modern resident is not placing thousands of central lines during their training as those of us from prior generations did, and therefore, the art of using external anatomic landmarks and a feel for where that vein could be hiding have been lost and are unlikely to be brought back in any meaningful way.

Percutaneous central venous catheters come in many sizes and varieties—single, double, or triple lumen; 5, 8, 12, and 15 cm lengths; and 4-, 5-, 6-, and 7-French (circumference in mm) sizes. The number of lumens is based on the intended use of the line (antibiotics, chemotherapy, TPN, pressors, blood draws). The caliber of the line is based on weight and age of the child. As a general rule of thumb, one might use 4 French in infants and toddlers, 5 French in some toddlers and most children, 6 French in some children and most adolescents, and 7 French in large adolescents and young adults. The length of the catheter is chosen based on the size of the patient and the site of insertion so that the tip of the catheter ends up in the right location, preferably at the

SVC–RA junction or superior RA. With experience, one eventually learns which catheter is best at any given site: 8 cm from the right subclavian vein, 8 or 12 cm from the right internal jugular vein, 12 or 15 cm from the left subclavian vein, and so forth.

In most institutions, PICCs are not inserted by surgeons but by radiologists, neonatologists, and nurse practitioners. They are generally well tolerated and useful in situations in which a line is needed for 2–6 weeks. However, they are fraught with complications, including thrombosis, infection, dislodgement, phlebitis, breakage, and unplanned return to ED. They are also expensive to place and maintain, are occasionally used by patients for injection of illegal drugs, and are probably overused. One should consider an alternative, such as a long peripheral IV, highly bioavailable oral antibiotics, or nasogastric feedings rather than being quick to recommend a PICC line.

Long-Term Access

Catheters that are needed for more than a few weeks are tunneled and made of silastic polymer or polyurethane. In most institutions these include externalized catheters (Hickman, Broviac) and subcutaneous venous access ports. Ports are generally preferred for patients who need intermittent infusions but not for those who need continuous infusions (TPN) because of the risk of infection and skin breakdown (due to being accessed with a needle for long periods of time) or for drugs that are sclerosants due to the risk of soft-tissue necrosis in the event of inadvertent needle dislodgement or extravasation. They are preferred in general because when not in use, the child may bathe and swim and there is no external portion of catheter that might become snagged or cause annoyance. Downsides include the need for a larger incision, the need to access it by passing a needle through the skin, and the fact that when infected they are usually more likely to have to be removed. Ports are also prone to complications and difficult access in children with morbid obesity, large breasts, and skin diseases (especially graft-versus-host disease) or who are emaciated and malnourished. They should always be placed below Scarpa's fascia and secured to the pectoralis fascia rather than have only skin covering them.

Ports can theoretically be left in place for years; however, it has been our experience, especially with the smallest ports, that ports that have been in place for more than 3 years tend to be very difficult to remove: the silastic polymer tends to dry out and crack, creating tiny crevices for scar tissue to intercalate, and we have had several that have broken off, creating a retained foreign body situation or, in some cases, an actual pulmonary embolus. Although the best advice is probably to plan to remove or replace the port every 2–3 years, there are a few tricks when removing the port to help avoid this scenario (and the subsequent and obligatory trip to IR): gentle tugging on the catheter, prolonged steady traction without increasing the tension excessively, and just being patient until it starts to slip; opening the incision in the neck or subclavian region so that the catheter can be pulled out straight rather than creating a tissue-pulley situation by trying to pull it out from below; passing a guide wire through the lumen and using the outer sheath of a peel-away introducer to slide over the outer surface of the stuck catheter; theoretically shearing off the fibrous tendrils holding it in place (the risk of course is pushing it into the body even further); and cutting down on the catheter practically into the vein, though many of these have been incorporated into the endothelial wall of the vessel itself. When they break off, they are usually stuck to the wall of the vein, having been wallpapered over by neointima. As such, while they likely pose little if any danger to the patient, the anxiety it creates for parents can be extreme.

