

Radial Artery Cannulation: A Systemic Review

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Abstract

The radial artery is the most commonly used arterial access site for monitoring arterial pressure or obtaining blood gas analysis, since it is easy to puncture and to acquire haemostasis. Transradial cannulation failures can be due to failure to puncture the artery, radial artery spasm, hypotension or anatomic variations of radial-brachial-axillary-subclavian artery axis or of the aortic arch. This article reviews the anatomy and anatomic variations of the upper limb vasculature and gives up-to-date information on the anesthesiological, surgical and interventional applications of radial artery cannulation and radial artery harvest.

Keywords: Transradial access, Cannulation, Vascular complications

Abbreviations: AT: Allen Test; ECMO: Extra Corporal Membrane Oxygenator; IABP: Intra Aortic Balloon Pump; ICU: Intensive Care Unit; MAT: Modified Allent Test; PSV: Peak Systolic Velocity; RA: Radial Artery; TR: Trans Radial; UA: Ulnar Artery

Introduction

The radial artery is frequently catheterized in the intensive care unit (ICU) and in the catheterization laboratory. The main benefits for short and long term cannulation of the radial artery are the easy puncture and the low vascular and infectious complication rate. Other alternative access sites are the brachial, axillary and femoral artery. The brachial artery is not routinely used for cannulation due to high number of vascular and nerve complications [1,2]. Axillary cannulation provides data on aortic pressure and poses minimal thrombotic risk, although it is associated with brachial plexus compression [3]. However, in many centers the axillary artery, is the cannulation site of choice in patients with atherosclerotic aneurysm, dissection and proximal aortic operations and this alternative access route can also be used for inflow perfusion in extracorporeal membrane oxygenator (ECMO) support [4]. The femoral artery is the preferred access site in patients with unstable haemodynamic conditions, since it is easy to puncture and allows introduction of different haemodynamic support devices (intraaortic balloon pump, ECMO) [5-7]. Still, the main disadvantage of the femoral access site is the high number of vascular complications; infectious complications have not properly been investigated yet.



Figure 1: Aortography shows an I type aortic arch (Picture 1A.) and normal subclavian artery with its branches on angiography.

This article reviews the anatomy and anatomic variations of the upper limb vasculature and gives up-to-date information on the anesthesiological, surgical and interventional applications of radial artery cannulation and radial artery harvest.

Anatomic Background

The most common aortic arch branching pattern in humans consists of 3 great vessels originating from the arch of the aorta (Figure 1A). The first branch is the innominate artery, which branches into the right subclavian artery and the right common carotid artery. Most commonly, the second branch is the left common carotid artery, and the last branch is the left subclavian artery. In approximately 0.5% of patients, the right subclavian artery arises anomalously as the terminal vessel from the descending aorta and courses toward its normal distribution to the right extremity. The most important branches of the subclavian artery arise from the first segment of the artery (Figure 1B): the vertebral and internal mammary artery is remarkably constant in their origin and course, arising as the first and second branch, respectively. In contrast, the thyrocervical trunk, which arises as the third branch, demonstrates significant variation in both the pattern and size of its various branches. In the arm, the brachial artery supplies the deep brachial branch that runs posteriorly, and the superior and inferior ulnar collateral arteries that supply collateral flow to the elbow region (Figure 2A). The brachial artery divides into the radial and ulnar arteries (Figure 2B-CD). The ulnar artery is usually the larger of the terminal branches of the brachial artery. Just distal to its origin, it gives off the anterior and posterior ulnar recurrent arteries that supply collateral flow to the elbow, and then gives off the major branch the common interosseus. The radial artery supplies the radial recurrent branch to the elbow, and descends on the lateral side of the forearm. In some cases the radial artery may originate high from the axillary or upper brachial artery. The arterial anatomy of the hand is extremely

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Figure 2: Selective angiography shows the brachial artery (Picture 2A.) and the forearm circulation with the radial, interosseus and ulnar artery (Picture 2B-C.). Picture 2D shows patent dual palmar arch.

