SciForschen

Open HUB for Scientific Research

ISSN 2379-769X

Journal of Heart Health

Review Article　　　　　　　　　　**Volume: 2.3**　　　　　　　　Open Access

Troubleshooting in Transradial Catheterization: The Lessons Learnt so Far

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Received date: 19 Feb 2016; **Accepted date:** 10 May 2016; **Published date:** 17 May 2016.

Citation: Dash D (2016) Troubleshooting in Transradial Catheterization: The Lessons Learnt so Far. J Hear Health 2(3): doi http://dx.doi.org/10.16966/2379-769X.126

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Abstract

Cardiac catheterization *via* the transradial approach has become the "gold standard" in many centres because it allows quite early ambulation, decrease in bleeding and vascular access site complications. The growing experience has led to an understanding of the anatomical variants leading to technical difficulties and complications that can result from the transradial approach. The purpose of the present manuscript is to review these issues with practical preventive strategies and specific treatment.

Keywords: Cardiac catheterization; Transradial approach; Complications

Introduction

Following the report of the transradial (TR) approach for coronary angiography by Campeau in 1989 [1], the technique was extended to percutaneous coronary intervention (PCI) by Kiemeneij and Laarman since 1993 [2]. The reported advantages of the TR approach as compared to transfemoral technique include decreased bleeding and vascular access site complications [3,4], improved patient satisfaction, decreased length of stay and improved economic outlook [5-7]. From this perspective TR approach might be "gold standard" for PCI. However, it requires specific skill set and significant learning curve. In addition, radial artery spasm, arterial puncture failure, vascular anomalies, and failure to reach the ascending aorta are the obstacles that could impede regular use of this approach. This paper will review the anatomical variations and problems encountered during TR catheterization, prevention strategies and methods of treatment.

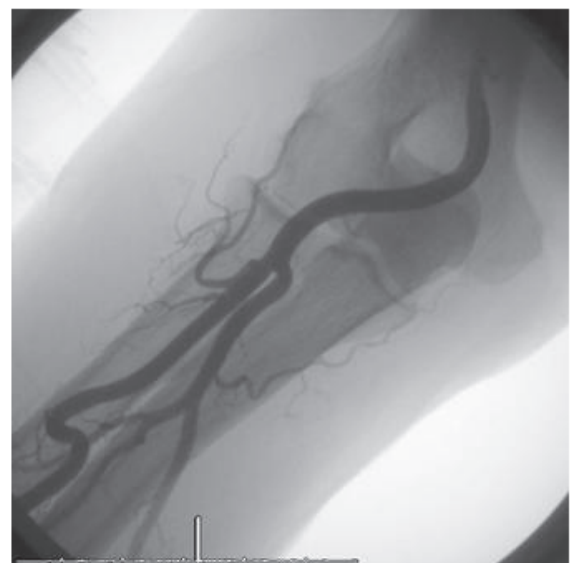## Anatomical Variations Encountered up to Sheath Insertion

Tortuosity

Tortuosity of radial artery is usually is recognized by difficulty in advancing the wire. It is most commonly seen in elderly small-framed women. It's incidence is 2 to 6.1% in different angiographic and ultrasonographic studies [8]. In different studies, different definitions of tortuosity (presence of a bend or angulation of more than 45° to 90°) have been used. But, more the angulation and less diameter, the procedure becomes increasingly difficult due to more chance of spasm (Figure 1). If radial artery (RA) is small and tortuosity segment is long, it should be crossed with a 0.025" or 0.032" J shaped hydrophilic guidewire or a 0.014" soft-tip coronary wire. A catheter should be negotiated over the wire using slow corkscrew movements. Direct push of the catheter should be avoided to prevent reactive spasm. Spasm in tortuous RA is a complex situation which may respond to repeat dose of spasmolytic cocktail. The balloon-assisted technique (BAT) should be reserved for most difficult situations [9].

Hypoplasia

It is an anatomical variation in which RA is palpable, but prevents insertion of sheath. Interventionists should adopt femoral or contralateral

TR approach. It is associated with large radio-carpal artery in 0.1% cases. Puncture of radio-carpal artery is difficult due to its superficial nature and the artery should be held between two fingers because of its tendency to roll.

Various options are available for wire selection and fluoroscopic control when catheter is advanced from the radial artery to the ascending aorta. The 0.035" J-tip radiofocus wire with hydrophilic coating is the easiest to navigate, but may lead to perforation if not done under fluoroscopic guidance. However, the ordinary 0.035" J-tip spring wire presents no risk of perforation and is not easy to get across. When wire or catheter cannot be advanced, additional force should not be applied and angiographic evaluation of the area should be done to identify possible variations like radio-ulnar loop, a high radial artery take-off, a tortuous brachial artery, or an arterial lusoria (right retro-esophageal subclavian artery).

Figure 1: Tortuous radial artery.

