Journal of Anesthesia & Clinical Research

Abdelaal et al., J Anesth Clin Res 2012, 3:6
DOI: 10.4172/2155-6148.1000217

Review Article Open Access

Radial Artery Cannulation for Diagnostic Coronary Angiography and Interventions: Historic Perspective, Overview, and State of the Art

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Abstract

Due to its superior safety and virtual elimination of access site complications, trans-radial access to cardiac catheterization and interventions is gaining popularity worldwide. Several types of puncture equipment and introducer sheaths are available for radial puncture, and their use depends on availability and local practice patterns. Pharmacological agents are routinely used in conjunction with this approach to minimize radial spasm, thrombosis, and subsequent occlusion. Today, practically any coronary intervention can be performed safely and effectively via trans-radial route.

Radial artery occlusion following trans-radial cardiac catheterization is relatively uncommon, and although usually silent, it should be avoided at all cost as it limits future radial access. Its pathophysiology is multifactorial and involves interaction of several factors such as local trauma, associated with local thrombus formation, and leading to occlusion over a variable time scale, with a percentage of spontaneous re-canalization. Patients with diabetes, vascular disease, low body weight, and those undergoing repeat procedures are at risk. It can be avoided by appropriately selecting patients suitable for this technique, use of heparin anticoagulation, and appropriately sized sheaths. Of crucial importance is the prompt removal of the radial arterial sheath following the procedure and implementation of patent hemostasis technique.

Keywords: Radial artery; Catheterization; Cannulation; Occlusion

Historic Overview of Cardiac Catheterization

The advent, development and refinement of invasive cardiac catheterization and related catheter-based interventions, indisputably represents one of the greatest achievements in the field of cardiovascular medicine in the past century [1]. The term cardiac catheterization was coined in 1844 by the French physiologist Claude Bernard, whose animal work formed the basis for invasive recording of cardiac hemodynamics in humans [2].

The first catheterization of a human heart was performed in 1929 by Werner Forssmann, who, undeterred from pursuing his experiments, succeeded in inserting a ureteral catheter through a cut down into his own left antecubital vein, documented catheter position in his right atrium with a Chest X-Ray, and made medical history. In return, hospital officials fired him for his "unconventional work"; however, he went on to share the Noble Prize in medicine with other pioneers of invasive cardiology, Cournand and Richards, in 1956 [3].

During the 1940's right heart catheterization was unraveled, and Seldinger technique, developed in 1953, became widely adopted for both left and right heart catheterization [4]. In late 1950's the time was suitable for unlocking left heart catheterization, and in stepped another genius, Dr. F. Mason Sones. He inadvertently performed a selective injection of contrast media into the right coronary artery of a middle-aged male whilst performing an aortography, and introduced a new era in cardiovascular medicine that was to transform our understanding of management of cardiac patient for the remainder of the twentieth century [1, 5].

The concept of arterial remodeling by angioplasty was introduced by Frank Dotter and Judkins in 1964 [6]. Ten years later, Andreas Gruentzig performed the first human peripheral angioplasty, and later presented the results of his animal studies of coronary angioplasty at the American Heart Association meeting in 1976 [1]. In 1977, he performed the first human coronary angioplasty intra-operatively in San Francisco, and in the same year performed the first catheter-lab-based angioplasty in a conscious patient in Zurich [7].

During the years to follow, this field continued to expand rapidly into diagnostic and therapeutic procedures, aided by the perseverance of pioneers and innovations in the fields of materials science and miniaturization of equipment. Between 1994 and 1997 coronary stents became a commonplace, and today percutaneous coronary intervention (PCI) is the most commonly performed cardiac intervention worldwide. Cardiac catheterization played an integral part in the development of newer technology, and is now used to regularly introduce newer intracoronary devices such as pressure wires, intravascular ultrasound, optical coherence tomography (OCT), eluting catheters etc., for diagnostic as well as therapeutic purposes.

This article aims to give a brief overview of the advantages of radial access, anatomical considerations, technical aspects of radial puncture and related pharmacology, hemostasis, and some of the radial artery occlusion avoidance strategies. This manuscript does not describe cardiac catheterization technique, and extra-cardiac interventions performed via radial route.

