Transcatheter aortic valve implantation (TAVI) has emerged as the current therapy of choice in patients with severe aortic valve stenosis who are not candidates for open heart surgery (1–3) and as an accepted alternative to high-risk surgery in patients who are operable (4). However, vascular complications have also emerged as a major limiting factor when using the large sheaths and catheters required for such procedures. In this paper, we review the evaluation of vascular access, sheaths used for transarterial access, wires, different access routes, and closure techniques.

Evaluation of Vascular Access

Femoral access anatomy. The infrarenal abdominal aorta bifurcates into the right and left common iliac arteries that, in turn, bifurcate into the external and internal iliac arteries. The external iliac passes under the inguinal ligament, at which point, it is referred to as the common femoral artery. The common femoral artery further bifurcates into the superficial and deep (profunda) femoral arteries. The inferior epigastric artery arises from the external iliac artery, superior to the inguinal ligament (Fig. 1). A puncture at or above the level of the inferior epigastric artery is often noncompressible and increases the risk of retroperitoneal hemorrhage.
However, retroperitoneal bleeding can develop after arterial puncture below the inguinal ligament should the puncture channel involve both extraperitoneal and retroperitoneal tissue (5). A puncture below the femoral bifurcation increases the risk of puncture in a smaller artery and is relatively noncompressible due to the lack of sufficient support from the femoral head (6). This may explain the higher risk of pseudoaneurysm formation (7). For percutaneous sheath insertion, a common femoral puncture between the inferior epigastric artery and the femoral bifurcation is desirable.

In the absence of atherosclerotic disease, the common femoral artery is compliant and can accommodate sheaths slightly larger than the artery diameter. In the presence of moderate or severe calcification, the external sheath size should not extend the minimal artery diameter. With the current ≤18-F to 19-F sheaths, iliofemoral arteries are large enough in the majority of patients evaluated for TAVI.

**Conventional angiography.** Given the high burden of vascular complications in TAVI, increasing the effectiveness of preprocedural screening of patients for TAVI is key. This often begins with conventional angiography as virtually all patients undergo coronary angiography. A calibrated pigtail (e.g., Beacon Tip Royal Flush, Cook Medical Inc., Bloomington, Indiana) is placed in the abdominal aorta just above the bifurcation. With injection of 20 to 35 ml of contrast dye over ~2 s, both iliac and femoral arteries can be visualized. The common femoral artery and the level of the femoral bifurcation in relation to the femoral head should be assessed. Localized femoral disease, extensive calcification, or a high femoral bifurcation may influence the site of puncture and reliability of closure. Using the catheter markers for calibration, the minimal lumen diameter of the iliac and femoral arteries on both sides can be measured.

The advantages of angiography are its high spatial resolution and that vessel movement can be evaluated and the degree of calcification can be estimated before the dye arrives. Limited vessel movement may indicate a more rigid and more calcified artery. Angiography provides only a limited evaluation of atherosclerotic disease burden as well as the degree of vessel tortuosity.

Digital subtraction angiography (DSA) is still considered the reference gold standard on the basis of its superior spatial resolution (8,9). However, both angiography and DSA depict arterial anatomy in a 2-dimensional plane particularly when rotational angiography is not performed. As a result, a stenosis that is only visible in the third dimension may be missed.

**Computed tomography.** Multidetector computed tomography (MDCT) allows high spatial resolution in 3 dimensions and rapid image acquisition, thereby overcoming some of the limitations of conventional angiography and DSA. Using a centerline approach to elongate the vessel image, multiple luminal measurements should be made in a plane orthogonal to the vessel rather than in the transverse axial plane. Using this approach, MDCT can evaluate vessel size, degree of calcification, minimal luminal diameter, plaque burden, and vessel tortuosity and also identify high-risk features including dissections and complex atheroma. In addition, MDCT is becoming the gold standard for annular sizing and may be used for coronary artery assessment (10). Approximately 80 to 120 ml of intravenous contrast is usually injected for visualization of the iliofemoral arteries (11). In a recent study of patients undergoing MDCT, the incidence of contrast-induced nephropathy was 0.6% in those with a glomerular filtration rate (GFR) of 40 to 60 ml/min and 7.8% in those with a GFR <30 ml/min (8). Therefore, MDCT is often not performed in patients with severe renal insufficiency (12).