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Radio-ulnar loop

Radial artery loops represent redundancy in the vessel that may be present since birth or develops due to aging process. The reported incidence is around 0.8 to 2.3%, but when present it gives greatest challenge to the operator as it is associated with TR failure rate of 17% to 37% [8,10,11]. Larger the diameter of the loop and smaller the caliber of the artery, it is more difficult to negotiate. Alpha loop in antero-posterior (AP) view is mistaken for small aneurysm. In most cases it is associated with the persistence of remnant vessel which is too small to permit passage of a catheter even if the guide wire enters into it (Figure 2). Sometimes oblique angiographic views are required to define the exact anatomy. Other radial loops include S loop, proximal and distal omega loops (Figure 3). Some of these loops are very complex and require conversion to femoral or contralateral TR approach. Some of the solutions for crossing these are downsizing of guide catheter, use of 0.035" hydrophilic wire technique (Figure 4), downsizing the guidewire to 0.025", the use of 0.014" coronary wire (Figure 5), coronary buddy wire technique and exchange with 0.035"

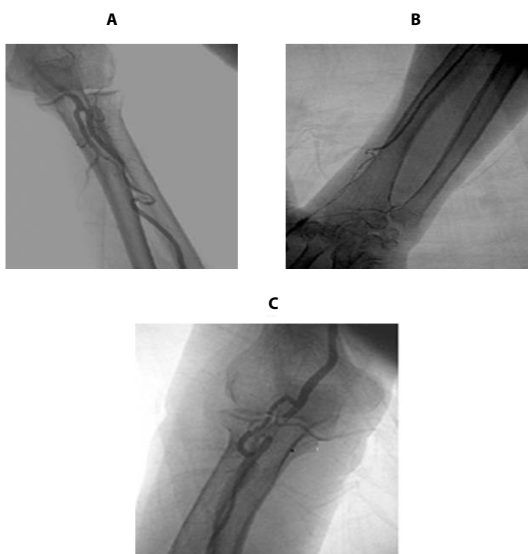**Figure 2:** Alpha Loop with recurrent radial artery.

Figure 3:
A. S radial loop.
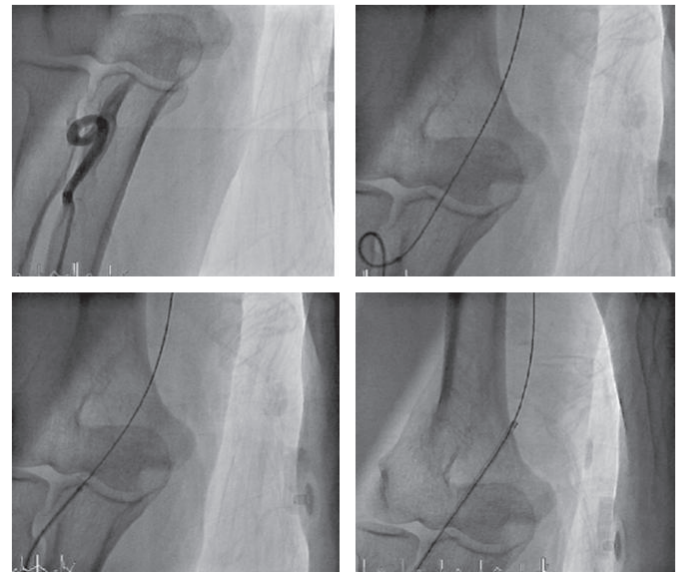B. Proximal omega loop.
C. Distal omega loop.

Figure 4: Overcoming of radial alpha loop with 0.034'' hydrophilic wire.
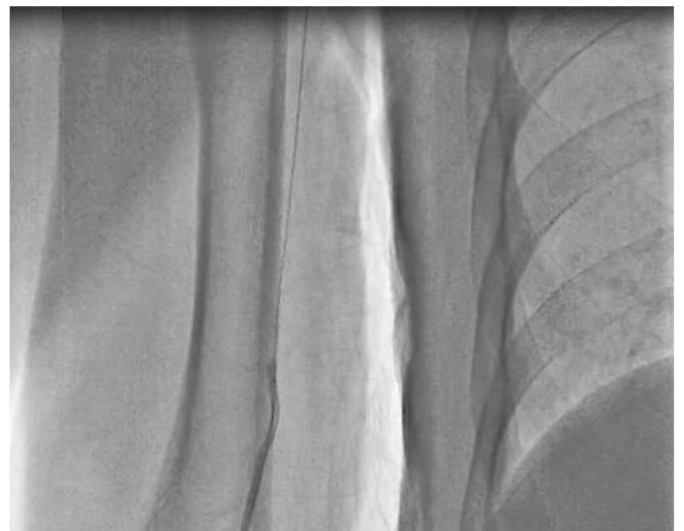

Figure 5: 0.014'' Coronary angioplasty wire technique in negotiating the radial loop.

J-tip spring wire, and also with low profile balloon support. The tip of the guidewire should be shaped to the angle of loop to facilitate crossing. Once the guidewire crosses the loop and it is parked as high as possible, the catheter is negotiated over it. In case of resistance, the operator can try pushing the catheter as far as possible into the loop, keeping the wire tip as high as possible (i.e., high brachial, axillary, or subclavian region) and pulling the entire assembly back. This maneuver opens up the loop and facilitates the advancement of the catheter. If the catheter is partly inside the loop, but has not crossed entirely, then the thin guidewire is exchanged for the standard 0.035" guidewire to provide extra support. A supper stiff guidewire is avoided unless the loop has been crossed and catheter tip is well into higher segment. BAT should be tried in case of failure of negotiation of a catheter through 360º loop [9].