Evolution of access sites for cardiac catheterization

Since its first introduction, access sites for left heart catheterization have undergone significant evolution and refinement. Known as "Sones-arteritomy", brachial arterial access via surgical cut down was used

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Received February 08, 2012; **Accepted** June 08, 2012; **Published** June 18, 2012

Citation: Abdelaal E, MacHaalany J, Bataille Y, Bertrand OF (2012) Radial Artery Cannulation for Diagnostic Coronary Angiography and Interventions: Historic Perspective, Overview, and State of the Art. J Anesth Clin Res 3:217. doi:10.4172/2155-6148.1000217

by early operators, but soon overtaken by the simpler percutaneous femoral approach (TFA). However, due to its neurovascular anatomical relations, TFA for cardiac procedures is associated with several important access site complications, which range from 3-5%, and include bleeding, superficial or retroperitoneal hematomas, pseudo aneurysms and arterio-venous fistulae. These can have a detrimental impact on patient outcomes, and inevitably delay ambulation, may prolong hospitalization, and increase procedural cost.

In 1989, the French-Canadian physician, Dr. Lucien Campeau, introduced the radial approach (TRA) for diagnostic coronary angiography using 5-F catheters [8], and by 1992, Dr. Ferdinand Kiemeneij had already started performing coronary intervention procedures via TRA using 6-F guiding catheters [9].

Being relatively superficial and easily compressible, the radial artery lends itself as a much safer approach to cardiac catheterization when compared to the femoral artery. Several randomized trials and meta-analyses have consistently shown lower risk of bleeding and vascular complications with the TRA compared to TFA, making it safer and more cost-effective [10-12]. The MORTAL study demonstrated that TRA for PCI was associated with less transfusion requirement, a finding that correlated with better survival in the TRA PCI group compared to conventional TFA PCI in all comers [13].

Peri-procedural major bleeding is a known powerful independent predictor of mortality and ischaemic outcomes after PCI, particularly in the setting of invasive management of acute coronary syndrome (ACS) [14-16]. By virtually abolishing access site bleeding, benefit of TRA is particularly evident in the setting of heavy anticoagulation, such as ST-elevation myocardial infarction (STEMI), and a recent meta-analysis demonstrated significant reduction in major access site complications and mortality benefit with TRA for STEMI PCI [17]. Safety of TRA is particularly apparent in certain patient subsets, including the elderly, females, and those who are restless, as it allows quicker mobilization and obviates the need for prolonged recumbence.

Given its consistent safety and superiority over femoral, the TRA to coronary catheterization and intervention continues to grow in popularity, and is increasingly adopted as the default access in large parts of Europe and Asia, where its uptake has reached up to 30-40%. Despite the evidence, its penetration in the US has remained in single figures, perhaps for a variety of reasons, including the relatively few number of interventional cardiologists who are trained in using the radial approach, although this is now changing. As a testimony of this recent growing interest and better recognition of better risk-benefit ratio compared to standard femoral approach, radial access is now a class IIa recommendation in the ACC/AHA/SCAI guidelines for PCI [18].

Anatomy of radial artery and palmar arches

The brachial artery bifurcates at the level of the cubital fossa into the radial and ulnar arteries, and these in turn form the arterial blood supply to the forearm and hand. At its origin, the radial artery lies medial to the biceps tendon, and continues its course toward the styloid process of the radius, mainly as an arterial conduit to the hand [19]. Anatomical variations of its origin can be found in up to a third of individuals [20,21], although these are far less common in the distal forearm where the radial artery lies superficially along the styloid process [20]. Again, the ulnar artery originates medial to the biceps tendon in the cubital fossa, and is usually larger in diameter at its origin compared to the radial artery [19]. However, as it gives rise to multiple branches in the forearm, including the anterior interosseous, the posterior interosseous, and (occasionally) the median artery [22], this difference in diameter tends to diminish by the time the ulnar reaches the lateral side of the pisiform bone at the level of the wrist [23].

At the level of the hand, the radial and ulnar arteries join to form an intricate and fascinating anastomotic network of four arches, which provide the blood supply to the hand. Three of these arches exist on the palmar aspect of the hand, namely the superficial palmar, the deep palmar, and the palmar carpal arches. The arterial network on the dorsal aspect of the hand is termed the dorsal palmar rete. The terminal branch of the radial artery forms the deep palmar arch[19,24]. Conversely, the terminal branch of the ulnar artery predominantly forms the superficial palmar arch[19,24]. At the wrist, a superficial branch arises from the radial artery, and continues to contribute to the superficial palmar arch [25]. The radial artery then crosses dorsally deep to the tendons of the “anatomic snuffbox”, entering the palm to form the deep palmar arch through its terminal branch. The ulnar artery enters the hand through the Guyon canal, where it divides into terminal superficial palmar branch, which forms the superficial palmar arch, and a deep palmar branch that contributes to the deep palmar arch.