Choosing the appropriate size of catheter is important. The catheter needs to be big enough to be used for blood draws and resists clotting but small enough to minimize the likelihood of vein thrombosis. Single-lumen Broviac catheters usually come in 2.7 French for preemies, 4.2 French for infants, 6.6 French for children weighing more than 8–10 kg, and 9.6 French or larger for adult-size patients who for some reason need a larger catheter (most teenagers do well with 6.6 French). Double-lumen Hickman catheters come in 5 French, 7 French, and 10 French. The 7-French catheter is a standard and very reliable catheter in most patients between 10 and about 80 kg. Because the smaller lumen tends to clot off early, the 5-French double-lumen catheter is very unreliable and should be avoided. Ports come in 5 French for infants, 6.6 French for those who weigh more than about 8–10 kg, and 9.6 French for children who are morbidly obese or who have very large breasts. Double-lumen ports are more difficult to place (the tip cannot be cut to length because the catheter needs to be placed over the hub of the port itself; they are often of an awkward shape and are difficult to handle) and usually come in 7- or 10-French sizes.

Placement of a Broviac or Hickman catheter, port, or permanent hemodialysis catheter can be very difficult and demands patience, an absolutely meticulous approach, and sometimes ingenuity in order to do it well. These lines are lifelines and we owe it to the children to place a line that is functional but also easy to maintain, safe, and durable for the length of their treatment. Even a meticulous surgeon needs to be even more fastidious than usual when placing an indwelling central line. Except in the most exceptional and truly desperate situations, these are never placed in a femoral vein. Likewise, general anesthesia is strongly preferred. IA small rolled blue surgical towel between the shoulder blades will slightly exaggerate the posterior inclination of the clavicles and expose the anterior aspect of the neck somewhat. We always sterilely prepare the entire anterior aspect of the neck and chest so as to have access to all four traditional sites of access. Everyone has their preferred sites—for some, the order of preference is LSC, RSC, RIJ, and LIJ. Some believe subclavian vein access results in thrombosis that can affect a child throughout life (especially if they ever need to have a shunt placed for hemodialysis) and therefore prefer to use an internal jugular vein whenever possible. We also prefer a percutaneous approach rather than a cutdown, mostly for cosmetic reasons, and to try to avoid having to sacrifice the vein by ligating it. The external jugular vein, though often tempting with its deceptive prominence, is very unreliable and its joining with the central veins is often weirdly angled, making central passage of the catheter frustrating or impossible.

Once the wire has been placed centrally and secured (only so that it is not snagged by the inattentive operator, they do not get sucked in), a site is chosen for the Hickman catheter or port to be placed on the chest. For external catheters, we prefer a paramedian location near the lower sternum, though large breasts can make this impractical. We generally avoid the upper chest whenever possible for cosmetic reasons and the axilla, lateral chest, or abdomen for practical and infectious reasons. Once a small incision has been made, create a small subcutaneous pocket for placement of the cuff, preferably below Scarpa's fascia, directly cephalad to the incision, and tunnel the catheter using any of several tools (silver probe, tunneler provided in the kit, tendon passer) around the breast tissue and in such a way that the catheter travels in smooth arcs without kinking and arrives at the venous puncture site below the platysma so that it does not end up directly against the skin incision of the insertion site. The cuff should be 1–2 cm above the incision but should be pulled up farther at first so that one can feel the cuff being held back by one of Cooper's ligaments when gentle traction is placed on the catheter. This prevents the cuff from working itself out without having to place it a long distance from the incision.

The tip of the catheter, cut straight across, should be at the SVC–RA junction, which on AP chest fluoroscopy is at the point where it appears to be just entering the atrium (the SVC enters on the posterior wall of the atrium) or 2 vertebral bodies below the carina (Fig. 13.1). A little deeper than this is ok too, but the lower half of the atrium is where the tricuspid valve is and should be considered too deep. The catheter must be pointing caudad in all projections, must not be flicking excessively during the cardiac cycle, and must draw back and flush with no resistance. Achieving this ideal position can be difficult and requires experience and patience. We keep the peel-away sheath in place until the catheter is trimmed to size, sometimes pulling out and replacing the