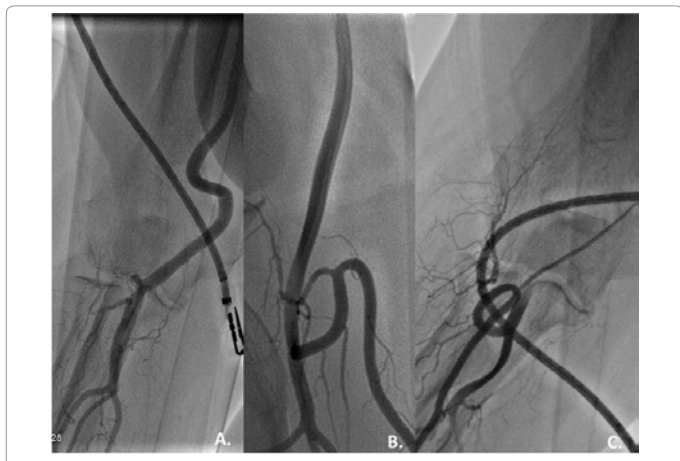


Figure 3: Angiography shows brachial tortuosity (Picture 3A.), radial arterial tortuosity (Picture 3B.) and severe loop (Picture 3C.) on selective angiography during cardiac catheterisation.

variable, and deviations from the classic pattern is common. The ulnar artery supplies the superficial palmar and the radial artery supplies the deep palmar arch. Typically the superficial arch is dominant and lies distal to the deep arch. The princeps pollicis and radialis indicis arteries arise from the radial artery and supply the thumb and index finger. The superficial palmar arch gives off three or four common digital arteries, and the deep arch gives off the palmar metacarpal arteries (Figure 2D).

Anatomic variations

Several unsuspected anatomic variations may exist, but have no consequence on the transradial approach for coronary and peripheral interventions. The main anatomic variation of the radial artery is the radial artery loop, which can be found in 1-2 % of the total population [8-11] (Figure 3.). The radial artery loop is found mainly in old females and patients with hypertension and it is responsible for the main cause of cross-over during coronary interventions [8-12]. Radial artery loop is detected by the operator as a resistance during J-wire advancement. The loop must be confirmed with fluoroscopy and it can be passed easily with hydrophilic wire. Recurrent brachial artery is also an important anatomic variant, since it might be responsible for severe spasm and perforation. Anatomic variations can be detected with

vascular ultrasound [13] before cannulation, hence when the guidewire advancement is not easy during the procedure, anatomic abnormality should be suspected and visualised under fluoroscopy. Common causes of resistance are congenital anatomic variations such as radial artery “loop,” early origin of the radial artery, accessory radial artery, tortuosity in the axillary, subclavian or innominate artery (especially in older hypertensive patients), and arterial spasm. In patients undergoing coronary angiography, forearm retrograde angiography showed three major anatomic variations: high radial artery bifurcation, radial artery loops and tortuous radial artery (ref). The major operational failure rate occurred in patients with loops and tortuous radial artery [9]. Palmar arch anomalies are also frequent, but only a few publications [14] report hand ischaemia after radial artery occlusion when the palmar arch is incomplete. Anatomic variations of the radial artery are summarized in Table 1.

Diseases affecting the forearm arteries

Arterial occlusive disease of the upper extremity may represent local or systemic diseases and the pattern varies according to etiology. From pathophysiologic standpoint, the upper extremity vascular diseases can be divided into large-vessel (proximal to the wrist) and small-vessel (distal to the wrist) diseases. The ones that affect the brachiocephalic vessels include atherosclerosis, arteritis, congenital anomalies, trauma and fibromuscular dysplasia. Small vessel obstructive diseases can be due to Buerger’s disease, peripheral emboli, hypercoagulable states, different type of small vessel vasculitis including Henoch-Schönlein purpura and frostbite. Symptomatic upper extremity arterial occlusive disease is uncommon due to the abundant collateral network and the fact that atherosclerosis is relatively uncommon in the upper extremity. Patients who present with upper extremity ischemia range from young adults with nonatherosclerotic causes to elderly patients with atherosclerosis. Digital gangrene is a frequent manifestation of connective-tissue disease or a hypercoagulable state. Buerger disease, which is a rare condition, [15] manifests with multiple digital artery occlusions caused by heavy smoking an is characterized by (Figure 4) multiple, bilateral focal segments of stenosis or occlusion, affecting the distal arteries associated with abundant ‘corkscrew’ collateral vessels (representing dilated vasa vasorum).