The deep palmar arch gives rise to 3 or 4 palmar metacarpal arteries [26], and conversely, the superficial, to the digital arteries [27]. Considerable variability in the anatomy of the palmar arches has been described in the literature, together with variants of origin and or course of the radial artery. This was summarized in a comprehensive review by Brzezinski et al. [28].

While anatomical variations related to the origin of radial artery were reported in up to a third individuals in earlier studies [20,21], more recently Lo et al. [29], demonstrated radial anomalies in 13.8% of the 1540 patients in their study who underwent retrograde radial arteriography during first TRA procedure. The commonest of these is often a high bifurcation level of the radial artery arising in the upper arm, and usually causes no procedural hindrance, unless spasm occurs. The more challenging, but rarer, vascular tortuosity is a significant cause of procedural failure [29].

The radial artery diameter is approximately 2.45-3mm in diameter at the wrist in the majority of individuals, and can therefore accommodate 6-french catheters or larger. In a small proportion of individuals (particularly females, the elderly, and diabetics) it tends to be smaller in caliber [30], however this does not necessarily preclude its use for cardiac procedures, since non-complex interventions could be performed with smaller catheters nowadays.

Radial arterial puncture for cardiac catheterization

Patient preparation and positioning: With the patient supine on the cardiac catheter laboratory table, the right (or left) arm is maintained in the neutral position and extended beside the patient on a “radial board” with the palm facing the ceiling, and the wrist exposed. Hyperextension of the wrist to 30 degrees is highly desirable to facilitate radial cannulation. This is achieved simply by placing a rolled-up towel under the wrist.

After usual skin preparation (e.g. with 4% chlorhexidine gluconate, or iodine), the right arm is suitably draped with the distal end of the forearm exposed for puncture.

The operator could either be sitting or standing to perform radial puncture and this is a matter of personal preference. The height of the catheter laboratory table can easily be lowered to suitable level if the operator is in the sitting position for the radial puncture, or conversely elevated if he/she was standing to avoid leaning forward to obtain puncture. Since this is a small artery, it is important that the operator places himself/herself in a comfortable position before puncturing the artery. Equally, making the patient relaxed and comfortable is important to prevent radial artery spasm.

Radial puncture kit and technique: Slight variation exists in the technique and equipment used for radial puncture in the cardiac catheter laboratory, but predominantly either trans-fixation (through-and-through or double-wall stick) with angiocath needle, or bare needle (single-wall stick) method is used.

Through-and-through technique uses a 21-gauge Teflon introducer. The radial artery is punctured at the site of maximal pulse, usually between 3-6 cm cm above the wrist skin crease (or 1-2 finger breadths above styloid process), with the needle at 30-45 degree angle to skin at puncture site. Once a flashback is obtained in the transparent chamber of the Teflon introducer marking entry into the radial artery, the needle and plastic sheath is gently advanced forward through the radial artery posterior wall. The metal needle or stylet is then removed, and the guide wire placed at the hub of the cannula. The plastic introducer is then slowly withdrawn parallel to the skin until it is luminal, and pulsatile flashback is obtained. The introducer wire is then gently inserted into the radial artery lumen, and cannula removed. As the advancement of the guide wire is based on tactile feedback, it is prudent to ensure painless advancement without any resistance, to ensure luminal position. If any resistance is encountered the operator then fluoroscopically attempts to advance the wire ensuring no radial loop or side branch wire entry at the level of the forearm or elbow. If doubt still exists, radial angiogram is performed with hand-injected contrast to delineate anatomy, and proceed further. Once wire successfully advanced, a small incision (2-3 mm) is made at the puncture site with a dedicated small blade, or size-11 blade, to facilitate sheath insertion through the skin. Depending on the case and operator's choice, either a 4-F, 5-F, or 6-F assembled sheath (sheath and dilator) is inserted over the wire into the radial artery, in a rotational manner to minimize trauma and spasm. The dilator is then removed, and blood aspirated from the side arm, before injecting the spasmolytic cocktail.

The bare-needle single-wall stick method utilizes the same concept, with the only difference being that only the anterior wall of the radial artery is traversed, and wire introduced through needle once good pulsatile flow is obtained. This method is essentially identical to the Seldinger technique as applied for the femoral artery puncture.