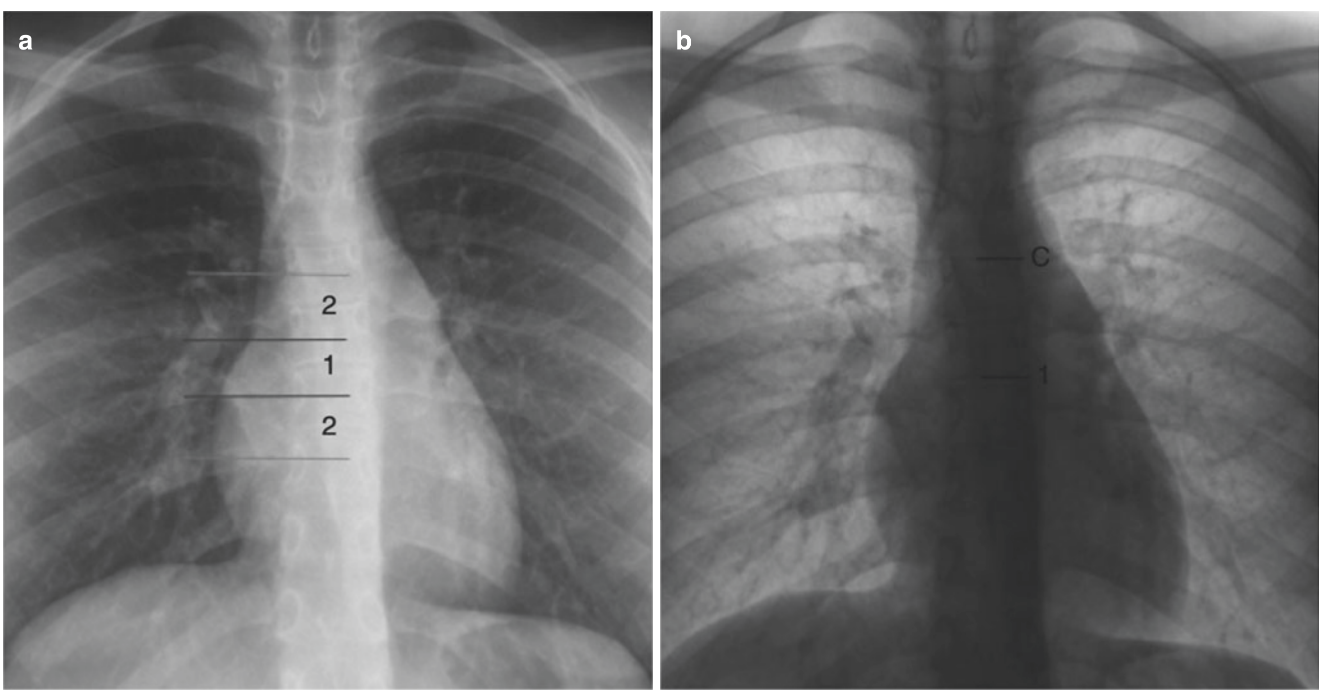

Fig. 13.1 Ideal placement of the catheter tip for central venous lines placed in the internal jugular or subclavian vein. (**a**) The zone delineated by the gray lines and labeled 1 is the RA–SVC junction and is the ideal location for the catheter tip. The zones labeled 2 are usually also acceptable though not ideal locations. Wherever the catheter tip resides, it must be pointing straight down, away from the wall of the SVC or atrium, in both AP and lateral projections. (**b**) Some prefer to use the carina as a guide, in which case the RA–SVC junction is located two vertebral bodies below the level of the carina

catheter 2–3 times. Others use external landmarks or a mathematical formula based on the length of the wire, but regardless it is absolutely critical that the catheter tip be in the best position possible when the child leaves the OR, even if that means removing it and placing a brand new one—whatever it takes to make it as close to perfect as possible. It also cannot be simply left in the mid- or upper SVC as it will have a tendency to flip up into the more proximal veins with movement or when forcibly flushed with a syringe under pressure (a trick that can also be used to force an errant catheter tip out of the subclavian or jugular vein and back into the atrium). Once in place and flushed, it should be stitched to the skin near the entry site with two fine monofilament sutures using a Roman Sandal technique and a dry sterile dressing applied according to institutional protocols.