To help reduce the risk of contrast-induced nephropathy, a number of contrast-reducing techniques have been published. Kubo et al. (13) reported that administration of 50 ml of contrast resulted in adequate contrast enhancement throughout the thoracoabdominal-aortoiliac system. Alternatively, direct arterial injection through a 4-F to 5-F pigtail catheter allows visualization of both iliofemoral arteries with only 10 to 20 ml of contrast (14). MDCT can be performed right after diagnostic angiography with the patient transferred with the sheath and pigtail catheter secured in place. MDCT can also be performed without contrast dye. Although estimates of luminal diameter may be less reliable, this still provides detail regarding calcification.

In a recent meta-analysis, MDCT had a sensitivity of 92% and a specificity of 93% to detect a >50% stenosis compared with DSA (9). In patients with heavily calcified arteries, overestimation of the plaque size and stenosis severity may occur (blooming/partial volume averaging), resulting in the underestimation of the minimal luminal diameter (15).

**Magnetic resonance angiography.** Magnetic resonance angiography (MRA) has the advantage of vascular screening with a low risk of nephrotoxicity, although its resolution is lower than that of MDCT (8). A recent meta-analysis found that MRA is very accurate for the detection of >50% stenoses with a median sensitivity of 95% and a median specificity of 97% (16). MRA without contrast enhancement may be a promising alternative, particularly for those patients with significant renal impairment (GFR <30 ml/min) to help reduce the potential risk of gadolinium-mediated nephrogenic systemic fibrosis. A recent study showed that nonenhanced MRA correlated very well with contrast-enhanced MRA (17).
**Intravascular ultrasound.** Intravascular ultrasound (IVUS) (Volcano Corp., Rancho Cordova, California, or Boston Scientific, Natick, Massachusetts) has the advantage of a very high resolution and allows vessel examination in all 3 dimensions. In addition, plaque composition and volume can be assessed without blooming artifacts from calcifications that sometimes reduce the quality of MDCT. It is also possible to differentiate between circular and noncircular plaques. In a study comparing IVUS with angiography, IVUS yielded comparable luminal diameters and stenosis measurements. The degree of calcification was graded less severe by IVUS (18).

**Sheaths**

Sheaths allow access to the vessel without loss of blood by using a haemostatic valve. Long 30- to 35-cm sheaths are used that are designed to deliver the prosthesis beyond the iliac artery directly to the aorta.

Sheath diameter has decreased over time. The Medtronic CoreValve (Medtronic Inc., Minneapolis, Minnesota) saw a gradual decrease in sheath size from 25-F (first generation) to 18-F (third generation). The Edwards SAPIEN valve (Edwards Lifesciences, Irvine, California) requires a 22-F/24-F sheath, and the Edwards SAPIEN XT valve requires an 18-F/19-F sheath for the 23- and 26-mm valves. The different sheath types are summarized in Table 1.

**Edwards RetroFlex3 and NovaFlex introducer sheaths.** The Edwards RetroFlex3 introducer sheath (Edwards Lifesciences) is used for implantation of the Edwards SAPIEN valve. It has an inner diameter of 22-F and 24-F for the 23- and 26-mm valve, respectively. The corresponding outer diameters are 8.4 and 9.2 mm. The Edwards NovaFlex Introducer Sheath (Edwards Lifesciences) has an inner diameter of 18-F and 19-F for the 23-mm Edwards SAPIEN XT and 26-mm Edwards SAPIEN XT, respectively. The corresponding outer diameters are 7.2 mm and 7.5 mm, respectively.

