5 Vascular Access for Left Heart Catheterization

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About Us The catheterization laboratories at Duke University Medical Center and the Durham VA Medical Center serve as quaternary referral centers for invasive cardiac care for the Southeastern United States.

Introduction

- While traditionally viewed as benign when compared with nonaccess-site complications, vascular access-site complications are associated with a short- and long-term risk of morbidity or mortality as well as increased costs [1–4].
- In a study of 17,901 consecutive patients undergoing transfemoral PCI at the Mayo Clinic, Doyle et al. demonstrated that major femoral complications (including major hematoma, external bleeding, and retroperitoneal bleeding) were independently associated with a 30-day adjusted hazard ratio (HR) for a mortality of 9.96 (95% confidence interval [95% CI]: 6.94–14.3, $p < 0.001$) [1].
- Similarly, Yatskar et al. reported that hematomas requiring transfusions were associated with an increased 1-year mortality (HR 1.65, 95% CI 1.01–2.70, $p = 0.048$) among patients undergoing PCI during the NHLBI Dynamic registry recruitment waves [2].
- While relatively uncommon, retroperitoneal bleeding remains a catastrophic vascular access-site complication, with 73.5% requiring transfusion and 10.4% dying during hospitalization [3].
- Furthermore, in an era of increasing public concern regarding healthcare costs, it is also worth noting that even after adjustments for baseline differences among patients enrolled in an economic sub-study of Gusto IIb, each moderate or severe bleeding event increased costs by $3770 and each transfusion event increased costs by $2080 [4].
- In current practice, while the risk of major bleeding is dependent on patient characteristics and to an extent the choice of antithrombotic agent, the choice of vascular access strategy (transfemoral vs. transradial) and a meticulous attention to good technique, proper equipment, and skilled operators may reduce major bleeding and thereby reduce morbidity, mortality, as well as costs.

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Choosing Between the Transradial Versus Transfemoral Approaches

- As neither radial nor femoral access can be used universally, operators should become and remain proficient in both approaches.
- The essence of the radial versus femoral approach choice may be summarized as the following—for inexperienced operators, radial access is more technically challenging and is perhaps associated with more radiation exposure than femoral access, but radial access decreases patient's bleeding and vascular complications and is associated with reduced mortality in high-risk patients such as those with ST-segment elevation MI [5].
- For experienced operators, i.e., those who have overcome the transradial learning curve, radiation exposure is similar between radial and femoral access (Table 5.1).

Since its introduction, a wealth of evidence has accumulated on the risk-benefit profile of transradial access, largely in its favor:

- The first trial of radial access was the ACCESS trial, published in 1997, which randomized 900 patients undergoing elective PCI to right-sided transradial, transbrachial, or transfemoral access [6].
- Procedure duration (40, 39, and 38 min, $p = 0.603$), fluoroscopy time (13, 12, and 11 min), procedural success (respectively, 91.7%, 90.7%, and 90.7%, $p = 0.885$), and 1-month events (6.7%, 8.3%, and 5.3%, $p = 0.342$) were similar across all three groups.
- Importantly however, transradial access was associated with fewer major entry-site complications (none, 2.3%, and 2.0%, $p = 0.035$).
- The TEMPURA study, conducted between 1999 and 2001, was the first to randomize patients with ST-elevation myocardial infarction (STEMI) undergoing primary PCI to transradial versus transfemoral access [7].
- In 149 patients, reperfusion success (96.1% vs. 97.2%, $p = 0.624$) and in-hospital major adverse cardiac events (5.2% vs. 8.3%, $p = 0.444$) were similar in both groups with two patients in the transfemoral group experiencing severe bleeding.
- Expanding upon this, the RIVAL trial randomized 7021 patients with acute coronary syndromes (ACS), and specifically 1958 patients with STEMI, to transradial versus transfemoral access [8]. The primary endpoint was a composite of death, myocardial infarction (MI), stroke, or non-CABG-related major bleeding at 1 month.
- For patients without suspected or confirmed STEMI, transradial access was associated with a similar risk of the primary endpoint (3.7% vs. 4.0%, $p = 0.50$), with the caveat that transradial access appeared to be more beneficial in high-volume radial centers (1.6% vs. 3.2%, p for effect = 0.015, p for interaction = 0.021).
- Importantly, transradial access was significantly safer than transfemoral access in

Table 5.1 Femoral versus radial vascular access

Feature	Femoral	Radial
Access-site bleeding	3–4%	0–0.6%
Vascular complications	0.3–5% (AV fistula, pseudoaneurysm, retroperitoneal bleed, local hematoma)	0–0.6% (local hematoma, pseudoaneurysm)
Arterial occlusion	Rare	0.1–9%
Patient comfort	**	*****
Ambulation	2–4 h	Immediate
Procedure time[a]	Perceived shorter	Perceived longer
Estimated radiation exposure[a]	Perceived shorter	Perceived longer
Learning curve	Short	Longer
>8-F guide catheters	Feasible	Not possible

[a]Operator dependent

patients with suspected or confirmed STEMI (3.1% vs. 5.2%, p for effect = 0.026, p for interaction = 0.025), with a significant mortality benefit (1.3% vs. 3.2%, p for effect = 0.006, p for interaction = 0.001).