The best place on the chest for a port in a boy is in the upper chest lateral to the manubriosternal joint, and in a girl in a more lateral infraclavicular location closer to the shoulder for aesthetic reasons, or very close to the clavicle in girls with large breasts. In rare cases an unusual location such as the inner arm, lateral chest, or abdomen is requested, though these are fraught with significant logistical problems and access issues. We prefer a transverse incision with creation of a subcutaneous pocket between the Scarpa's fascia and the pectoralis fascia inferior to the incision. I use one monofilament suture to tack the port to the pectoralis fascia and then tunnel and insert the catheter using Seldinger's technique and peel-away sheath. Passing the dilator or peel-away sheath should be considered a potentially dangerous maneuver as the SVC or right atrium can be punctured if not done with deliberate caution and smooth precision. The port incision is closed in layers with interrupted absorbable sutures and cyanoacrylate glue. If it is to be used within a few days, it should be accessed with a right-angle Huber needle, flushed, and dressed.

Tunneled hemodialysis catheters are placed like Hickman catheters except that they are stiffer and larger and need to be tunneled with even larger arcs and smoother bends than the more pliable and forgiving standard catheter. This usually means bringing it out near the axilla or lateral chest wall. They can also not be cut to size, and therefore, it takes planning to make sure the cuff sits an appropriate distance from the skin insertion site and the tip of the catheter is in an appropriate location. The distal tip should usually sit in the mid-atrium so that the proximal tip is at the SVC–RA junction. We usually make the skin incision longitudinal and err on the side of making it too close so that it can be extended and the Scarpa's fascia and skin can be closed over the cuff if it has to be pulled back somewhat. These need to function flawlessly for, however, long the child needs it, often many months.

Removing a Hickman catheter is straightforward and in adolescents can be done under mild sedation, but at our institution is customarily done under deep sedation or even general anesthesia. The cuff is dissected free with a small mosquito clamp and fine scissors and the catheter removed. We routinely close the skin incision with cyanoacrylate glue and sometimes a single deep-dermal stitch and have never had an infection. Alternatively, ointment can be applied and the wound allowed to close by secondary intention. Ports can usually be removed by opening the prior incision. We do not routinely excise the pseudocapsule and instead close the wound in layers and skin glue while holding pressure at the vein entry site.

Cutdown Techniques

For those uncommon situations when percutaneous access is not an option, the surgeon should be able to access the femoral vein via the saphenous vein in the thigh, the subclavian vein via the cephalic vein at the deltopectoral groove, and internal jugular vein by way of the external jugular or facial vein in the neck. These skills are only obtained by practice but intermittent review of relevant anatomy and a good surgical atlas is useful. Though not a cutdown, intraosseous access is underrated and underutilized. It is used most often in the trauma bay but is very safe and extremely versatile—another skill with which a pediatric surgeon should be familiar.

The facial vein is especially useful in small preemies. The patient should be properly anesthetized and the arms pulled down gently with tape to expose the right side of the neck. A small transverse incision is made in the skin crease just anterior to the sternocleidomastoid muscle below the angle of the mandible. The incision is made directly over where the IJ lives so that if the facial vein is absent or too small, direct entry to the IJ is an excellent plan B. The facial vein usually resides just below the platysma and can be ligated and entered through a small venotomy. These are usually small infants so a 2.7-French or 4.2-French catheter is used and tunneled after the vein is controlled with sutures. If the IJ is used instead, it is better not to ligate it distally and instead pass the tip of the catheter, which has been cut at a sharp angle, through a venotomy created with a 20-gauge needle, allowing a watertight seal around the catheter and obviating ligation or a purse-string suture, which is near impossible in such a small vein anyway. One still needs to control the proximal and distal IJ with ties but ligation should be rarely necessary. Making sure the tip is in a good position is much more difficult given that fluoroscopy is rarely available in the NICU, but takes practice to get right based on external landmarks. The nipple line is usually a good guess in most infants.