Guide-wire: Both methods utilize over-the-wire Seldinger technique, and a variety of guide-wires are available for this purpose, depending on the specific kit used (Table 1). Some of the newer kits offer a 21-Gauge micro-needle, with a matching 0.021" nitinol floppy palladium-tipped wire, with a hydrophilic-coated introducer sheath (Terumo Medical). Others offer a 21-Gauge micro-needle, with a 0.018" floppy guide-wire in their kit (Arrow International trans-radial access kit). The AVANTI trans-radial access kit, available from Cordis (Cordis Corporation), comes with an AVANTI sheath introducer with 3-way stopcock, a vessel dilator, a 0.021" mini-guidewire, and a 21-G needle. The 11 cm long sheath is available in 4-7F sizes, and the 23 cm long in 4-6F sizes.

Guide-wires are either hydrophilic-coated or non-hydrophilic. The advantage of hydrophilic wires also plays in the hand of their slight disadvantage, in that whilst they are slippery and aid negotiation of radial tortuosity and are useful in calcified vessels, they exhibit a somewhat higher risk of causing localized arterial dissection, and higher risk of small branch perforation in the forearm, especially in the early phase of operator learning curve, although in practical terms this is less of an issue.

The micro wire theoretically offers atraumatic access and simultaneous good support. It remains highly debated, however, whether micro-puncture radial kits offer significant advantages, compared to standard materials. In our institution where transradial approach has been the default technique for almost 20 years, operators still use either a 19G bare needle or 21G cathlon needle with a short 0.035 wire as an introducing wire. This mandates the use of 0.035" compatible sheaths but has the advantages of avoiding the need to stock different sheaths on the shelves. Indeed, in the very rare instances of impossibility to use radial or ulnar arteries as access site, the operator may shift to the femoral artery without using different materials. Furthermore, in case of upsizing sheath for ad hoc procedures for example, exchange over standard long (0.035" in diameter) wire is straightforward.

Pharmacology for Trans-Radial Cardiac Catheterization

The two main objectives of using pharmacological agents in conjugation with trans-radial cardiac catheterization are to prevent radial vasospasm and thrombotic occlusion.

Company	Product	Coaxial sheath diameter (Fr)	Sheath length (cm)	Needle Gauge	Wire		
					Characteristics	Length (cm)	Diameter (inch)
Terumo Medical	GuideAccess system Hydrophilic coated	4-5 F		21 (echogenic or non-echogenic	Platinum-tipped Nitinol or stainless steal	40	0.018
Cordis Corporation	AVANTI + Access kit	4-7 (11cm), or 4-6 F (23cm)	11 or 23	21			0.021
Cordis Corporation	RadialSource transradial Access kit	5-6 F	10		Polymer-coated (P) or Spring wire (S)		P=0.014
Arrow international distributed by Teleflex Medical	Radio-opaque polyurethane sheath (either ETFE thin-wall or hydrophilic coated	4-5 F	11 (also 24 cm in 6-F)	21	Floppy to super floppy Nitinol core wire	45	0.018
Vascular Solutions	VSI Radial MicroHV introducer Kit Siliconized sheath coating	5-7 Fr	12	21	Nitinol Mandrel guidewire with floppy Gold-AD or Platinum wire coil tip	45	0.018
Merit Medical (distributed by Inter V medical)	Prelude Mini access sheath introducers	4-6Fr	4-11	21	Nitinol Wire with Platinum tip	40	0.018

Table 1: Examples of available Trans-radial access kits.

Prevention of radial spam

The radial artery is a conduit muscular vessel, with a dense and dominant supply of alpha-1 adrenoceptors to its smooth muscle cells [31]. Circulating catecholamines as well as mechanical stimulation evoke these receptors, resulting in vasospasm, which can both cause significant discomfort to patients, and considerably impede the ability to manipulate coronary catheter. Therefore, prevention of radial spasm is a key to successful trans-radial cardiac catheterization. The incidence of radial spasm was estimated to be between 2-5% in some studies [32]. The true incidence, however, remains difficult to assess given the lack of uniform definition of radial spasm. As discussed, it is crucial to ensure patient's comfort and relaxation, and a warm pleasant environment, to dampen any sympathetic overdrive. Occasionally, in very anxious individuals, it might be necessary to administer a small intravenous dose of a benzodiazepine (e.g. Midazolam) as an anxiolytic, or an opiate (eg. Fentanyl) as an analgesic, to reduce incidence of radial spasm. In the rare event of serious radial spasm entrapping sheath and/or catheter, it might be required to use general anesthesia and sympathetic block to relieve extreme spasm,

Local anesthetic: In the cardiac catheter laboratory, a local injection of 2-4 ml of 1-2% lignocaine is infiltrated subcutaneously over the intended area of radial puncture. In some laboratories, including our own, 3-5 ml of a 50-50 mix of lignocaine 1-2% with nitro-glycerin is often used to infiltrate over the radial puncture site with great success. This has the added benefit of spasmolytic effect of nitroglycerin, and facilitates radial arterial puncture [33,34].