High RA take-off

High origin of RA is rarely diagnosed as it really causes a problem if the artery is of sufficient caliber. The presence of atheromatous lesion is

a rarity at this level. In majority of cases, the RA takes-off from brachial, and rarely from the axillary artery. The RA is rarely underdeveloped in this scenario. If the operator experiences unexpected resistance in the mid part of brachial artery after inserting the catheter, or find that torque transmission is impossible once the catheter is into the ascending aorta, this type of anatomical variation may be well culprit. As a counter measure, downsizing the guide catheter would probably allow better manipulation. If it fails, the interventionist should adopt contralateral TR or femoral approach.

Arteria Lusoria or Retro-Esophageal Right Subclavian Artery

The arteria lusoria or retro-esophageal right subclavian artery (RORSA) generally arises from the distal and posterior margin of the horizontal part of the aortic arch at its junction with the descending aorta, less frequently from the proximal descending aorta, and thus the catheter is preferentially oriented towards descending aorta. It is encountered in 0.4 to 2% in right TR approach [12-15]. It is generally not a problem while adopting left TR approach. In AP view, the catheter in the RORSA at its origin is oriented more towards the left than usual and engages the ascending aorta with a peculiar angulation (Figure 6). For diagnostic procedures, selective catheterization of left coronary artery (LCA) is easier with left Judkins (JL), internal mammary artery (IMA) and TIG catheters. For right coronary artery (RCA), the standard right Judkins (JR) catheter is the best followed by an Amplatz right (AR). For interventions in the left coronary system, an extra back up guide catheter is the first choice followed by an Amplatz left (AL) or a wider JL catheter (Figure 7). AR catheter is the first choice for right coronary interventions. JR or AL catheters may be used in case of failure. It is preferable to perform all catheter exchanges using a long exchange 0.035" wire [11].

Both the catheters and guidewire should be withdrawn together as an assembly if they enter into descending aorta repeatedly. After asking the patient to take a deep breath, a 0.035" standard guidewire is pushed gently after patient takes deep breath. The catheter is then negotiated into the ascending aorta once the guidewire enter into it. If the guidewire remains in the descending aorta, the guide catheter is replaced with 5-F IMA diagnostic catheter and is placed in the descending aorta over the guidewire. Then previous maneuver is repeated which usually leads to
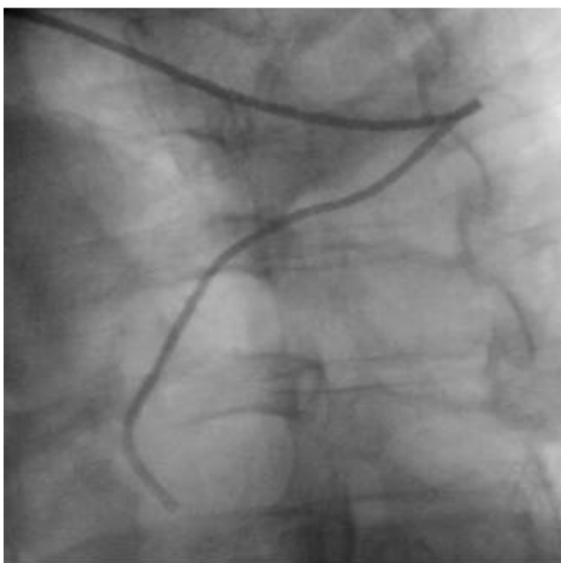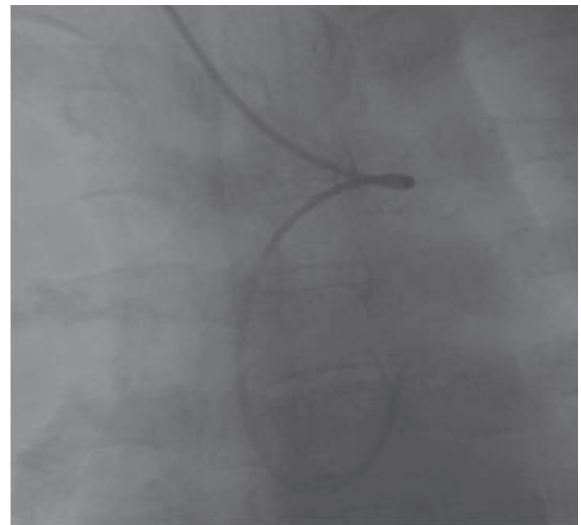

Figure 7: A loop was made using 0.25" Terumo to enter the ascending aorta with 6F EBU guide catheter in arteria lusoria-left anterior descending artery.

successful entry into the ascending aorta. If IMA catheter fails, a 5-F Simmons-1 catheter can be used to enter the ascending aorta. If 0.035" standard guidewire repeatedly slips into the descending aorta, it should be replaced with 0.032" or a 0.025" hydrophilic guidewire that facilitates entry into ascending aorta even through challenging anatomy.