**Edwards eSheath expandable introducer sheath.** The Edwards eSheath is a 36-cm long expandable sheath with a compliant seam that allows transient expansion as the delivery catheter is passed through it. After passage of the prosthesis, the sheath contracts to some degree toward its unexpanded size (Fig. 2). The sheath is introduced in its low-profile configuration, reducing the risk for iliofemoral injury. When inserting the eSheath with the introducer, the expansion seam is oriented toward the posterior wall of the artery being accessed, thus avoiding any damage to the softer seam by the calcified artery wall. The eSheath is available in unexpanded inner diameters of 16-F, 18-F, and 20-F for the 23-, 26-, and 29-mm Edwards SAPIEN XT valves.
valves, respectively. Because the sheath transiently expands and then contracts, there is the possibility of incomplete arterial sealing. To avoid this, it is best to advance the sheath all the way into the patient where the larger and nonexpandable strain relief portion of the sheath provides reliable sealing.

Check-Flo Sheath. The large Check-Flo sheaths (Cook Medical) are available with inner diameters of 16-F, 18-F, 20-F, and 22-F and are most frequently used with the Medtronic CoreValve. The sheath has a working length of 30 cm, but longer sheaths are available.

St. Jude Medical Ultimum Sheath. The Ultimum Sheath (St. Jude Medical, Inc., St. Paul, Minnesota) is available with internal diameters of 12-F, 14-F, 18-F, and 20-F. All sheaths have a working length of 30 cm. There is also a 16-F sheath available that is 35 cm long as well as a 22-F sheath with a length of 25 cm.

SoloPath Balloon Expandable Transfemoral Access System. The SoloPath sheath (Terumo Interventional Systems, Inc., Somerset, New Jersey) is a balloon-expandable sheath. It is available with internal diameters of 18-F, 19-F, and 21-F and has an expandable length of 25 cm and a working length of 25 to 35 cm. The sheath is inserted in its unexpanded state with an outer diameter of only 4.3 mm, facilitating delivery through difficult anatomy. A balloon is then inflated to expand the sheath and reach the intended diameter (18-F to 21-F) (Fig. 3) (19).

GORE DrySeal Sheath. The GORE DrySeal Sheath (Gore Medical, Flagstaff, Arizona) is available in different sizes ranging from 12-F to 26-F and has a working length of 28 cm. The sheath has a stopcock, through which 2.5 ml of saline solution is injected to pressurize the hemostatic balloon valve. This way, the sheath can accommodate multiple wires simultaneously with minimal blood loss.

**Wires**

The purpose of the wire is to allow safe delivery of the device without causing trauma to the artery. Different guidewires are currently used for TAVI. Currently used wires have a diameter of 0.035 inch (0.9 mm). Exchange wires with a length of 260 cm are required to exchange catheters while...
keeping the tip of the wire in the left ventricle. The wires are constructed of an inner stiff core that is tapered distally and does not extend into the softer, atraumatic, shapeable tip. Although the guidewires have names such as “extra stiff” or “super stiff,” these names do not always correlate with the actual stiffness (e.g., the Lunderquist Extra Stiff wire is much stiffer than the Amplatz Super Stiff wire) (20). The very stiff wires may be useful in very tortuous and borderline anatomy to advance the sheath, but should not be used to support TAVI. All wires that are currently used have some sort of coating, most commonly tetrafluoroethylene, which reduces friction considerably. Some have an antithrombogenic heparin coating.

**Amplatz Extra Stiff Guidewire.** The Amplatz Extra Stiff Guidewire (Cook Medical Inc.), most commonly used for TAVI, is a heparin-coated stainless steel wire with a diameter of 0.035 inch (0.9 mm) and a length of 260 cm. Among commonly used stiff guidewires, the Amplatz Extra Stiff has the least stiffness (20). The wire has a straight tip or a small distal J with a radius of 3 mm. The distal 1, 3, or 6 cm of the wire are flexible. To avoid trauma to the left ventricle, an exaggerated J is usually formed by the interventionalist. It is important that the stiffer part of the wire extends into this exaggerated J curve to provide more stability and to protect the left ventricular wall from trauma through the nose cone.

**Amplatz Super Stiff Guidewire.** The Amplatz Super Stiff Guidewire (Boston Scientific), is a coated stainless steel wire with a diameter of 0.035 inch (0.9 mm) and a length of 260 cm. The wire is stiffer than the Amplatz Extra Stiff Guidewire. It has a straight tip or a small distal J with a radius of 3 mm and a soft, atraumatic tip 1 to 6 cm in length. If a guidewire with a soft tip of 7 cm is used, the exaggerated J has to be formed with several loops to ensure that the stiffer part of the wire extends into the exaggerated J curve. This wire is widely used in centers that implant the Medtronic CoreValve.