- These results were confirmed by the RIFLE-STEACS trial which focused only on patients with suspected or confirmed STEMI and involved only centers with an established expertise in transradial access [9]. The primary endpoint was a 30-day rate of net adverse clinical events (NACE), defined as a composite of cardiac death, MI, stroke, target vessel revascularization, and bleeding, which occurred in 13.6% of patients allocated to transradial access versus 21.0% in those allocated to transfemoral access (p = 0.003). 30-day mortality (5.2% vs. 9.2%, p = 0.020) and bleeding (7.8% vs. 12.2%, p = 0026) were lower in patients receiving transradial access.
- The STEMI-RADIAL trial randomized 707 patients referred for STEMI presenting <12 h of symptom onset [10]. The primary endpoint was the cumulative incidence of major bleeding and vascular access-site complications at 30 days.
- The primary endpoint occurred in 1.4% of the radial group versus 7.2% of the femoral group (p = 0.0028).
- The MATRIX trial randomized 8404 patients with ACS to transradial or transfemoral access [11].
- While at a pre-specified alpha of 0.025, MACE defined as death, MI, or stroke at 30 days was not statistically significant (8.8% vs. 10.3%, p = 0.0327), NACE defined as MACE or Bleeding Academic Research Consortium (BARC) non-CABG major bleeding was lower in patients receiving transradial access (9.8% vs. 11.7%, p = 0.0092).
- This difference was driven by reductions in BARC non-CABG major bleeding (1.6% vs. 2.3%, p = 0.0013) and all-cause mortality (1.6% vs. 2.2%, p = 0.045).
- The SAFE-PCI for Women trial sought to determine the effect of radial access on outcomes in 1781 women undergoing PCI using a novel registry-based randomized trial.
- Among women undergoing cardiac catheterization or PCI, radial access significantly reduced bleeding and vascular complications (0.6% vs. 1.7%, OR 3.70, 95% CI 2.14–6.40). Moreover, more women preferred radial access [12].
- Several systematic reviews have in large part confirmed the above findings, albeit increasing statistical precision as well as bolstering external validity [13, 14].
- Given this, there has been increased adoption of radial access and many centers are moving to a “radial first” approach [15] especially in high-risk populations (ACS [especially STEMI]; high bleeding risk; obese patients; octa- and nonagenarians; and women).
- Several situations however exist where transradial access may best be avoided except by highly experienced operators (Table 5.2).

Patient Preparation

- Pre-procedure planning begins with thoughtful review of a patient’s chart to determine the planned objectives of the investigations or interventions, the patient’s history of presenting illness, prior medical history (prior CABG anatomy, PAD, iliofemoral grafts), allergies, laboratory values (particularly those related to coagulation/hemostasis), medications (especially anticoagulants), EKG, noninvasive investigations (particularly recent stress testing), and difficulties encountered with sedation, vascular access, or navigation of the femoral or radial arteries during prior procedures.
- A physical examination focused on identifying anatomic conditions that may influence the choice of sedation or access site is mandatory. For example, a patient’s inability to lay flat for several hours post-procedure due to orthopnea or preexisting spinal disease, diminished or absent pulses or bruits, or presence of arteriovenous fistulas for hemodialysis is important to note.
- In patients in whom radial access is a consideration, the utility of performing the modified

Table 5.2 Practical Hints for Patient Selection for Transradial Access from "Best Practices for Transradial Approach in Diagnostic Angiography and Intervention," Table 3–4, pg. 23

	Suitability	
	Inexperienced operators	***Experienced operators***
Ideal Situations for Transradial Access		
Acute coronary syndrome (especially ST-elevation myocardial infarction)	+/–	+/+
High bleeding risk (including anticoagulants)	++	++
Obese patients	++	++
Octogenarians	++	++
Previous bypass surgery (with single internal marnmary graft)	+/–	++
Women	+/–	++
Situations in which transradial access may best be avoided		
End-stage renal failure or dialysis	+/–	++
Known innominate/subclavian axis anomalies	– –	+
Patient is a candidate for bypass surgery in centers commonly using radial grafts	+/–	+/–
Previous bypass surgery (with bilateral internal mammary graft)	– –	+
Prior severely painful transradial access or radial spasm	– –	+/–
Pulseless cardiogenic shock	– –	+/–
Raynaud's syndrome or small artery inflammatory disease	+/–	+
Very complex or high-risk PCI (e.g., on last remaining vessel)	– –	+

++, highly recommended; +, recommended; +/-, possible; -, not recommended;--, avoid; PCI, percutaneous coronary intervention

Allen's or Barbeau's test to assess ulnar flow into the palmar arch is of unclear clinical significance.

- In the RADAR study of 203 patients undergoing elective or urgent angiography via the radial approach, thumb capillary lactate concentrations, handgrip strength, and discomfort ratings did not differ between patients with a normal, intermediate, or abnormal modified Allen's test at 1 day, 1 month, or 1 year [16].
- Furthermore, vascular recruitment as confirmed by plethysmographic readings and Doppler examination occurred in patients with intermediate or abnormal modified Allen's tests, thus preventing objective and subjective signs of hand ischemia even in patients with poor collateral circulation at baseline and loss of a previously documented radial pulse at day 1 following catheterization.
- An assessment of periprocedural bleeding risk, which may inform the use of bleeding avoidance strategies such as bivalirudin, radial access, and in some studies vascular closure devices, is useful [17].
- Using detailed clinical data from >1,000,000 PCI procedures from the NCDR CathPCI registry, a bedside bleeding risk score using ten variables has been published with a high concordance between the risk predicted by the model and observed bleeding events:
  - STEMI
  - Age
  - BMI
  - Previous PCI
  - Chronic kidney disease
  - Shock

  - Cardiac arrest within 24 h
  - Female
  - Hemoglobin
  - PCI status [18]
- In a study of 6941 PCIs at a single healthcare system, use of the NCDR bleeding risk model was associated with an increase in bivalirudin use in patients at intermediate and high bleeding risk and decreased use in lower risk patients, leading to a reversal of the risk-treatment paradox [19].
- Patients should be given the opportunity to ask questions regarding who, what, where, when, why, and how of the planned diagnostic investigations or interventions.
- Specifically, patients should receive an explanation regarding the differences between the transradial and transfemoral approaches, with the advantages/disadvantages of performing the procedure through the anticipated approach for each individual patient discussed in detail.
- Any preferences patients have (laterality, good or bad experiences with prior access attempts) should be taken into consideration.
- Audiovisual adjuncts may increase information retention and may make patients more familiar with both the environment of the catheterization laboratory and the technical aspects of the procedure [20].
- Prior to arriving in the catheterization laboratory, all jewelry and watches should be removed from the wrist and rings should be removed from the fingers.
- Patients should have preferably two peripheral intravenous (IV) lines placed, with one ideally well away from the radial site if that is the anticipated site of access. If an IV must be placed on the side of planned radial/ulnar access, it should be placed well proximal to the wrist, ideally at or above the level of the elbow.
- For transradial/ulnar cases, hair on the wrist of interest should be removed with clippers, and consideration should be given to prepping both femoral sites in case they are needed, especially in the presence of weak radial pulses, with the potential need for hemodynamic support, or during the learning curve for radial access.
- In the catheterization lab, it is important that both the patient and the operator feel comfortable and consequently arm preparation and positioning are of paramount importance.
- While either the left or the right wrist may be used for radial/ulnar access, the preferred access site has historically been the right radial [21]. In this case, with the patient lying supine, the arm should be maintained as close to the patient's right side as possible (radial artery running parallel to the femoral artery) in the anatomic position with the palm up.
- Hyperextension of the wrist to 30–60°, which may allow easier cannulation of the radial artery, can be achieved using a roll of gauze, a rolled-up towel, or a commercially available wrist splint.
- Extreme hyperextension of the wrist should be avoided as it may blunt the pulse and can be uncomfortable for the patient.
- To maintain this position, the arm can be immobilized with tape across the palm. In obese patients, it may be necessary to place an arm board or arm extension under the patient's mattress along the table to provide a suitable working area (Fig. 5.1).
- Since there can be ergonomic challenges to performing procedures via the left radial approach if the operator stands on the right side of the patient, optimal arm positioning is key.