Evaluation of Hand Circulation before Radial Artery Cannulation

Allen test (AT)

Its modifications have been the standard for assessing collateral flow to the hand before radial artery catheterisation. The AT is easy to perform: the examiner faces the patient, whose hand is supinated. The radial artery (RA) and ulnar artery (UA) are located by their pulses, and both arteries are compressed simultaneously by 4 fingers. During direct pressure, the patient is asked to clench and unclench her fist several times. The patient is then asked to relax the hand and extend the fingers

Author	Patient population	Radial artery loop	Tortuous radial artery n (%)	High radial take-off	Radial or ulnar stenosis
Toshiharu Fujii ⁸	163	2 (1.2)	25 (15.3)	8 (4.9)	4 (2.5)
Lo TS ⁹	1540	35 (2.3)	30 (2)	35 (2.3)	39 (2.5)
Nie Bin ¹⁰	3000	33 (1.1)	150 (5)	231 (7.7)	43 (1.4)
Yoo BS ¹¹	1191	16 (1.3)	67 (4.2)	38 (3.2)	no data
N. Yokoyama ¹²	115	1 (0.9)	6 (5.2)	0	2 (1.7)

Table 1: Anatomic variations of the radial artery.

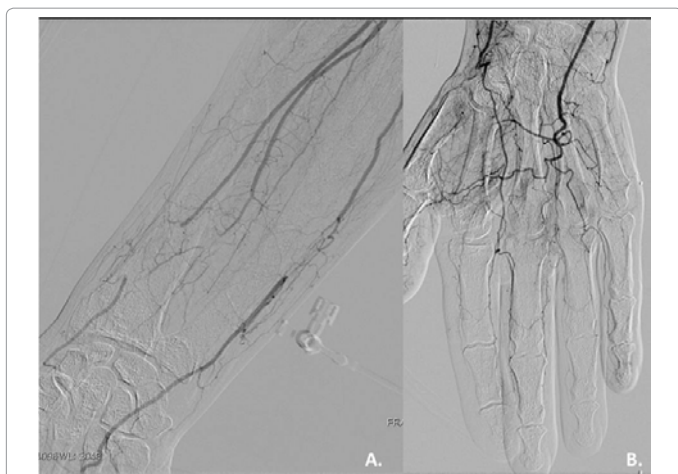


Figure 4: presents a typical heavy smoker patient with digital gangrena and Bueger disease. The radial and ulnar artery are occluded (Picture 4A.) The deep palmar arch is occluded due to distal embolism (Picture 4C).

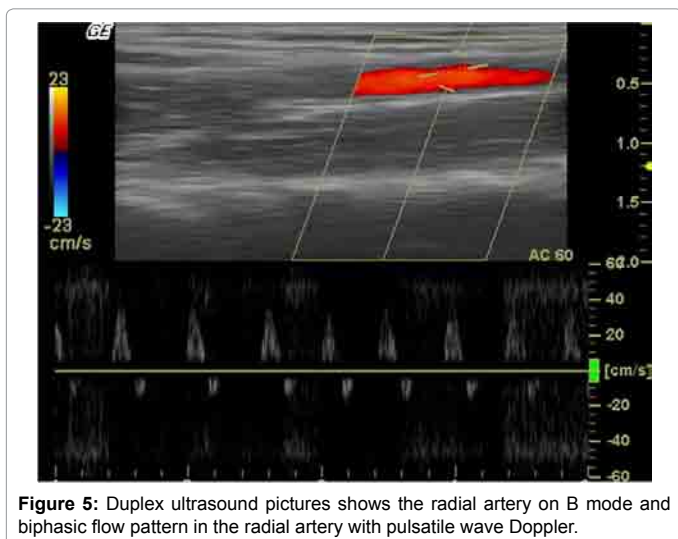


Figure 5: Duplex ultrasound pictures shows the radial artery on B mode and biphasic flow pattern in the radial artery with pulsatile wave Doppler.

into a slightly flexed position while the examiner maintains pressure on the RA and UA. The hand at this point should appear blanched. Examiner then releases the pressure on the UA and continues applying pressure to the RA. The return of color to the hand and fingers is noted. An abnormal Allen test (positive) result is defined as a recovery time of more than 5 seconds [16], but the test is limited by false positive and negative results - sztem ha erről nem írsz részletesen, nem biztos hogy kell bele).