**Backup Meier Guidewire.** The Meier wire (Boston Scientific) is a coated stainless steel wire with a diameter of 0.035 inch (0.9 mm) and a length of 260 cm. It has a greater shaft stiffness than the Amplatz Extra Stiff and Super Stiff guidewires. The length of the flexible tip is 10 cm.

**Hi-Torque Supra Core 35 Guidewire.** The Hi-Torque Supracore wire (Abbott Vascular Inc., Redwood City, California), has a 1-to-1 torque response for improved steerability. The wire has a length of 300 cm and a diameter of 0.035 inch (0.9 mm).

**Lunderquist Extra Stiff.** In case of extensive tortuousity, extremely stiff guidewires such as a Lunderquist Extra Stiff guidewire (Cook Medical Inc.) are used. The Lunderquist guidewire is a coated stainless steel wire with a diameter of 0.035 inch (0.9 mm) and a length of 260 cm. It has a 4-cm flexible J-shaped tip. The guidewire is stiffer than the Amplatz Extra Stiff and Super Stiff Guidewires and the Meier Guidewire.
**Transfemoral Access**

Transfemoral access is considered the access of choice due to its least invasive nature and is feasible in the majority of patients undergoing TAVI. Most interventional cardiologists are very familiar with the transfemoral route due to their experience with percutaneous coronary intervention. Although sheath size is decreasing with newer generation valves, some patients have unfavorable iliofemoral arteries that warrant an alternative access route (21). In such patients, the options are the transapical (currently mainly used with the Edwards SAPIEN, SAPIEN XT, and next generation valves) and the direct aortic, transaxillary, or subclavian access (mainly for the Medtronic CoreValve) (22).

Transfemoral access with a surgical cutdown. With the initial very large diameter sheaths (22-F to 24-F), early studies used a surgical cutdown to expose the iliofemoral artery for transfemoral access (1,23–25). A planned surgical cutdown can be performed at the beginning of the procedure to allow visualization and selection of the ideal puncture site and control of the artery above and below the puncture. Alternatively, a percutaneous puncture is performed, and the artery is exposed for closure only. Although most of transfemoral procedures are now performed percutaneously, a surgical cutdown might still be desirable in very obese patients, where there is a femoral graft or stent or where a high puncture is needed due to a high femoral bifurcation (26).

Percutaneous transfemoral access. For adequate functioning of the available suture-mediated closure devices, a precise puncture in the center of the lumen is important. Usually, a puncture of the common femoral artery in the middle of the femoral head is desirable. There are several ways to achieve this. A hemostat can be placed over the approximate middle of the femoral head. Fluoroscopy is needed to find the exact position. The puncture is then performed a bit lower, aiming to hit the artery in the middle of the femoral head. Another method is to position a catheter from the contralateral side. With small bolus injections, the common femoral artery is visualized. Alternatively, the tip of the catheter can be positioned in the targeted area. Puncture is then performed under fluoroscopy, aiming for the tip of the catheter. Many use ultrasound to visualize the artery and guide puncture (Fig. 4). In a previous study, ultrasound-guided access reduced complication rates and procedural time in endovascular aortic aneurysm repair (27). The micropuncture technique (Micropuncture Introducer Set, Cook Medical Inc.) can be used to obtain access in TAVI. However, a recent publication suggested that the rate of retroperitoneal bleeding may be increased due to the angled tip of the micropuncture guide wire, which tended to be diverted from the main vessel to the small side branches of the femoral or iliac arteries (28). Other ways to achieve a puncture in the middle of the femoral head are using DSA and road mapping as well as real-time crossover angiography. With these techniques, the needle can be manipulated under fluoroscopy with reference to the arterial wall and lumen.