Spasmolytic cocktails: Without the use of spasmolytic agents, radial artery spasm often ensues after radial puncture, and is associated with significant pain in a majority of subjects. Kiemeneij et al. [35], elegantly demonstrated this in the early days of trans-radial cardiac catheterization. Using an automatic pullback device, he and his colleagues demonstrated that radial artery spasm inducing pain was associated with a traction force greater than 1 Kg. He went on to demonstrate in a subsequent study that intra-radial injection of a spasmolytic cocktail of verapamil 5mg plus 200 mcg of nitrate significantly reduces the incidence and severity of radial spasm [36]. Prior to this, He et al. [37], also demonstrated the effectiveness of this combination in providing a rapid, and long-lasting relaxation of the radial artery harvest for bypass grafting. In a randomized trial of 1,219 patients, Varenne et al. [38], demonstrated that radial spasm was effectively eliminated by the administration of vasodilators, and the combination of verapamil 2.5 mg and molsidomine 1mg was the strongest in achieving this, compared to placebo.

In today's practice, either verapamil alone at a dose of 2.5-5 mg, or in combination with 100-200 mcg of nitroglycerine (cocktail) is injected intra-radially through the side arm of the sheath, prior to catheterization, to prevent radial spasm. To minimize the local hotness experienced by patients upon injection, this is often diluted with saline, in a 10 ml syringe, injected slowly, and diluted further by blood withdrawn from the side arm of the radial sheath. A recent study showed no additional benefit by adding intra-arterial lidocaine to reduce pain during administration of vasodilator cocktails [39]. Indeed, the transient burning feeling is caused by the acidic pH of verapamil, and it is more useful to simply warn the patient, administer slowly the medication using blood aspirate as a buffer.

Hydrophilic coated introducer sheaths: Radial artery spasm is one of the commonest complications of trans-radial approach to cardiac catheterization, causing both patient discomfort and reducing procedural success [36,40,41].

A number of studies have shown that the use of introducer sheath and catheters with hydrophilic coating significantly reduces the incidence of radial artery spasm, and optimizes patient's comfort during catheter manipulation [32,42-44].

Prevention of radial artery thrombotic occlusion (RAO)

Anticoagulation per se and timing: For the purpose of cardiac catheterization, once the radial puncture has been successfully performed, and after sheath insertion, unfractionated heparin is administered intravenously at a dose of 5,000 units for diagnostic procedures, for it has been shown to greatly reduce the incidence of thrombotic radial artery occlusion (RAO) associated with radial artery cannulation [45].

Dosing of heparin: As described by Lefevre and co-workers in the original report of the role of heparin in TRA, the effect of heparin in prevention of RAO appears to be dose dependent, with a substantial reduction in the incidence of RAO by increasing the dose of heparin from 2,000 to 3,000 and further to 5,000 IU [45]. This has been substantiated further in a recent study of the incidence and predictors of RAO in a large of cohort of >7,000 patients who underwent TRA coronary intervention [46]. In a more recent study, Bernat et al. compared the incidence of RAO with single intravenous heparin bolus of 2,000 IU vs. 5,000 IU [47]. Using patent hemostasis, he and colleagues demonstrated that immediate post-hemostasis RAO rate was higher in the 2,000 IU group compared to the 5,000 IU group (5.9% vs. 2.9%, P 0.17). The authors also described a non-pharmacological technique of 1-hour ulnar compression to treat RAO, with again higher efficacy with higher heparin dose (final incidence of RAO was 4.1% in the 2,000-IU group, vs. 0.8% in the 5,000-IU group, p=0.03). Thus, it seems prudent to recommend a minimal fixed dose of 5,000 IU or 70 IU/kg heparin after radial sheath insertion, even for simple diagnostic angiography.