Once the standard 0.035" guidewire or the hydrophilic guidewire enters into the ascending aorta, it is replaced with a 0.035" super stiff guidewire and a loop is made. The catheter is slowly negotiated over this so that the assembly (catheter and guidewire) can traverse the aortic loop. By slowly pulling the guidewire slightly inside the mouth of the catheter and then pulling the assembly back facilitates cannulating the LCA. For cannulation of RCA, a slow and gentle clockwise rotation of the assembly is done.
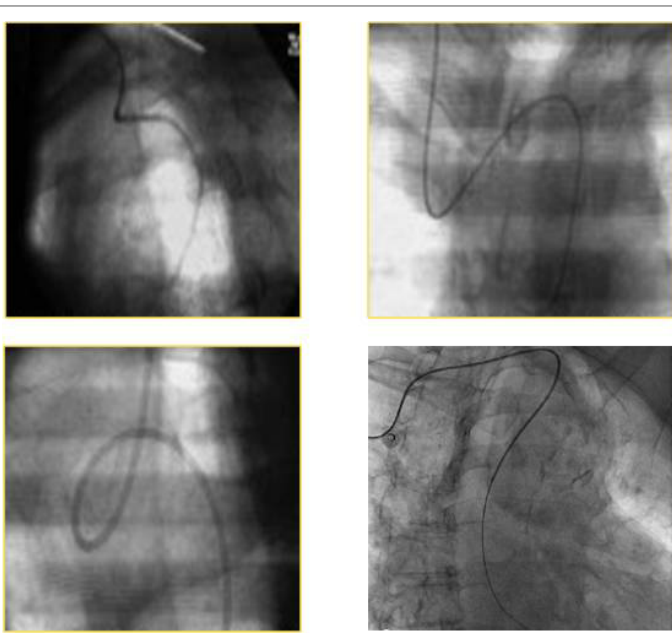
Brachio-cephalic trunk tortuosity

There are many side branches at this level and it is very important to monitor progression of the wire with fluoroscopy to prevent its entry into mammary or vertebral artery. Manipulation of the wire and catheter with a deep inspiration generally allows easy access to the ascending aorta. Subclavian loops, either congenital or acquired, are more often observed in elderly, obese patients, and patients with hypertension. These could be 90° or Z shaped or very complex as depicted (Figure 8). Crossing could be facilitated by deep breathing combined with the use of 0.035" hydrophilic wire exchanged with 0.035" super stiff wire, parallel wire technique and the BAT [9].

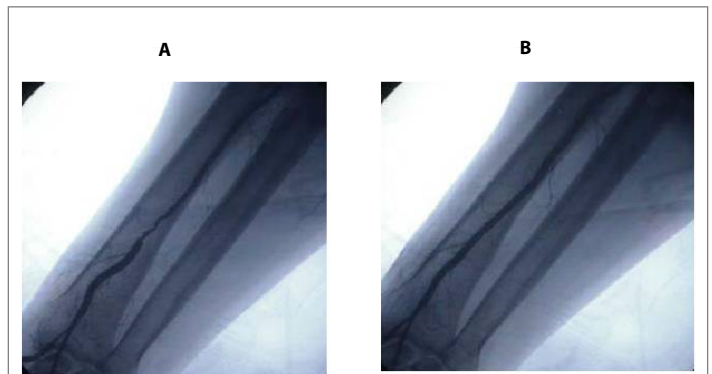### Complications of TR Approach

Knowledge of complications encountered during TR approach, their preventive strategies and methods of treatment are sin qua non of any TR program (Table 1).

Radial artery spasm

Radial artery spasm (RAS) remains one of the major challenges of this approach and is the most common causes of procedural failure [16,17]. The reported incidence of RAS varies from 5% to 30% [16,18,19] with most recent literature reported spasm in 10% of cases. Predictors of spasm include younger age, female gender, diabetes, smaller wrist circumference and lower body weight, multiple catheter exchanges, larger sheath size and operator inexperience [16,19]. The vessel has a prominent medial layer

Figure 6: Left anterior oblique projection revealing the characteristic angle L of the catheter in arterial lusoria.

Figure 8: Negotiation of subclavian loops using 0.035 inch extra-stiff guidewire.

Radial artery spasm
Radial artery occlusion
Dissection/perforation
Arterial eversion
Compartment syndrome
Catheter entrapment
Cardiovocal syndrome
Atheroembolism

Table1: Complications of radial access.

largely dominated by α-1 adenoreceptor function [20]. Thus increased levels of circulating catecholamines are a cause of radial artery spasm. Pain from RAS increases vasomotor tone resulting in further spasm. In current practice, local anaesthesia and adequate sedation to control anxiety, careful puncture technique, antispasmodic "cocktails" and hydrophilic-coated sheaths are mainstay of RAS prevention (Figure 8) [19]. A preventive approach would improve procedural success and decrease procedure duration [18]. Intraarterial (IA) administration of antispasmodic medications has been shown to decrease the incidence of RAS (Figure 9) [21-23]. Calcium channel blockers, nitrates, local anaesthetics (e.g., lidicaine) and α-antagonists are most common medications [24] used for this purpose.

A cocktail composed of nitroglycerin 200 μg and verapamil 5 mg reduces RAS significantly as compared to placebo [22]. Verapamil 2.5 mg compared to phentolamine 2.5 mg is more efficacious in RAS prevention [25]. Adding verapamil 1.25 mg to nitroglycerin 100 μg does not reduce RAS significantly as compared to nitroglycerine alone [26]. Some have called for caution when using verapamil in patients with left ventricular dysfunction [27]. In another study, addition of nitroglycerin 100 μg, nitroprusside 100 μg, or both to a basic cocktail (unfractionated heparin 2500 U, lidocaine 20 mg, diltiazem 5 mg) did not show any benefit in RAS prevention [23]. Nicorandil 4 mg is equally effective in RAS prevention as compared to a cocktail composed of a small dose of verapamil 100 μg and nitroglycerin 200 μg [27]. Nicardipine is a second-generation dihydropyridine calcium antagonist that does not intrinsically decrease myocardial contractility or influence AV conduction and is useful

Figure 9:
A. Radial artery spasm.
B. Normal of radial spasm after intrararterial nitrates and dilatiazem.

in patients with depressed left ventricular function and bradycardia. Combination of both nitroglycerine (200 μg) and nicardipine (200 μg) has shown more powerful radial artery dilatation effect. While there is no consensus on the exact regimen or dose, the routine use of a "cocktail" containing a calcium channel blocker with or without a nitrate is an effective modality in decreasing the occurrence of RAS.