Percutaneous preclosure and closure. The first cases of percutaneous closure using the ProStar device (Abbott Vascular Inc.) were reported in 1996 (29). Later, to reduce the invasiveness of endovascular aortic aneurysm repair, the ProStar and Perclose devices were used off-label to preclose

![Figure 4. Puncture Guided by Hemostat, Pigtail, or Sonography](image)

(A) To determine the exact puncture site, a radiopaque object can be placed over the femoral head. (B) Alternatively, a catheter can be introduced from the contralateral femoral artery and used as a target or for contrast injections to facilitate puncture under fluoroscopy. (C) Finally, ultrasound can be used to achieve a puncture in the middle of the common femoral artery (asterisk).
the femoral artery (30). This was initially done with surgical exposure and direct visualization of the femoral artery using 2 ProStar devices (30) and later without a cutdown, resulting in totally percutaneous aortic aneurysm repair (31,32). Totally percutaneous endovascular aneurysm repair was found to be associated with a lower rate of late groin complications, shorter procedure time, and less severe scar tissue formation (32,33).

Percutaneous closure has been increasingly used (12,24,34–41). A fully percutaneous procedure facilitates performing the procedure with the patient under conscious sedation with local anesthesia and allows earlier patient ambulation (42,43).

Suture-based closure devices have high success and very low vascular complication rates after percutaneous coronary angioplasty with 6-F to 8-F sheaths (42,44,45). In TAVI, the larger caliber sheaths used require a more careful closure. To maintain access to the artery, a guidewire should be left in place while removing the large sheath. The blood pressure should be monitored for rapid detection of signs of perforation such as hypotension and/or tachycardia because large volumes of blood loss may enter the retroperitoneal space without being noticed at the puncture site. Once the sheath is removed, the ProGlide or ProStar sutures are tightened. To prevent a sudden gulp of blood and a subsequent sudden pull on the sutures tearing the vascular wall, the dilator may be reintroduced carefully to allow a gradual closure of the artery with continuous pulling on the sutures. If hemostasis is accomplished, the guidewire is removed and the sutures are further tightened. This way, access to the artery is preserved in case of possible closure failure. Completion angiography from the contralateral side may be performed to ensure integrity of the iliofemoral arteries. Postprocedural death from unrecognized iliac rupture has been reported in the literature (46).

Perclose Proglide. Figure 5 illustrates percutaneous closure with 2 Proglides. Usually, the femoral artery is punctured and dilated with a standard arterial sheath. Then, the Proglide device is advanced over the guidewire, and the first suture is deployed slightly angulated at the 10 o'clock position. Guidewire access is maintained, and a second Proglide device is inserted and deployed at the 2 o'clock position. The regular J wire is now exchanged for a stiffer wire, and the large sheath is advanced under fluoroscopy. After conclusion of the procedure, the introducer sheath is slowly removed, but the guidewire is left to maintain access. The sutures are tightened. In case of sufficient hemostasis, the guidewire can be removed and the sutures are further tightened using the knot pusher to ensure approximation of the knot to the vessel wall. Should hemostasis fail, it is possible to implant a third (or fourth) Proglide over the guidewire.

ProStar. Figure 6 illustrates percutaneous closure with the ProStar device. The 10-F ProStar device is advanced over
the guidewire until the dedicated marker lumen shows blood marking indicating that the sutures and needles are within the vessel lumen. The 4 needles are pulled back while maintaining the position and entry angle of the ProStar device. The sutures are removed from the hub, taking care to identify the upper and lower sets of sutures. The device is retracted, and the guidewire is reinserted through the guidewire port. Then the device is removed, and a dilator is inserted. As described earlier, the J guidewire can be exchanged for a stiffer guidewire to insert the large sheath. At the end of the procedure, the sutures are tied with a sliding knot and the knot pusher (47). Both the ProStar and ProGlide devices require experience, and there is a significant learning curve. With experience, it should be possible to achieve a success rate >90% (12,48).

Crossover balloon occlusion. If necessary, the iliac or femoral artery hemostasis can be achieved using a contralaterally introduced 8- to 12-mm peripheral angioplasty balloon. Prophylactic placement of a crossover sheath or balloon may be advisable when percutaneous closure is considered to be more likely, as with larger 22-/24-F sheaths, very obese patients, or difficult pre-closure (49,50).