Modified Allen test (MAT) with pulseoxymetry

The MAT is performed with placing pulseoxymetry on the index finger. During dual radial and ulnar artery compression hand ischaemia is induced. The oxygen saturation and the waveform are assessed. MAT is considered positive if the oxygen saturation gets lower than 70 % on the index finger during compression and the waveform is diminished or weak [17].

MAT test with Doppler probe

The effect of compression of the ulnar and radial arteries on the mid-palmar sign is assessed. Ordinarily, there should be no

interruption of flow, when releasing one artery. Non-resumption of flow indicates occlusion of that artery.

Duplex scan

It is extremely accurate in providing anatomic and physiologic information on a stenosis all the way to the digital vessels [18]. Normal waveforms are triphasic, but peripheral resistance decreases with arm exercise or warming causing the waveform to become monophasic with continuous flow through diastole (Figure 5). It is important to note, that the systolic reversal phase of the Doppler signal obtained from the radial and ulnar arteries is absent in up to 50% of healthy individuals. Otherwise, qualitative changes in the waveform (eg. spectral broadening, monophasic morphology) infer similar conclusions regarding the hemodynamic significance of obstructive disease.

Segmental limb pressures

This test is similar to the test performed in the lower extremities and involves placement of cuffs around the forearm, upper elbow and wrist and measuring pressures by Doppler and recording waveforms at these levels. A pressure difference of more than 15Hgmm is suggestive of a hemodynamically significant stenosis [19].

Method used for assessing hand ischemia before radial artery cannulation

In routine practice the Allen test and its modifications can be used for prevention of ischaemic damage of the hand; however only one publication exists, which investigates the potential role of radial artery occlusion in patients with positive Allen test. Greenwood et al. [20] have investigated the effect of the RA occlusion in patients previously screened with modified AT. They have occluded the RA for 30 minutes and screened the patients for hand ischaemia, ulnar artery flow and venous lactate level. It has been found that patients with PAT had higher ulnar artery flow after radial artery occlusion than patients with NAT (240 vs. 135%), but the flow in the principal artery of the thumb was diminished better (3.2 vs 15.9 cm/s) and the lactate level was increased higher in the thumb than in NAT group patients. The paper has scientific and clinical importance, but many radialist operators abandon the Allen test because hand ischaemia is infrequent during coronary procedures [14] - sztem ez itt egy kicsit hosszsan van taglalva... The rate of forearm stenosis has been found to be 1-2% in patients referred for coronary angiography [8-12] and cadaver dissections showed the presence of incomplete palmar arch in 3.6-34 % [21]. The absence of flow in the digital thumb with radial artery compression has been found to be an absolute contraindication for radial artery catheterization since it forecasts severe hand ischemia due to incomplete palmar arch. The increased recovery time during MAT also predicts hand ischemia [22]. Radial artery occlusion in patients with peripheral vascular disease has not been investigated before, although these patients might have high number of ischaemic complications when ulnar stenosis is present or the palmar arch is not complete.

Transulnar Access

The dominant artery of the hand is the ulnar artery. There are reports of coronary and peripheral cases performed from ulnar artery in the case of radial artery hypoplasia [23]. Karacalar S. et al. compared the TR and transulnar (TU) cannulation and found that the RA cannulation success was significantly higher than the TU cannulation (90% vs. 82%). Compared to the radial artery, the ulnar artery is generally not as well centered over the underlying bone, coursing

slightly medially and there is more intervening tissue. This makes compression hemostasis slightly more difficult. In the study performed by Karacalar the vascular complications rate was not higher compared with radial access [24], but for intervention we recommend the ulnar artery preserved only for the interventions which can not applied for radial artery access.