Hydrophilic-coated sheaths have been shown in various studies to decrease the incidence of RAS and improve patient comfort during sheath insertion and removal [16,28-30]. Sheath length, in spite of coating, does not have any significant effect on RAS reduction [16]. Once severe spasm occurs, it can be managed with repeated doses of IA vasodilators, increased analgesia and sedation. Deep sedation with propofol, axillary nerve block, or even general anaesthesia has been employed to allow sheath removal [31,32]. The operator should take utmost care not to forcibly remove equipment should resistance occur as this may cause transaction or eversion endarectomy of the radial artery [33].

Radial artery occlusion

Radial artery occlusion (RAO) after TR procedure is a well recognized complication occurring in 2% to 10% of patients [34]. It may be related to prolonged cannulation, small diameter of the radial artery, ratio of the radial artery diameter to sheath outer diameter, and inadequate anticoagulation during cannulation [34-37]. Other factors predictive of RAO could be low body weight, advanced age, female gender, and prolonged occlusive pressure while achieving hemostasis. It can be documented by abnormal Barbeau's test, visible obstruction on two-dimensional ultrasound or absence of Doppler flow distal to puncture site. It is usually asymptomatic and benign. The presence of radial artery pulse does not rule out RAO due to the presence of collateral circulation though palmar arches which is an extremely protective mechanism. Although some operators emphasize the importance of normal Barbeau's test [38], also referred to as the modified Allen's test, this is controversial. However, patients with an abnormal modified Allen's test demonstrate early evidence of hand ischemia with RAO compared to patients with a normal study [39]. Even if there exits case report of significant hand ischemia following TR intervention, RAO is usually clinically quiescent [40]. However, its presence makes repeat radial access difficult [41]. RAO is supposed to be thrombotic process the incidence of which is significantly reduced with adequate anticoagulation with UFH [34,42]. Its incidence decreased from 71% to 4.3% with the use of 5000 units UFH [42]. It can be administered intravenously (IV) or through IA with similar efficacy [43], because of burning sensation in the intraarterial (IA) route, some operators may choose the IV route in view of similar outocomes with regard to RAO [43]. Bivaluridin could be effective in preventing RAO in patients undergoing ad hoc PCI [44].

Catheter size is an important predictor of post-procedure RAO. Saito et al. [45] demonstrated that a ratio of the inner diameter of the radial artery to the sheath's outer diameter of less than 1.0 predicts severe flow reduction after TR intervention. Use of a smaller size sheath and/or guide catheter may prevent RAO.

A strategy of "patent hemostasis" guided by plethysmography or mean arterial pressure (MAP) with use of a hemostasis device allowing adjustable levels of compression appears to reduce the incidence of RAO [46].

Even if it is usually asymptomatic, RAO may limit future TR catheterization. Low-molecular weight heparin has been found to resolve symptoms when RAO is symptomatic [47]. The patient suffering from hand ischemia could be treated with angioplasty [40]. Finally transient (1-h) ulnar compression has been described recently to recanalize acute RAO [48].

Hematoma

Hematoma is usually apparent during TR procedures due to the superficial course of radial artery. It rarely requires blood transfusion. TR approach does not impact non-access site bleeding that is more a function of patient and anticoagulation regimen [49]. Bertrand described a classification scheme of hematoma with Grade I and II being related to puncture site issues and Grade III and IV related to intramuscular bleeding [50] (Table 2).

Hydrophilic coated sheath reduces local hematoma non significantly as compared to uncoated sheath in one study [16].

Radial artery perforation

Radial artery perforation is a rare complication but can lead to severe forearm hematoma if not treated promptly. Its reported incidence is 1% [51]. Forceful manipulation of the guidewire and catheters in elderly and hypertensive patient leads to perforation. Anatomical variations like tortuosity, radial loops, a high radial take-off and short ascending aorta increase the risk of perforation [52]. It should be suspected when there is resistance to guidewire navigation as well as with the patient's complaint of pain. Usually radial artery perforation could be effectively managed without switching over to an alternate access site [53]. Several series have reported the safety of continuing the procedure either with use of a long sheath [52], guiding catheter [53] or prolonged (5 min) peripheral balloon inflation [54] to seal the perforation.

Forearm compartment syndrome

A compartment syndrome is rare but the most dreaded complication of radial artery hemorrhage, with an incidence reported be 0.004% in a large series [55]. Even a small volume of bleeding in the arm can lead to catastrophe given the limited free space in lower arm as compared to upper thigh. The diagnosis is based on the symptoms of acute forearm pain, swelling and tumefaction with disturbances in distal sensitivity and distal pallor. Direct measurement of compartment pressure confirms the syndrome while diagnosis is principally a clinical one [56]. Access site bleeding and hematoma, perforation or radial artery laceration could be common inciting factors for compartment syndrome. Most perforations are due to aggressive guidewire manipulation or excessive anticoagulation. It may not be detected during procedure because of temporary tamponade by the catheter shaft; as such it often manifests postprocedurally as a forearm hematoma. Conservative measures such as arm elevation, ice application and blood pressure cuff inflation may prevent progression of hematoma to compartment syndrome. However, emergency fasciotomy is required once elevated compartment pressures are documented.