Protamine. Heparin reversal with protamine may be helpful if there is persistent oozing. However, this is rarely necessary and may increase the risk of femoral artery thrombosis, particularly when femoral compression is also used (49) (Fig. 7).

Alternative Access Routes

Transapical access. A left anterolateral mini–thoracotomy in the fifth or eventually in the sixth intercostal space is performed. Using minimal rib spreading, the apex of the left ventricle can be exposed after opening the pericardium. The definite location of entry is chosen slightly lateral and anterior to the true apex aiming at muscular tissue that provides sufficient strength. Access is obtained through 2 purse-string sutures with interrupted felt pledgets with sufficient depth but without tearing of the myocardium. After deployment of the valve, the left ventricular sheath is removed, and hemostasis is secured with the previously placed pledgeted sutures (51). Additional Teflon-reinforced sutures might be required in case of residual bleeding (52).

Transaxillary/subclavian access. For transaxillary access, the sheath is introduced through the axillary and subclavian arteries to the aorta (53). Given the angled course of the subclavian artery at the offspring of the vertebral artery, use of a more kink-resistant sheath is advised for valve delivery. In the absence of calcification, the artery diameter should be at least 6 mm for an 18-F sheath. In patients with a patent left internal mammary artery graft, the diameter should be at least 7.5 mm to allow continuous flow besides the sheath. As an alternative, the sheath can be withdrawn distal to the ostium of the graft after the valve has been introduced in the ascending aorta. Surgical exposure of the subclavian artery has been routine (34,38,54,55) and familiar to most cardiac surgeons as it is used routinely for arterial cannulation for extracorporeal circulation in more complex redo procedures. Recently, even a fully percutaneous procedure has been described without a surgical cutdown (56,57).

Direct aortic access. Recently, the direct transaortic approach has become increasingly popular for implantation of the Medtronic CoreValve but also the Edwards SAPIEN and SAPIEN XT valves (58–61). Depending on the

![Figure 6. ProStar XL Deployment](image_url)
anatomic position of the ascending aorta, the angulation of the aorta, and the location of calcifications, access is obtained by either a limited J-shaped sternotomy or a right-sided mini-thoracotomy and the proximal ascending aorta is exposed. No double lumen tube ventilation is needed. The sheath is inserted in a soft spot that is relatively free of disease, which can often be found even in a heavily calcified aorta (62). For the Medtronic CoreValve, the puncture site should be at least 6 to 7 cm above the aortic valve to allow complete deployment of the frame outside the sheath. Two purse-string sutures with or without Teflon pledgets are placed and the aorta is punctured. The valve is still implanted in a retrograde fashion, and positioning and deployment are similar to a more peripheral approach. Transaortic access may have some advantages compared with femoral or transaxillary access. The large-bore sheath is directly inserted in a large-caliber vessel, avoiding smaller arteries like the iliofemoral or the subclavian artery, thus reducing the risk of complications. Furthermore, in some patients, the approach to the aortic valve is a direct straight line, which may facilitate the positioning of the prosthesis, especially in a horizontal root.

**Transcarotid.** Very limited experience exists with surgical access via the carotid artery. In a small series of 12 patients, the procedure was successful in all, there was no mortality, but 1 patient had a stroke (63). The proximal part of the left common carotid artery is relatively easily accessible through a small incision in the neck using local anesthesia. The patient should tolerate temporary unilateral carotid occlusion, having adequate anterior communicating artery at the circle of Willis. Passive antegrade carotid perfusion through a temporary shunt into the common carotid has been used to ensure adequate cerebral perfusion during the procedure (64). Further research is needed to clarify whether this approach is an alternative for patients who do not meet the criteria for any other access route.

**Summary**

Transfemoral access can be considered the least invasive approach for arterial access and therefore is generally the preferred means of access for TAVI.

Despite ongoing decreases in sheath diameter, some patients will not be suitable. Alternative access options include direct aortic, transapical, transaxillary, and, more recently, transcarotid access. Part 2 of this review will focus on incidence, risk factors, relevance, and treatment of specific vascular complications.

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**REFERENCES**