Fig. 5.1 Ideal right-arm positioning for radial artery access. Adopted from Kern, Morton J. The Interventional Cardiology Handbook, 2, 38–82

- A common approach is to prepare the left wrist in a manner analogous to that described above for right but following access raise and adduct the arm to lay in on the patient's abdomen as close to midline as possible.
- Following arm/groin preparation, one of several commercially available drapes, with pre-cut radial and femoral fenestrations, can be used to cover the patient and create a sterile field.

Radial/Ulnar Approach

Radial/Ulnar Anatomy

- Knowledge of the anatomy of the vessels of the upper extremity and aortic arch is essential for successful radial access.
- The aortic arch gives off three great vessels: the innominate on the right and the common carotid and subclavian arteries on the left.
- The innominate artery becomes the right subclavian artery after the takeoff of the right carotid artery and then the axillary artery at the lateral margin on the first rib. At the inferior border of the teres major muscle, the axillary artery continues as the brachial artery that then bifurcates in most patients into the radial and ulnar arteries below the elbow. The radial artery then continues along the lateral aspect of the forearm into the wrist where it divides into the deep and superficial palmar arches.
- The deep and superficial branches of the of the radial artery communicate with the corresponding divisions of the ulnar artery to complete the two palmar arches and provide dual-collateral blood flow to the hand in most patients. The ulnar artery begins below the bend of the elbow and reaches the ulnar side of the forearm at a point about midway between the elbow and the wrist. Then it runs along the ulnar border to the wrist and divides into two branches, which complete the two palmer arches (Fig. 5.2).
- The arm arteries may also demonstrate a variety of tortuosity and loops, particularly in patients above 75 years old, of female gender, with prior coronary artery bypass surgery, and of short stature [22].
- Most problems involve variant origins to the radial artery and anastomosis at the antecubital fossa, but problems can also occur in the brachial, axillary, and subclavian arteries.
- There are two arterial anomalies that can significantly complicate transradial or transulnar procedures. The first is the radial artery loop that often occurs at the level of the elbow (Fig. 5.3a). This is often accompanied by the recurrent radial artery, a very small caliber artery that runs parallel with the brachial artery.
- The recurrent radial artery can be large enough to accommodate the 0.035″ wire and sometimes even a 5-French or 6-French diagnostic catheter. However, the small caliber of the artery

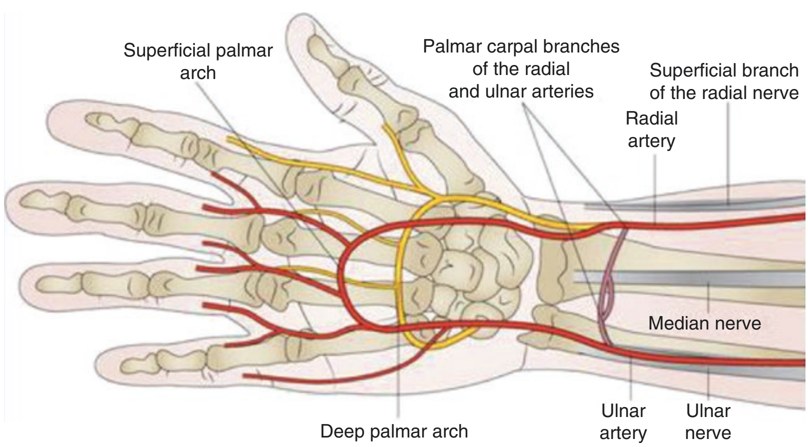


Fig. 5.2 Essential anatomy for radial artery access. Adopted from Byrne, R. A. et al. Nat. Rev. Cardiol. 10, 27–40 (2013)

Fig. 5.3 A radial loop (A) complicating radial artery access for coronary angiography. Adopted from Rao, SV. Approaching the Post-Femoral Era for Coronary Angiography and Intervention. JACC Cardiovascular Interventions. Volume 8, Issue 4, 20 April 2015, 524–526

leads to significant difficulty in manipulating the catheter that is often interpreted as severe spasm with significant patient discomfort.

- The development of severe spasm should prompt angiography of the radial artery to identify a radial loop and presence of the recurrent radial artery. Loops can be crossed using the technique described below or the procedure can be completed using an alternative access site. The use of pre-procedure ultrasound of the radial and ulnar arteries as well as the antecubital fossa may facilitate transradial or transulnar procedures by identifying arterial anomalies prior to the procedure [23].
- The other anomaly that can complicate transradial and in this case even transulnar procedures is arteria lusoria. This congenital anomaly is when the right subclavian artery courses behind the esophagus and connects to the aorta distal to the right subclavian (Fig. 5.4). This is a relatively rare anomaly that occurs in 0.5–1.8% of patients.