Radial artery eversion and catheter entrapment

Eversion of the radial artery has been reported with sheath removal after severe RAS. The interventionist must employ various therapies to counter the vasospasm, including sedation and local and systemic delivery of antispasm medication.

Catheter entrapment occurs due to severe RAS or aggressive torquing of the catheter. Aggressive antispasm therapy and general anaesthesia allows the catheter removal. If entrapment is due to kinking or tortuosity, undoing the kink with fluoroscopic guidance or negotiating a wire to straighten the tortuous segment almost always allows catheter removal [24].

Pseudoaneurysm

This is a rare complication with an incidence of less than 0.1% as reported in one series [57]. It presents with pulsatile swelling with or without tenderness several days to weeks after the procedure. It is caused by penetrating injury of the arterial wall during cannulation with resultant hemorrhage and hematoma and is associated with multiple puncture attempts and aggressive anticoagulation therapy. Diagnosis is usually confirmed with Doppler ultrasound. Pseudoaneurysm is successfully treated with prolonged compression, is indicated if identified soon after the procedure. However, thrombin injection and surgical correction may be required in some cases.

Garnuloma

There are reports showing an association between hydrophilic sheaths and granulomatous foreign body reaction at the access site. These sterile granulomas, often confused with infected pseudoaneurysm, results in unnecessary surgery. Typically occurring 2 to 3 weeks after the procedure, these are most likely owing to the sheath coating. These granulomas are self-limiting and are managed conservatively unless and until symptomatic [58].

Chronic pain

Rarely prolonged aggressive haemostatic compression at the access site may lead to vascular and/or neurologic complications, including persistent pain. There may be a chronic regional pain syndrome characterized by hand swelling, allodynia, paresthesia, and the limited range of motion of interphalangeal, metacarpophalangeal, and wrist joints [59]. Sympathetic blockade, analgesics and physical therapy are potential management options.

Grade	I	II	III	IV	V
Incidence	≤ 5%	<3%	<2%	≤ 0.1%	<0.01%
Definition	Superficial local hematoma	Local hematoma with moderate muscular infiltration	Forearm hematoma with muscular infiltration below the elbow	Hematoma with muscular infiltration extending above the elbow	Compartment syndrome
Treatment	Analgesia Local ice Additional bracelet	Analgesia Local ice Additional bracelet	Analgesia Local ice Additional bracelet BP cuff inflation	Analgesia Local ice Additional bracelet BP cuff inflation	Consider surgery

Table 2: Transradial hematoma classification [49].

Conclusions

The feasibility and safety of TR approach adopted by interventionists is supported by robust data. However, these exits many real and perceived barriers for the operators to switch into this approach. The ability to recognize and troubleshoot anatomical variations and various complications unique to TR approach is fundamental in avoiding unnecessary morbidity and mortality. The field has undergone rapid transformation and would likely to improve further with experience, equipment modifications and pharmacological treatment. TR access offers the operators a unique opportunity to provide optimal care with reduced risk.

References:

1. Campeau L (1989) Percutaneous radial artery approach for coronary angiography. Cathet Cardiovasc Diagn 16: 3-7.

2. Kiemeneij F, Laarman GJ (1993) Percutaneous transradial artery approach for coronary stent implantation. Cathet Cardiovasc Diagn 30: 173-178.

3. Brueck M, Bandorski D, Kramer W, Wieczorek M, Höltgen R, et al. (2009) A randomized comparison of transradial versus transfemoral approach for coronary angiography and angioplasty. JACC Cardiovasc Interv 2: 1047-1054.

4. Kiemeneij F, Laarman GJ, Odekerken D, Slagboom T, van der Wieken R (1997) A randomized comparison of percutaneous transluminal coronary angioplasty by the radial, brachial and femoral approaches: the access study. J Am Coll Cardiol 29: 1269-1275.

5. Cooper CJ, El-Shiekh RA, Cohen DJ, Blaesing L, Burket MW, et al. (1999) Effect of transradial access on quality of life and cost of cardiac catheterization: A randomized comparison. Am Heart J 138: 430-436.

6. Mann T, Cubeddu G, Bowen J, Schneider JE, Arrowood M, et al. (1998) Stenting in acute coronary syndromes: a comparison of radial versus femoral access sites. J Am Coll Cardiol 32: 572-576.

7. Agostoni P, Biondi-Zoccai GG, de Benedictis ML, Rigattieri S, Turri M, et al. (2004) Radial versus femoral approach for percutaneous coronary diagnostic and interventional procedures; Systematic overview and meta-analysis of randomized trials. J Am Coll Cardiol 44: 349-356.

8. Yoo BS, Yoon J, Ko JY, Kim JY, Lee SH, et al. (2005) Anatomical consideration of the radial artery for transradial coronary procedures: arterial diameter, branching anomaly and vessel tortuosity. Int J Cardiol 101: 421-427.

9. Patel T, Shah S, Pancholy S, Rao S, Bertrand OF, et al. (2014) Balloon-assisted tracking: a must-know technique to overcome difficult anatomy during transradial approach. Catheter Cardiovasc Interv 83: 211-220.