Radial arterial lines are often useful though probably overused in the PICU and OR. Pediatric surgeons should become experts in the percutaneous approach, which should always include the use of sterile technique, a guide wire, and the option of using US guidance. Cutdowns for arterial access should also be in the armamentarium but only used when absolutely necessary. It is important to have good lighting, magnification, and delicate instruments. The artery in children is always very small, prone to spasm, and easily confused with nerves and tendons in the wrist. We never ligate the artery and prefer to place the catheter through a separate skin puncture so the incision can be closed neatly with absorbable sutures without having a catheter coming through it.

Complications

If a line is placed without difficulty and the tip position is confirmed by fluoroscopy or CXR in the OR, then a postoperative radiograph is unnecessary. Pneumothorax is rare and can usually be observed unless symptomatic or enlarging. Hemothorax is also rare but can be difficult to manage if caused by injury to the inferior aspect of the subclavian artery in the chest and can be life threatening if caused by puncture of the sidewall of the SVC with a dilator. Catheters that are left deep in the atrium can erode and perforate the atrium and create pericardial tamponade. This can occur with hyperosmolar solutions or parenteral nutrition and is potentially life threatening. If recognized in time, the catheter can often be simply removed but contingencies need to be made for possible thoracotomy, bypass, and repair of the injury. Catheter tips situated deep in the atrium can also cause arrhythmias, especially SVT. These should almost always be replaced and pulled back a few centimeters to avoid the conduction pathways of the heart. Infection can often be treated effectively with antibiotics alone, but if bacteremia persists the catheter will need to be removed and then replaced, preferably more than 24 h after removal rather than at the same operation. This is especially true for infections caused by encapsulated organisms or fungus. Although these are typically endovascular infections, the old skin entry site can apparently harbor organisms for weeks or months, and therefore, it is usually advisable to use a completely different skin site for the new catheter. Small catheter-associated thrombi are probably much more common than we appreciate, especially with PICC lines. Although it is unclear if they are always clinically significant, when identified, even incidentally, they tend to induce significant anxiety and frequent recommendations for therapy with anticoagulants.

Lines whose tips have flipped back into the subclavian vein or jugular vein can sometimes be repositioned by forcibly injecting saline under high pressure with a 10-mL syringe, which causes the tip to be propelled into the SVC by action of the jet created, similar to what happens on a larger scale with a fire hose. This is usually best done with real-time visualization by fluoroscopy. When the cuff of a Hickman or Broviac catheter becomes extruded, it is at high risk for infection and dislodgement and should therefore usually be replaced somewhat urgently.

Ports can be difficult to access if they are too small and too deep or if they have flipped upside down. This is especially a problem in morbidly obese patients and in girls with very large breasts. Some will place the port between the skin and the breast tissue or cut away breast tissue to minimize the amount that obscures the port. Some place the port near or practically on the clavicle with some success. Regardless, it is important to place a larger port in these patients.

Breakdown of the skin overlying a port is a concern in patients who are emaciated, have skin diseases (especially graft-versus-host disease), have ports that have been placed superficial to Scarpa's fascia (covered only by skin), or have frequent or continuous needle access. If the port is visible through the skin, it cannot be salvaged and needs to be removed and a new one placed is a completely new site. Many extravasations and hematomas can be managed by resting the port, but a port suffused with purulent fluid must be removed. Every institution should have guidelines for who can safely receive a subcutaneous port and who should be recommended for an external catheter. Relative contraindications to use of a port include morbid obesity, large breasts, malnutrition or emaciation, osteogenesis imperfecta (risk of rib fracture during attempts to access the port), graft-versus-host disease or other dermatologic conditions associated with open sores or poor wound healing, severe neutropenia or thrombocytopenia, some connective tissue disorders, and certain cognitive or psychiatric disorders that would prevent safe handling or maintenance of an imbedded access needle for long periods.

Summary

In any hospital that takes care of children, pediatric surgeons should be the experts in all forms of vascular access, especially when a child needs a well-placed and well-functioning long-term access or for critical access in an emergency. We are also available when a line is malfunctioning, becomes infected, or needs to be replaced, even if the line was placed by someone else, especially when the stakes are high. Most importantly, all access procedures demand meticulous attention to detail and careful precision.

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