Transradial Access for Coronary Interventions

In 1989, Lucien Campeau published his successful series of 100 coronary angiographies performed via the radial artery with minimal complications [25]. Subsequently in 1993, Kiemeneij described and published the use of transradial access for percutaneous coronary interventions using 6 French (Fr) guiding catheters in a time when most interventional procedures were performed with larger 8 Fr catheters [2]. The dominant site of access during angiography has been the femoral artery for over two decades and remains so today; however in some centers of invasive cardiology the transradial access is the dominant and femoral artery access is restricted for patients unsuitable for the transradial access. The rationale for the TR approach has been to attempt to reduce the incidence of bleeding complications and the vascular access site and the necessity for prolonged bed rest. Being able to avoid local complications of TR coronary angioplasty is mainly determined by the favorable anatomic relations of the radial artery to its surrounding structures. A number of studies have confirmed its applicability and potential advantages over the TF approach in elective [26-29] and acute procedures [31-40]. One recent analysis comparing the TRA to the TFA in cardiac catheterizations noted that the total procedural cost, including access devices, contrast material volume, catheters, closure devices, and recovery, was significantly reduced using the former approach [30]. Aggressive antithrombotic therapy in the treatment of STEMI is very important in order to limit the occurrence of thrombotic complications during and after the procedure. Nevertheless, during transfemoral PCI this aggressive antithrombotic treatment is associated with a high risk of access site complications. Although the bleeding rate from the femoral approach has reduced significantly over recent years, it remains a troublesome issue [27,28]. The negative prognostic implications of peri and post procedural bleeding is well established in the literature, particularly its association with an increased mortality rate [28,29]. According to this data it seems plausible that the radial approach should achieve lower mortality rates when compared to the femoral approach due to lower access site major bleeding. It is important to note that so far no study has demonstrated a decrease in mortality among radial approach primary PCI patients compared to the femoral approach. Restrospective study over 5 years patient population was published by Ruzsa et al. [33] compared the radial and femoral access for primary and rescue PCI and has found that the vascular complication and the MACE rate was significantly lower in the radial group. One metaanalysis published by Vorubcsuk [34] was published recently comparing the femoral and radial access for primary and rescue PCI. Authors has found that the radial approach

for primary PCI reduced the risk of major bleeding by 70%, with an associated reduction of the composite endpoint of death, MI and stroke (3.65% vs. 6.55%, OR 0.56 [95% CI 0.39-0.79], P=0.01). Different prospective studies are listed in Table 2. comparing the major adverse cardiac events, vascular complications in different studies. The radial access for PCI in cardiogaenic shock was not investigated before, but with the increasing skill in transradial angioplasty one femoral access for balloon pump insertion and one radial access for the intervention is suitable [41].

Transradial Access for Peripheral Interventions

Radial access for coronary intervention has gained popularity due to a low rate of access site bleeding complications and the possibility for early discharge. The preferential access site for peripheral intervention remains femoral, via antegrade or retrograde puncture. Not all peripheral lesions are suitable for transradial intervention due to the distance between the access site and the lesion location. The rationale for doing peripheral intervention from radial access is to decrease the peripheral complications and to mobilize the patient after the procedure. From another hand, femoral access may be difficult in obese patients, extensive postoperative scarring, and severe peripheral disease (aortic, iliac artery occlusion and tortuosity), or relatively contraindicated (coagulopathy). For these patients the brachial and radial approach may be useful to catheterize supraaortic [42,43], mesenteric [44], renal [45], iliac [46] and the proximal part of the femoral arteries [47]. The major advantages of the technique are the immediate mobilisation after the sheath removal, the improved patient comfort, the low risk of access site complications. Peripheral procedures on an outpatient basis can be performed, which reduces the cost and patient discomfort. The major contraindication of the technique is the negative Allen test and the inpalpable radial artery and relative is, the planned radial artery harvest and Cimino fistulae.

Complications of Radial Artery Access for Interventions

Zero vascular complication rates during the transradial interventions is not true. Several complications were reported including radial artery spasm, occlusion, perforation and compartment syndrome, pseudoaneurysm formation, distal embolisation and granuloma formation. The radial artery spasm is a common problem and in most cases can be prevented with intra-arterial vasodilators and/or hydrophilic guidewires; however recent publication by (Figure 6)

Study	Radial/ Femoral(n)	Success(%)	MACE(%)	Major bleeding
TEMPURA, 2003 ³⁵	77/72	96.1/97.2	5.2/8.3	0/2
RADIAL-AMI, 2005 ³⁶	25/25	87/88	0/4	0/0
FARMI, 2007 ³⁷	57/57	91.2/96.5	NA	3/3
RADIAMI, 2009 ³⁸	50/50	88/92	4/8	3/7
Hetherington et al, 2009 ³⁹	571/480	92.7/91.2	2.6/5.2	NA
Pancholy et al, 2010 ⁴⁰	109/204	89/91	23.8/25.5	16/0

Table 2: Comparative studies of primary PCI performed form radial and femoral access.