10. Valsecchi O, Vassileva A, Musumeci G, Rossini R, Tespili M, et al. (2006) Failure of transradial approach during coronary interventions: anatomic considerations. Catheter Cardiovasc Interv 67: 870-878.

11. Louvard Y (2003) The Amplatz catheter as sole catheter for transradial coronary angiography. In: Hamon M, McFadden E (eds) Transradial approach for cardiovascular interventions. ESM editions, Carpiquet, France.

12. Papadatos D (1976) 3 anatomical observations of a right subclavian artery originating from the aortic arch (arteria lusoria). Anat Anz 140: 100-117.

13. Miller JM, Miller KS (1992) A note on the historical aspects of dysphagia lusoria. Am Surg 58: 502-503.

14. von Segesser L, Faidutti B (1984) Symptomatic aberrant retro-esophageal subclavian artery: considerations about the surgical approach, management and results. Thorac Cardiovasc Surg 32: 307-310.

15. Abhaichand RK, Louvard Y, Gobeil JF, Loubeyre C, Lefèvre T, et al. (2001) The problem of arteria lusoria in right transradial coronary angiography and angioplasty. Catheter Cardiovasc Interv 54: 196-201.

16. Rathore S, Stables RH, Pauriah M, Hakeem A, Mills JD, et al. (2010) Impact of length and hydrophilic coating of the introducer sheath on radial artery spasm during transradial coronary intervention: a randomized study. JACC Cardiovasc Interv 3: 475-483.

17. Dehghani P, Mohammad A, Bajaj R, Hong T, Suen CM, et al. (2009) Mechanism and predictors of failed transradial approach for percutaneous coronary interventions. JACC Cardiovasc Interv 2: 1057-1064.

18. Goldberg SL, Renslo R, Sinow R, French WJ (1998) Learning curve in the use of the radial artery as vascular access in the performance of percutaneous transluminal coronary angioplasty. Cathet Cardiovasc Diagn 44: 147-152.

19. Kiemeneij F (2006) Prevention and management of radial artery spasm. J Invasive Cardiol 18: 159-160.

20. He GW, Yang CQ (1998) Characteristics of adrenoceptors in the human radial artery: clinical implications. J Thorac Cardiovasc Surg 115: 1136-1141.

21. He GW, Yang CQ (1995) Comparison among arterial grafts and coronary artery. An attempt at functional classification. J Thorac Cardiovasc Surg 109: 707-715.

22. Kiemeneij F, Vajifdar BU, Eccleshall SC, Laarman G, Slagboom T, et al. (2003) Evaluation of a spasmolytic cocktail to prevent radial artery spasm during coronary procedures. Catheter Cardiovasc Interv 58: 281-284.

23. Coppola J, Patel T, Kwan T, Sanghvi K, Srivastava S, et al. (2006) Nitroglycerin, nitroprusside, or both, in preventing radial artery spasm during transradial artery catheterization. J Invasive Cardiol 18: 155-158.

24. Dandekar VK, Vidovich MI, Shroff AR (2012) Complications of transradial catheterization. Cardiovasc Revasc Med 13: 39-50.

25. Ruiz-Salmerón RJ, Mora R, Masotti M, Betriu A (2005) Assessment of the efficacy of phentolamine to prevent radial artery spasm during cardiac catheterization procedures: a randomized study comparing phentolamine vs. verapamil. Catheter Cardiovasc Interv 66:192-198.

26. Chen CW, Lin CL, Lin TK, Lin CD (2006) A simple and effective regimen for prevention of radial artery spasm during coronary catheterization. Cardiology 105: 43-47.

27. Kim SH, Kim EJ, Cheon WS, Kim MK, Park WJ, et al. (2007) Comparative study of nicorandil and a spasmolytic cocktail in preventing radial artery spasm during transradial coronary angiography. Int J Cardiol 120: 325-330.

28. Saito S, Tanaka S, Hiroe Y, Miyashita Y, Takahashi S, et al. (2002) Usefulness of hydrophilic coating on arterial sheath introducer in transradial coronary intervention. Catheter Cardiovasc Interv 56: 328-332.

29. Dery JP, Simard S, Barbeau GR (2001) Reduction of discomfort at sheath removal during transradial coronary procedures with the use of a hydrophilic-coated sheath. Catheter Cardiovasc Interv 54: 289-294.

30. Koga S, Ikeda S, Futagawa K, Sonoda K, Yoshitake T, et al. (2004) The use of a hydrophilic-coated catheter during transradial cardiac catheterization is associated with a low incidence of radial artery spasm. Int J Cardiol 96: 255-258.

31. Pullakhandam NS, Yang ZJ, Thomas S, Wasenko J (2006) Unusual complication of transradial catheterization. Anesth Analg 103: 794-795.

32. Eltahway EA, Cooper CJ (2010) Managing radial access vascular complications. Card Interv Today 46-49.

33. Dieter RS, Akef A, Wolff M (2003) Eversion endarterectomy complicating radial artery access for left heart catheterization. Catheter Cardiovasc Interv 58: 478-480.

34. Stella PR, Kiemeneij F, Laarman GJ, Odekerken D, Slagboom T, et al. (1997) Incidence and outcome of radial artery occlusion following transradial artery coronary angioplasty. Cathet Cardiovasc Diagn 40: 156-158.

35. Chatelain P, Arceo A, Rombaut E, Verin V, Urban P (1997) New device for compression of the radial artery after diagnostic and interventional cardiac procedures. Cathet Cardiovasc Diagn 40: 297-300.