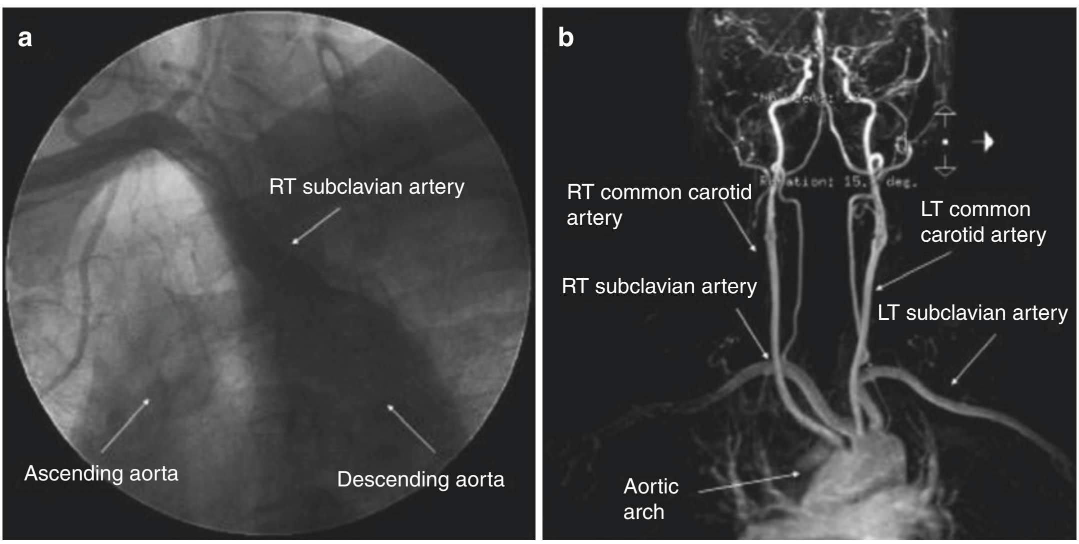


Fig. 5.4 Arteria lusoria complicating right radial artery access for coronary angiography. Adopted from Yiu, Kai-Hang. Arteria Lusoria Diagnosed by Transradial Coronary Catheterization. J Am Coll Cardiol Intv. 2010;3(8):880–881

- While the procedure can sometimes be completed using stiff Amplatz wires to facilitate entry of the catheters into the ascending aorta, it is often more straightforward to complete the case via the left radial approach or femoral approach.
- If tortuosity or loop is suspected, an angiogram of the radial or ulnar artery should be performed. Tortuosities may often be carefully crossed using a 0.025 or 0.032 hydrophilic J wire, a Wholey wire, or a 0.014 soft-tip coronary guide wire. Once the tortuous segment is crossed, the procedure may be completed in the usual fashion.
- Loops/curvatures may require downsizing of the guide wire, use of a buddy wire, straightening of the loop, or upsizing of the guide wire [24].
- In the most extreme cases, balloon-assisted tracking (BAT) may be necessary (Fig. 5.5) [25]. Balloon-assisted tracking involves minimizing the "razor effect" of the large transition between the catheter tip and the guide wire by advancing a 0.014″ coronary guide wire through the tortuous segment, protruding an angioplasty balloon halfway out of the tip of the catheter, inflating it to low pressure, and advancing the catheter-balloon assembly over the guide wire through the tortuous segment. If the patient experiences significant pain or the procedure time is significantly prolonged, consideration should be given to bailing out to either the contralateral radial artery or the femoral approach.

Left Versus Right Transradial Access

- While vessel diameters are usually comparable between right and left vessels, a difference in pulse strength and palpability can occur. Moreover, tortuosities/loops/curvatures are not always bilateral and may differ in complexity.
- The use of the left transradial approach is associated with several important anatomical and technical advantages including a shorter learning curve [26], reduced severe tortuosity of the subclavian artery [27, 28], and easier cannulation of the left internal mammary artery (LIMA) in patients with previous use of the LIMA as a coronary artery bypass [29].
- The TALENT trial randomized 1540 patients undergoing diagnostic (1467 patients) or interventional (668 patients) coronary procedures to right versus left radial access [30]. While left radial access was associated with a lower fluoroscopy time (149 s vs. 168 s, $p = 0.003$) and dose area product (107 Gy-cm^2 vs. 12.1 Gy-cm^2, $p = 0004$) in the diagnostic group (but not in the interventional cohort), subgroup analyses showed that the differences were significant only in older patients and with operators on the transradial learning curve.
- In a meta-analysis of 6840 patients from 14 randomized controlled trials, no significant differences in the rate of procedure failure of the left and right radial approaches (RR 0.98,