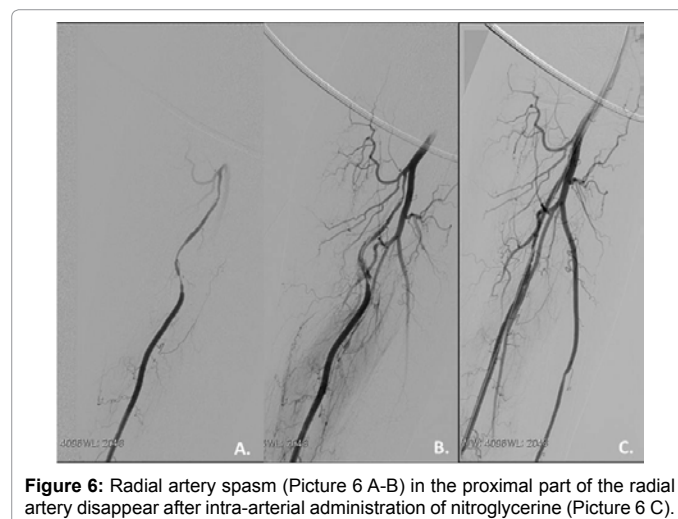


Figure 6: Radial artery spasm (Picture 6 A-B) in the proximal part of the radial artery disappear after intra-arterial administration of nitroglycerine (Picture 6 C).

Hizo et al. [48] reported that intraarterial administration of verapamil didn't reduce the occurrence of the radial artery spasm. Forearm compartment syndrome followed by radial artery perforation can be a serious complication, however the immediate diagnosis and lower arm bandage can prevent the occurrence of the forearm compartment syndrome in the vast majority of the cases [49]. Radial artery occlusion is a frequent (1-3%) complication but it has no clinical importance if the Allen test is negative [50], however the radial artery must be preserved for further interventions, radial artery harvest and Cimino fistulae. For this reason all preventive measures must be taken to prevent the radial artery occlusion including fast and atraumatic puncture, intraarterial administration of NaHeparin and verapamil, and the use of non-occlusive bandage [51]. There are reports of successful radial artery recanalizations in patients with symptomatic radial artery occlusions [52]. Another rare vascular complication is the pseudoaneurysm formation, which can be treated with long term compression bandage and in resistant cases with ultrasound guided thrombin injection [53] (Figure 7). All reported vascular complications and their prevention and treatment are listed in Table 3.

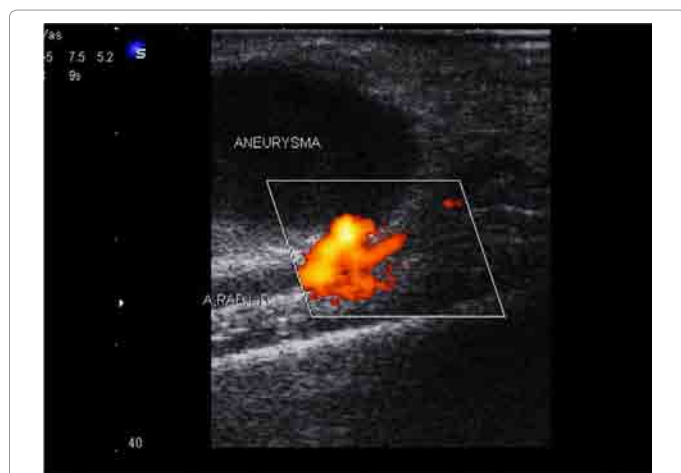


Figure 7: Radial artery pseudoaneurysm after US guided manual compression shows the thrombosed pseudoaneurysm on color Doppler.

	Incidence (%)	Prevention	Treatment
Spasm	1-5	Immediate, fast puncture Prophylactic Verapamil and Nitroglycerine Proper patient sedation	Intraarterial nitroglycerin or verapamil
Radial artery occlusion	1-3	Prophylactic NaHeparin Non-occlusive bandage	In symptomatic cases PTA
Perforation	very rare	GW removal and compression bandage	Compression bandage In symptomatic cases coronary stent graft
Dissection	very rare	Cross over to femoral site	In symptomatic cases PTA with stent
Pseudoaneurysm	very rare	Proper pressure bandage position	Long term compression bandage US guided thrombin injection
Granuloma formation	very rare	-	-

Table 3: Reported vascular complications, their prevention and treatment.