36. Saito S, Miyake S, Hosokawa G, Tanaka S, Kawamitsu K, et al. (1999) Transradial coronary intervention in Japanese patients. Catheter Cardiovasc Interv 46: 37-41.

37. Yokoyama N, Takeshita S, Ochiai M, Koyama Y, Hoshino S, et al. (2000) Anatomic variations of the radial artery in patients undergoing transradial coronary intervention. Catheter Cardiovasc Interv 49: 357-362.

38. Barbeau GR, Arsenault F, Dugas L, Simard S, Larivière MM (2004) Evaluation of the ulnopalmar arterial arches with pulse oximetry and plethysmography: comparison with the Allen's test in 1010 patients. Am Heart J 147: 489-493.

39. Greenwood MJ, Della-Siega AJ, Fretz EB, Kinloch D, Klinke P, et al. (2005) Vascular communications of the hand in patients being considered for transradial coronary angiography: is the Allen's test accurate? J Am Coll Cardiol 46: 2013-2017.

40. Rhyne D, Mann T (2010) Hand ischemia resulting from a transradial intervention: successful management with radial artery angioplasty. Catheter Cardiovasc Interv 76: 383-386.

41. Pancholy SB (2007) Transradial access in an occluded radial artery: new technique. J Invasive Cardiol 19: 541-544.

42. Spaulding C, Lefèvre T, Funck F, Thébault B, Chauveau M, et al. (1996) Left radial approach for coronary angiography: results of a prospective study. Cathet Cardiovasc Diagn 39: 365-370.

43. Pancholy SB (2009) Comparison of the effect of intra-arterial versus intravenous heparin on radial artery occlusion after transradial catheterization. Am J Cardiol 104: 1083-1085.

44. Plante S, Cantor WJ, Goldman L, Miner S, Quesnelle A, et al. (2010) Comparison of bivalirudin versus heparin on radial artery occlusion after transradial catheterization. Catheter Cardiovasc Interv 76: 654-658.

45. Saito S, Ikei H, Hosokawa G, Tanaka S (1999) Influence of the ratio between radial artery inner diameter and sheath outer diameter on radial artery flow after transradial coronary intervention. Catheter Cardiovasc Interv 46: 173-178.

46. Pancholy S, Coppola J, Patel T, Roke-Thomas M (2008) Prevention of radial artery occlusion-patent hemostasis evaluation trial (PROPHET study): a randomized comparison of traditional versus patency documented hemostasis after transradial catheterization. Catheter Cardiovasc Interv 72: 335-340.

47. Zankl AR, Andrassy M, Volz C, Ivandic B, Krumsdorf U, et al. (2010) Radial artery thrombosis following transradial coronary angiography: incidence and rationale for treatment of symptomatic patients with low-molecular-weight heparins. Clin Res Cardiol 99: 841-847.

48. Bernat I, Bertrand OF, Rokyta R, Kacer M, Pesek J, et al. (2011) Efficacy and safety of transient ulnar artery compression to recanalize acute radial artery occlusion after transradial catheterization. Am J Cardiol 107: 1698-1701.

49. Verheugt FW, Steinhubl SR, Hamon M, Darius H, Steg PG, et al. (2011) Incidence, prognostic impact, and influence of antithrombotic therapy on access and nonaccess site bleeding in percutaneous coronary intervention. JACC Cardiovasc Interv 4: 191-197.

50. Bertrand OF (2010) Acute forearm muscle swelling post transradial catheterization and compartment syndrome: prevention is better than treatment! Catheter Cardiovasc Interv 75: 366-368.

51. Calviño-Santos RA, Vázquez-Rodríguez JM, Salgado-Fernández J, Vázquez-González N, Pérez-Fernández R, et al. (2004) Management of iatrogenic radial artery perforation. Catheter Cardiovasc Interv 61: 74-78.

52. Pyne C, Mann T (2010) Overcoming anatomic challenges to transradial access. Cardiac Interventions Today 38: 40.

53. Gunasekaran S, Cherukupalli R (2009) Radial artery perforation and its management during PCI. J Invasive Cardiol 21: E24-E6.

54. Rigatelli G, Dell'Avvocata F, Ronco F, Doganov A (2009) Successful coronary angioplasty via the radial approach after sealing a radial perforation. JACC Cardiovasc Interv 2: 1158-1159.

55. Tizón-Marcos H, Barbeau GR (2008) Incidence of compartment syndrome of the arm in a large series of transradial approach for coronary procedures. J Interv Cardiol 21: 380-384.

56. Lipschitz AH, lifehez SD (2010) Measurement of compartment pressures in the hand and forearm. The Journal of Hand Surgery 35: 1893-1894.

57. Sanmartín M, Cuevas D, Goicolea J, Ruiz-Salmerón R, Gómez M, et al. (2004) Vascular complications associated with radial artery access for cardiac catheterization. Rev Esp Cardiol 57: 581-584.

58. Zellner C, Yeghiazarians Y, Ports TA, Ursell P, Boyle AJ (2011) Sterile radial artery granuloma after transradial cardiac catheterization. Cardiovasc Revasc Med 12: 187-189.

59. Papadimos TJ, Hofmann JP (2002) Radial artery thrombosis, palmar arch systolic blood velocities, and chronic regional pain syndrome 1 following transradial cardiac catheterization. Catheter Cardiovasc Interv 57: 537-540.