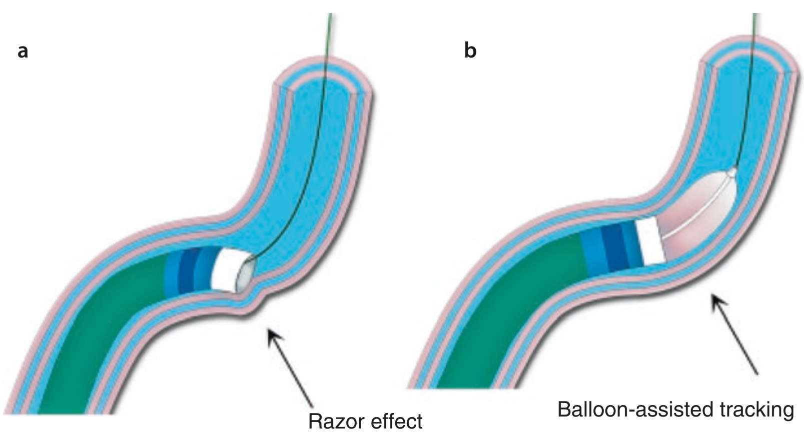
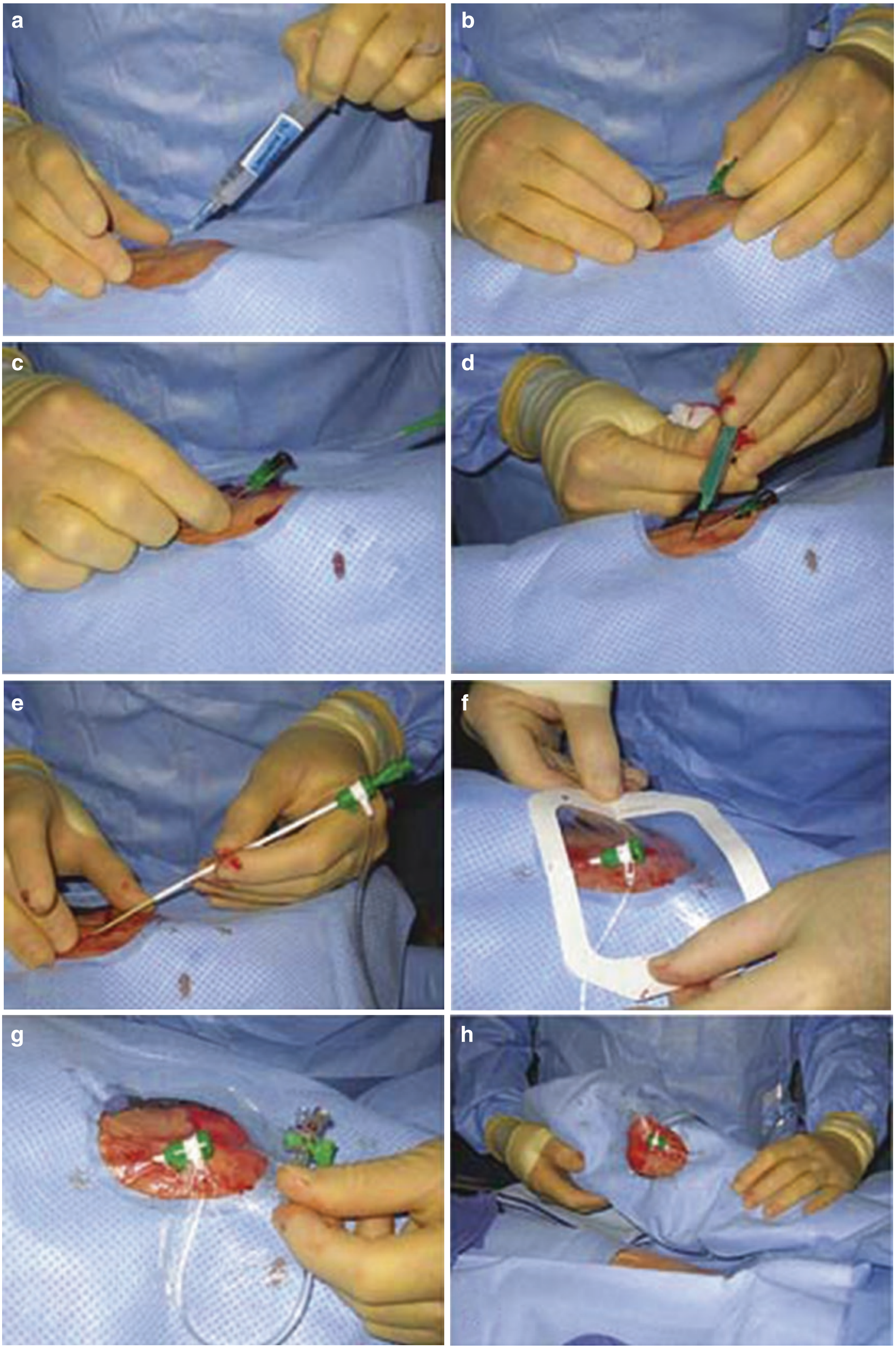


Fig. 5.5 Balloon-assisted tracking technique for tortuous radial artery anatomy. Adopted from Patel T. Balloon-assisted tracking: A must-know technique to overcome difficult anatomy during transradial approach. Catheter Cardiovasc Interv. 2014;83(2):211–20

95% CI 0.77–1.25, $p = 0.88$) or procedure time ($p = 0.38$) were seen [31]. Ultimately, the selection of the artery with the best radial pulse is usually advisable.

Radial Artery Access

- The course of the radial artery is identified by palpitation over several centimeters along the wrist. The ideal puncture site is 1–2 cm proximal to the bony prominence of the distal radius (radial styloid).
- Distal puncture sites (closer to the hand) risk puncture of the radial artery after its bifurcation into the deep and superficial palmar arches where it is smaller, more tortuous, and partially located below the transverse carpal ligament.
- More proximal punctures may be associated with large hematoma formation as they are more difficult to compress.
- Following a combination of low-dose opiates and benzodiazepines to minimize patient discomfort and anxiety and thereby the risk of radial artery spasm, a small amount (no more than 1 mL) of subcutaneous local anesthetic is given to raise a small wheal (Fig. 5.7, Panel A).
- It is important to avoid large amounts of lidocaine as large wheals may obscure palpation of the radial pulse and make cannulation more difficult. The course of the radial artery is then fixed between the index and middle fingers of the nondominant hand in preparation for arteriotomy.
- The use of ultrasound guidance for radial access was explored in RAUST [32]. Ultrasound guidance significantly improved first-pass success rate (64.8% vs. 43.9%, $p < 0.0001$), median number of access attempts (1.64 vs. 3.05, $p < 0.0001$), and median time to access (64 s vs. 74 s, $p < 0.0001$).
- When using a **"through-and-through" technique**, a micropuncture catheter-over-needle system is inserted with bevel up at a 45-degree angle along the direction of the radial artery until a flashback of blood is visualized. The system is then advanced until the back wall of the artery is punctured and blood flow stops. The needle is then removed and the catheter is carefully withdrawn parallel to the skin until its tip is intraluminal as confirmed by free-flowing blood. A 0.018 or 0.025-in. guide wire with a hydrophilic coating and a straight or slightly angulated tip is gently inserted using a twirling motion. **There should be little to no resistance to wire introduction.**
- If resistance is encountered, it is important to avoid forceful introduction of maneuvers. Difficult advancement of the guide wire may be due to artery spasm, placement into a small branch vessel, tortuosity, loop, or partial embedment into the vessel wall. Fluoroscopy should be immediately used to visualize the position of the wire if resistance is met.
- In a study of 412 patients randomized to a "through-and-through" (counterpuncture) technique versus a single anterior wall puncture, access time, procedure time, and number of attempts to get access were significantly shorter with a "through-and-through" technique with no increases in the incidence of hematoma or radial artery occlusion (ROA) [33].
- Should a **single anterior wall puncture technique** of the radial artery be used (Fig. 5.6), following the initial flashback of blood, the bare metal needle is advanced slightly to ensure that the whole tip (not just the tip of the bevel) is intraluminal.
- If blood continues to flow freely, a 0.025-in. nitinol wire is advanced into the needle and the needle is removed. Notably, only metal wires should be used with bare metal needles as plastic-coated wires can be shredded if pulled back again the bevel.
- In patients with radial artery spasm caused by failed access attempts, three options exist:
  - Observation for the spasm to resolve
  - The administration of 400 mcg of sublingual nitroglycerin
  - The subcutaneous injection of 200 mcg of nitroglycerin on the medial and lateral aspects of the radial artery
- The mean time for the radial pulse to reappear was 18 ± 5, 8 ± 1, and 3 ± 1 min for observation, sublingual nitroglycerin, and subcutane-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ous nitroglycerin, respectively, with the subsequent rate of successful radial cannulation 72, 90, and 100% [34].