Radial Artery Harvest

The use of radial artery for coronary bypass surgery has increased in the past years due to its excellent early and long-term patency [54,55]. The latest study concerning the clinical and angiographic results of the radial artery used as a coronary bypass graft over 20 years was published in 2011 [56]. Separating four groups at successive follow-up intervals, radial artery patency was: 86.2%, 81.9%, 81.4%, and 81.6% at 1.0, 5.4, 8.3, and 13.1 years, respectively. In conclusion bypass surgery with the radial artery offered long-lasting clinical benefit, and radial artery patency was remarkably stable for up to 20 years. Improved outcomes have been achieved with novel techniques regarding the graft preparation and the prevention of perioperative vasospasm.

Randomized study was published to compare Harmonic scalpel and conventional surgical methods [57]. Two hundred patients were divided into two equally groups. In the conventional group electrocautery and haemostatic clips were used and in the Harmonic group the ultrasonic scalpel was used. Harvesting time (23.7 vs. 33.4 min), spasm rate (2 vs. 8%) and the need for postoperative analgesia (5 vs. 17%) was shorter in the Harmonic group than in the Conventional group. The occurrence of neurological complications was similar in both groups.

Minimally invasive surgical techniques have been applied also for radial artery harvest. Randomised study was published concerning the functional and histological quality of the endoscopically harvested radial artery graft [58]. In this small study (18 patients in each group), harvesting method did not have any effect on the functional or histological quality of graft patency. Peri- and postoperative vasodilator therapy includes drugs with different mechanisms of action including calcium channel blockers [59,60], papaverine [60], milrinone [61], nitroglycerin [62], nicorandil [63] and adrenergic receptor blockers [64,65].

Patient characteristics and target vessel quality seriously effect radial artery patency. The patency rate is considerably poorer if the radial artery was anastomosed to a vessel with less than 70% stenosis. Patency rates were comparable to the thoracic artery patency when the radial artery was anastomosed to a vessel with 80 to 85% stenosis. Target vessel territory did not affect the patency. Peripheral vascular disease however a risk factor to radial artery graft failure and it is recommended not to use radial artery in patients with severe peripheral vascular disease [66].

Removal of the radial artery will definitely cause circulatory changes in the forearm. A number of studies have been published concerning the consequences of radial artery removal in coronary bypass patients. There is a strong evidence that this procedure is associated with significant increase in ulnar artery flow velocity after surgery. In a series of 34 asymptomatic patients, the ulnar artery peak systolic velocity was greater in the operated arm compared with the control arm after five years underwent radial artery harvest [67]. Long-term follow up data suggest that the intima-media thickness of the ulnar artery is significantly higher on the operated side, and this difference reached statistical significance at 10 years follow-up. There is also significantly higher prevalence of atherosclerotic plaques in the ulnar artery of the operated versus control arm [68]. In a recent, larger series this effect was not observed [69].

Radial Artery Cannulation in Operative Room

The radial artery is the most commonly used access site for arterial cannulation in the operating room for haemodynamic monitoring.