- If the spasm is intense and irreversible, it may become necessary to switch to a completely different site altogether—ideally to the contralateral radial artery.
- Following sheath insertion over the wire, an antispasmodic cocktail should be given to reduce the risk of radial artery spasm.
- Available agents include calcium channel blockers (verapamil, diltiazem, nicardipine) or nitroglycerin. Intravenous unfractionated heparin (50–70 U/kg, up to 5000 U) should also be given at some point during the procedure to reduce the risk of radial artery occlusion (RAO) [35].

Ulnar Artery Access

- Transradial access has been the preferred approach in light of conflicting evidence for ulnar access, with Hahalis et al. reporting increased MACE and major arm vascular events with transulnar access compared with transradial access [36] but others reporting no differences [37].
- A recent meta-analysis by Dahal and colleagues of 2744 patients undergoing transulnar versus transradial access reports similar efficacy and safety except for more access attempts and increased access-site crossover with ulnar approach [38].
- Ulnar artery cannulation may however serve as a reasonable and useful alternative, especially when the radial access site is not available, at high risk of failure or complications after repeated radial catheterizations, or tortuous or anomalous radial arterial vasculature.
- Ulnar artery puncture can be more challenging because of the deeper course of the ulnar artery and lower intensity of palpable pulsations.
- Compression of the ipsilateral radial artery may improve weak or hardly palpable ulnar artery pulsations.
- Ideally, the ulnar artery should be punctured 0.5–3.0 cm proximal to the pisiform bone, where the risk of post-procedural hematoma is lower. The ulnar artery however can be punctured up to the mid-forearm as long as the pulsations can be felt.
- **However, the ulnar nerve is very close to the ulnar artery in that region, so the puncture has to be very accurate, avoiding accidental nerve damage.**
- Real-time ultrasound guidance may facilitate ulnar artery puncture.
- Following the administration of sedation and local anesthetic, either the counterpuncture or anterior wall puncture technique can be used.

Sheath Types for Radial/Ulnar Approach

- While sheath selection is often dictated by operator preference, patient anatomy, and size of the catheters planned to be employed in the

Fig. 5.6 Radial artery access for cardiac catheterization. Lidocaine is instilled at the intended site of puncture to make a small wheal (**Panel A**). Here a single anterior wall puncture technique is demonstrated with flashback of blood from the radial artery (**Panels B** and **C**). Once a guide wire is placed within the radial artery without resistance, a small cut can be made with a scalpel at the point of insertion of the introducer (**Panel D**). This is not mandatory given that most sheaths are hydrophilic and so tend to pass easily over the wire and through the skin into the radial artery without much resistance (**Panel E**). Once the sheath is in place, secure with adhesive dressing (**Panel F**), and flush with heparinized saline to confirm patency (**Panel G**). Once the sheath is secure the arm can be moved into a more comfortable position for the patient if necessary (**Panel H**). Reproduced with permission from the Cardiac Catheterization Handbook, First Edition by Kern MJ. “Radial artery access for cardiac catheterization” Page 55–97; Copyright Elsevier (1996) procedure, sheath size should be kept as small as possible in order to minimize vascular complications.

- Furthermore, following the completion of the planned procedure, sheaths should be removed as quickly as possible as both the risk of bleeding and thrombotic complications increase with the duration of time that the sheath is left in place.
- Most commercial radial sheaths available today range from 4 to 7 Fr outer diameter and often feature a tapered edge that allows smooth insertion of the sheath through the skin and subcutaneous tissue into the artery (Fig. 5.6, Panel E).
- Furthermore, many feature a hydrophilic coating that has been shown to be associated with less patient discomfort and local pain, easy removal, and less post-procedural inflammatory reactions, particularly in the case of the small-caliber radial artery [39].
- However, rare cases of allergic reactions and noninfectious granulomas associated with the use of these sheaths have been described [40–42]. The ideal sheath length is not codified, but sheath length does not appear to affect the risk of radial artery spasm [39].
- "Slender sheaths," such as the 6 Fr GlideSheath Slender (Terumo Interventional Systems Inc., Somerset, NJ) that features a 6 Fr inner diameter but 5.5 Fr outer diameter, can minimize radial arterial trauma while facilitating the use of 6-French equipment [43].
- Slender sheaths are also available in 4.5F and 6.5F outer diameters that accommodate 5- and 7-French equipment, respectively.

Complications

- Up to 5% of access attempts may be associated with radial artery spasm (RAS), which is diagnosed by resistance during manipulation of intra-arterial equipment and by a patient complaining of pain in the forearm, generally without serious lasting clinical complications but often leading to procedural failure and patient discomfort.
- Independent predictors of radial artery spasm include:
  - The presence of radial artery anomalies
  - Female gender
  - Younger age
  - Diabetes
  - Anxiety
  - Multiple catheter exchanges
  - Unsuccessful access at first attempt

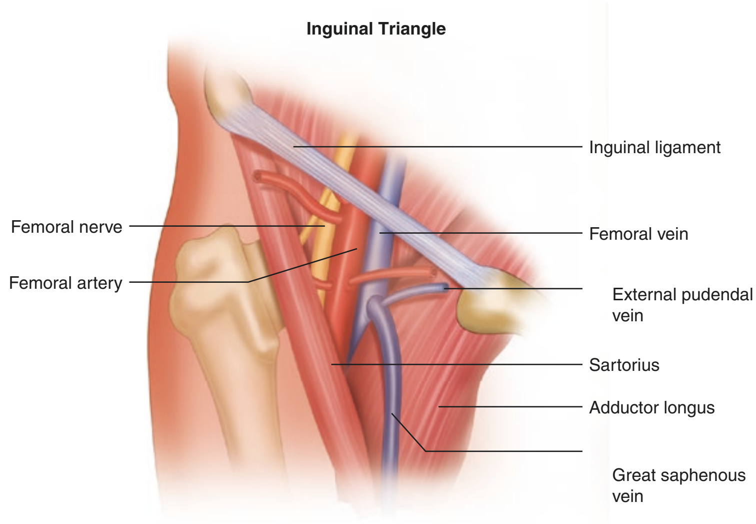

Fig. 5.7 Relevant anatomic features for femoral artery cannulation

  – Pain during radial cannulation
  – Radial diameter after administration of vasodilatory agents
  – Operator experience [44]
- Many strategies have been developed to prevent spasm. By far the best prevention is a clear arteriotomy with a gentle and smooth technique that emphasizes minimal manipulation. It is also essential that the patient be comfortable and relaxed.
- As described above, meticulous patient preparation, low doses of opiates and benzodiazepines, and subcutaneous lidocaine may be used in combination to achieve this.
- Various antispasmodic cocktails have been tried, with the most commonly used vasodilators being diltiazem or verapamil (2.5–5.0 mg, diluted up to 15 mL with blood or saline) and nitroglycerin (100–200 mcg, diluted up to 15 mL with blood or saline).
- In a randomized trial of 150 patients undergoing transradial access, diltiazem plus nitroglycerin showed no advantage compared to nitroglycerin alone in the prevention of RAS [45]. Similarly, in a randomized trial of 406 patients by Chen et al., verapamil plus nitroglycerin was no more effective than nitroglycerin alone in the prevention of RAS [46].
- The patient should be warned of a transient burning sensation in the arm during vasodilator injection. Radial artery spasm that is refractory to pharmacological agents should prompt consideration that the catheter is in the recurrent radial artery rather than the main radial artery as described above.
- Subintimal positioning of the wire and/or a dissection plane may be seen on radial artery angiography. If this occurs, the procedure can usually proceed if the wire can be repositioned intraluminally.
- Insertion of a long radial sheath or a catheter across the dissection will tack up the intimal flap and heal the dissection by the time the procedure ends.
- Radial-brachial perforation is identified by significant resistance during manipulation of intra-arterial equipment and by a patient complaining of significant pain in the forearm, with or without development of a large forearm hematoma. In case series, the incidence has been 0.1–1% [47, 48]. Injection of dilute contrast through the side port of an introducer sheath confirms the location and size of the perforation. **The procedure should not be abandoned.** Crossing the area of perforation with a soft-tipped 0.014″ coronary guide wire, followed by balloon-assisted tracking, will result in “internal tamponade” and sealing of the perforation. Repeat radial angiography should be performed at the end of the case to assess for any residual dissection or perforation.
- Another type of perforation involves small branches of the radial artery that are traumatized by the small profile of the access wire. These perforations result in the insidious formation of forearm hematomas that are often evident after the procedure. These hematomas should be recognized quickly and compressed gently with wrapping of the forearm.
- The most serious complication of forearm bleeding is compartment syndrome with resultant hand ischemia. While extremely rare, this requires emergent surgical fasciotomy when it occurs.
- Radial artery occlusion (RAO), estimated to occur in 1–10% of cases, is a silent complication of transradial access that can lead to permanent occlusion of the radial artery, thereby making it unusable as an access site for future catheterization or as an arterial conduit for bypass surgery.
- Risk factors for RAO include a large sheath to artery ratio, the omission of anticoagulation for diagnostic catheterizations, and radial artery spasm [35].
- Interestingly, techniques achieving patent hemostasis have been shown to significantly decrease the risk of RAO when compared with occlusive hold hemostasis [49, 50].
- In the PROPHET study, 436 patients undergoing transradial catheterization were randomized to either occlusive hold hemostasis or patent hemostasis [49]. In patients receiving patent hemostasis, RAO was decreased by 59% at 24 h and by 75% at 30 days ($p < 0.05$).

- Furthering this, the PROPHET-II study randomized 3000 patients to patent hemostasis or patent hemostasis and ipsilateral ulnar artery compression [50]. The primary endpoint, 30-day RAO, was significantly reduced in patients receiving patent hemostasis and ipsilateral ulnar artery compression compared with standard patent hemostasis (0.9% vs. 3.0%, $p = 0.0001$) without an increase in hand ischemia.
- In the case of RAO as assessed by duplex ultrasonography 3–4 h after hemostasis, 1-h ulnar artery compression can be safely used to recanalize the radial artery [51].

Femoral Approach

Femoral Anatomy

- The common femoral artery is a zone defined as that continuation of the external iliac artery that is bounded superiorly by the inguinal ligament and internal epigastric artery and inferiorly by the femoral sheath and its subsequent bifurcation into the superficial femoral artery and profunda femoris artery (Fig. 5.7).
- It is an ideal target for arteriotomy and sheath access because it is relatively large, less involved with atherosclerosis, and readily compressible against the underlying head of the femur [52].

Femoral Artery Access

- As compelling evidence exists that femoral arterial access complications are related to the site of puncture, appropriate femoral access technique is important to reduce complications.
- Femoral artery access should occur in the "safe zone" of the common femoral artery above the femoral artery bifurcation and below the origin of the internal epigastric artery (Fig. 5.8).
- Several methods can be used to facilitate access into the safe zone, and using the pulse to solely guide access is the least effective method. Fluoroscopic guidance was proposed as early as 1978 [53].