Patients requiring arterial lines may be hypotensive or obese, resulting in difficulty in palpating the pulse. In addition, often the catheter may not be passed successfully into the artery, despite apparent good blood return on initial puncture, or the artery may develop spasm after a failed attempt, thus making any further attempts more difficult. There are randomized studies to compare ultrasound-guided versus traditional palpation placement of arterial lines for time to placement, number of attempts, sites used, and complications. In a well organized study [70] sixty patients were enrolled, with 30 patients randomized to each group. Patients randomized to the ultrasound group had a shorter time required for arterial line placement (107 vs. 314 seconds; difference, 207 seconds; $p = 0.0004$), fewer placement attempts (1.2 vs. 2.2; difference, 1; $p = 0.001$), and fewer sites required for successful line placement (1.1 vs. 1.6; difference, 0.5; $p = 0.001$), as compared with the palpation group. The procedure may be technically challenging in atherosclerotic patients. Prospective randomized study was conducted to compare the efficacy and complications with 20- and 22-G catheters for radial arterial cannulation in atherosclerotic patients [71]. Thirty patients with atherosclerosis, American Society of Anesthesiologists (ASA) III-IV, undergoing general anesthesia were enrolled in the study. Radial artery cannulation was performed in group 20G ($n = 15$) with a 20-gauge catheter and in group 22G ($n = 15$) with a 22-gauge catheter. In conclusion a 22-gauge catheter for radial arterial cannulation in patients with atherosclerosis provided unchanged postcannulated radial artery diameter, decreased postcannulation complications, and improved the first-attempt success rate. During cardiac surgery, or when non-cardiac surgical patients are haemodynamically unstable, a continuous measurement of cardiac output is highly recommended. There are a number of different methods available for use in the operating room. Among the pulse contour methods available, the PiCCO system, using femoral artery pressure as an input signal is widely used. However, femoral artery catheterisation may fail in some patients. In these patients, the standard radial artery catheter could be used as an alternative input signal [72]. The investigators found that the femoral artery pressure and radial artery pressure signals were interchangeable as inputs for the PiCCO device to calculate cardiac output. There is a continuously increasing attendance about the use of the ulnar artery for haemodynamic monitoring as an alternate site for arterial catheterization when attempts at insertion in other locations was unsuccessful. Randomized, controlled study was conducted to compare the ease of cannulation, success/failure rate, and complication rate between ulnar and radial arteries in the operating room. Karacalar et al. [73] has found that the success rate of an ulnar arterial cannulation in a patient with a strong ulnar pulse is the same as for radial artery cannulation. Ease of cannulation and complication rates of cannulations were not statistically different in both groups.

Prolonged Radial Artery Cannulation in the Intensive Care Unit

Indications for prolonged arterial cannulation in the intensive care unit include the need for continuous haemodynamic monitoring, frequent arterial blood-gas analysis, and repeated blood sampling for laboratory evaluation. Maintaining the patency of arterial catheters is a crucial question of the intensive nursing care. Several randomized trials were conducted to compare non-heparinized solutions with heparin for maintaining radial artery catheter patency in the intensive care unit. Randomized double-blind trial [74] found no significant difference between flushing with normal saline and heparinized saline in the maintenance of radial arterial line patency in the surgical intensive care unit. However, according to the authors, the use of a

continuous heparinized flush solution in pressurized arterial lines is beneficial in that it results in greater accuracy of blood pressure monitoring than normal saline infusion. Another double-blind, randomized study [75] demonstrated that the use of 0.9% sodium chloride as a continuous flush for radial artery catheters is associated with an increased frequency of catheter occlusion and malfunctions compared with solution containing heparin. In patients requiring radial artery catheter during the perioperative period, a randomized, double-blind, controlled study [76] was conducted to compare heparinized and nonheparinized infusions for the maintenance of arterial catheter patency and the incidence of subsequent radial arterial occlusion. Two-hundred patients were randomized into 2 groups to receive heparinized (group H, $n = 100$) or nonheparinized (group S, $n = 100$) flush solutions. In conclusion, there was no significant difference between heparinized and non-heparinized flush solutions for the maintenance of perioperative radial artery catheter patency. Another randomized, double blind, placebo-controlled clinical trial [77] confirmed this observation in adult intensive care unit. There is no agreement about the optimal heparin concentration applied in the flush solutions. A study comparing two heparin concentrations, 0.25 and 1 U/mL [78], found no significant difference in arterial line patency, low dose 0.25 U Heparin/mL was sufficient to maintain the patency for adult patients with lines in place for up to 3 days. In many intensive care unit arterial catheters are routinely changed in every seven days, based on several reasons. In one study [79] it was suggested that the low incidence of catheter-tip colonization and no catheter-related bloodstream infection may be due to the fact that most arterial catheters were removed within four days. The current CDC guidelines for the prevention of intravascular catheter-related infections [80], however, recommend not routinely replacing arterial catheters to prevent catheter-related infections. According to the guideline arterial catheters should be replaced only when there is a clinical indication.

Conclusions

Radial artery is the preferred arterial access route for short and long term cannulation when haemodynamic status is stable. The radial access is the first choice of access site for coronary procedures when the operator is skilled in transradial technique and no contraindications are present. For peripheral interventions transradial access is an alternative to femoral access, however further randomized studies are needed to compare the efficacy and complications. Radial artery is an alternative for venous grafting in coronary artery bypass with promising long term results, however careful non-invasive investigations are needed before harvesting the radial artery to prevent hand ischaemia.

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