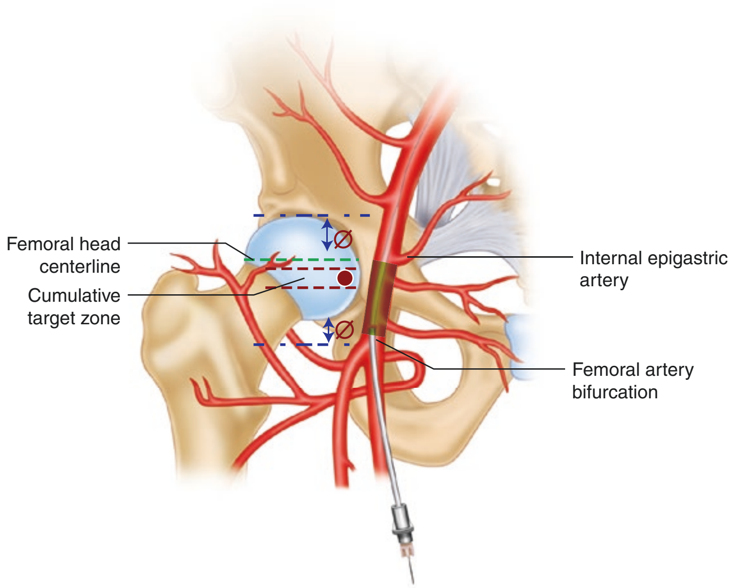

Fig. 5.8 Safe zone for femoral artery cannulation. Adopted from the PCR-EAPCI Textbook, Ch. 3, Figure 5.3

- The safe zone for arteriotomy can be identified using the femoral head. The safe zone of the common femoral artery runs between lower border of the femoral head and its midportion.
- At present, ultrasound-guided femoral access is the most evidence-based approach to facilitate safe zone arteriotomy. In a randomized trial of ultrasound guidance versus standard access technique, the use of ultrasound increased first-pass success into the safe zone and was particularly useful in patients with reduced pulses and obese patients [54].
- When obtaining transfemoral access, a single anterior wall puncture is highly desirable. An 18-gauge needle is inserted with the bevel up at a 30–45-degree angle and advanced along the direction of the femoral artery until a good, pulsatile blood flow returns.
- A 0.035 J-tip guide wire is then advanced through the needle into the femoral artery, iliac artery, and descending aorta. If resistance is felt, fluoroscopy should be immediately used to visualize the position of the wire.
- While conceptually attractive as they decrease the size of the arteriotomy by 56% and blood flow sixfold, no clear evidence exists to suggest that the routine use of micropuncture needles reduces the risk of vascular complications during transfemoral access.
- Micropuncture needles may however have a role to play in patients with access complicated by severe PAD as well as in patients with iliofemoral grafts.

Complications

- Cannulation of the femoral artery above the lowest point of the internal epigastric artery is associated with an increased risk of retroperitoneal hemorrhage due to a lack of underlying bony structures against which effective compression and tamponade may occur.
- Similarly, cannulation of the femoral artery immediately underneath the inguinal ligament may be problematic because the taut inguinal ligament prevents effective compression.
- Cannulation of the superficial femoral artery or profunda femoris artery, which lacks an underlying bony structure and scaffolding provided by the femoral sheath, is associated with an increased rate of bleeding, hematoma, arteriovenous fistula, and pseudoaneurysm.
- One of the most feared complications of transfemoral access remains retroperitoneal hemorrhage. The incidence ranges from 0.2 to 0.6% and is associated with a mortality rate from 4 to 12%.
- Predictors of retroperitoneal hemorrhage include a “high stick,” large sheath size, duration and intensity of anticoagulation, and longer procedural times. The treatment of a retroperitoneal hemorrhage may include transfusion, covered-stent placement, embolization, or emergency surgery.
- The incidence of femoral artery pseudoaneurysms is <1%. In current practice, ultrasound-guided direct thrombin injection is the preferred treatment [55–57].
- Arteriovenous fistulas are rare complications associated with the inadvertent puncture of the femoral vein while attempting to cannulate the femoral artery. Treatment may include close observation (one-third of A-V fistulas close spontaneously at 1 year) [58], endovascular embolization or coiling, or open surgical repair.

Brachial Approach

Brachial Artery Access

- Transbrachial access is rarely used for left-heart catheterization in the modern era as it is more prone to complications compared with transradial or transfemoral access. This includes antecubital hematomas that may rapidly progress to compartment syndrome.
- It is usually indicated when severe PAD precludes femoral access and lack of adequate radial or ulnar artery caliber.
- Access technique is similar to femoral arterial access and manual compression should be used for hemostasis.

Hemostasis

- For radial/ulnar cases, hemostasis can be achieved by manual compression (occlusive hold hemostasis) or more commonly through the use of a specifically designed mechanical device (patent hemostasis). The preferred and recommended technique is patent hemostasis.
- For femoral arterial access, manual compression is the most commonly used. Before removing the sheath, the activated clotting time (ACT) should be <180 s for unfractionated heparin. If bivalirudin is used and the patient's kidney function is normal, the sheath can be removed 2 h after the bivalirudin infusion has been discontinued. In the presence of compromised renal function, sheath removal should be guided by the ACT.
- After sheath removal, the duration of compression varies with the French size of the catheter, with larger sheaths requiring longer compression times. A variety of assisted mechanical compression devices such as C-type clamps or the FemStop (St. Jude Medical, St. Paul, MN) are available to use as an adjunct when longer pressure application is needed.
- Vascular closure devices (VCD) have emerged as an alternative to manual/mechanical compression after transfemoral access. The data on the efficacy and safety of these devices is mixed but seems to indicate earlier patient mobilization and decreased length of stay compared with manual compression at the expense of an increased rate of complications (infection, inflammation, scarring).
- The recently completed ISAR-CLOSURE trial randomly assigned 4524 patients undergoing diagnostic coronary angiography to intravascular VCD, extravascular VCD, or manual compression [59]. The primary endpoint was access-site-related vascular complications at 30 days. The rate of the primary endpoint was 6.9% in the VCD group and 7.9% in the manual compression group ($p < 0.001$ for non-inferiority). VCD use compared with manual compression resulted in fewer large hematomas (4.8% vs. 6.8%, $p = 0.006$) and a shorter time to hemostasis.

Summary

- Attaining vascular access is among the most critical parts of the cardiac catheterization procedure and requires meticulous attention to good technique, proper equipment, and skilled operators.
- Thoughtful patient selection, including an assessment of periprocedural bleeding risk, should guide the choice of left or right transradial, transulnar, or transfemoral access.
- While the transradial and transulnar approaches are associated with significantly reduced patient's bleeding, vascular complications, and mortality when compared with transfemoral access, they may be more technically difficult for those operators still on the radial/ulnar "learning curve."
- If transfemoral access is planned, fluoroscopic and/or ultrasound guidance, smaller sheath sizes, and vascular closure devices may decrease access-site complications.

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