The role of new anticoagulants, such as bivalirudin, a direct thrombin inhibitor, in conjunction with radial access remains to be discussed. Indeed, considering its higher price, it cannot be envisaged that bivalirudin be used in replacement of heparin for diagnostic angiography only. Plante et al. performed a randomized study comparing a single 70U/kg heparin bolus administered at the completion of the diagnostic angiography to bivalirudin administration in case of ad-hoc PCI [48]. Overall, the incidence of RAO at 30 days in the heparin-only group was 7% compared with 3.5% in the bivalirudin-only group. Although numerically lower in the bivalirudin group, the difference did not reach statistical significance (p=0.18). It should be emphasized that the incidence of RAO remained quite high in both groups, perhaps due to the fact that the authors did not use patent-hemostasis and used a classic compressive bracelet to obtain hemostasis. At this point, it seems that the incidence of RAO is independent of the type of anticoagulant [48,49]. Conversely, given the low risk of access-site related bleeding, some authors have advocated the initiation of the diagnostic procedure with a reduced heparin bolus and simply complementing with bivalirudin in case of ad-hoc PCI [49,50]. The time to obtain hemostasis after radial sheath removal is also independent of the type of intravenous anticoagulant. It should be emphasized though that patients on Coumadin derivatives still require intravenous anticoagulant therapy after radial sheath insertion to prevent RAO.

Route of administration: Although the original report on the beneficial effect of heparin for prevention of RAO used the intravenous route of administration, some units administer heparin intra-radially together with the spasmolytic cocktail. However, a recent study demonstrated that intravenous heparin is equivalent to intra-arterial heparin in reducing the incidence of RAO, suggesting the systemic rather than local effect of heparin is the most important factor[51]. As such, and given its acidity that causes patients to experience local burning sensation in the hand when given intra-arterially (similar to verapamil administration), heparin is routinely administered intravenously in our unit.

Radial Artery Occlusion

Predictors and prevention

Radial artery occlusion (RAO) is one of the few complications of trans-radial catheterization, and although usually clinically silent in appropriately selected patients, it limits future TRA. The course is usually benign and, although remains controversial, does not result in digital ischemia, due to the protective dual blood supply to the hand. There have been a few reports of distal ischemia post-TRA catheterization but it remains unknown whether this was due to radial artery occlusion in patients with inadequate collateralization, or the result of distal embolization. In critically ill patients with prolonged cannulation of the radial artery in intensive care units, there have been some reports of distal ischemia and digital or skin necrosis.

A number of variables predict occurrence of radial occlusion (Table 2). As summarized above, anticoagulation with heparin following radial puncture is paramount to prevent thrombotic radial occlusion [45]. Occlusion is also directly related to the size of the introducer sheath and relates to the ratio of the arterial diameter compared to the sheath as demonstrated by Saito et al. [52]. He reported the incidence of RAO to be 4% in patients with a radial artery internal diameter greater than the outer diameter of the sheath (ratio >1), vs. 13% in those with an outer sheath diameter greater than the inner diameter of radial artery (ratio < 1). In addition, and as demonstrated in the Japanese experience, the incidence of RAO was higher with successive cannulations, probably due to narrowing directly related to multiple punctures [53].

Occlusive hold vs. patent hemostasis

Despite the use of heparin during cardiac catheterization, RAO was noted in 7-10%, presumably related to occlusive pressure applied post-procedurally for hemostasis, and local thrombus formation as the initial catalyst for early occlusion. Sanmartin et al. has recently demonstrated in a prospective observational study of 275 patients who underwent trans-radial catheterization, that flow limiting or occlusive compression of the radial puncture site is a strong and independent predictor of RAO at follow-up [54].

Pancholy reported the finding of an occlusive "plug" successfully retrieved from 5 of 12 re-accessed radial arteries, which had been occluded for less than 4 weeks. Histopathological examination of retrieved material confirmed this to be an organizing thrombus, with signs of neovascular micro-channel formation [55]. Therefore, it is reasonable to assume thrombus formation as a mechanistic process for early radial occlusion.

In view of these observations, Pancholy, et al randomized 436 patients undergoing elective cardiac catheterization to patent hemostasis vs. conventional compression for hemostasis to determine its effect on incidence of radial occlusion (PROPHET Study) [56]. Dual hand circulation and patency of the palmar arch was confirmed at baseline using a Barbeau's test. Following successful trans-radial cardiac catheterization, 219 patients were randomized to conventional compression for hemostasis, and 218 to patent hemostasis (compression of radial artery with documented patency). Briefly, in the patent hemostasis group, once Hemoband™ plastic band was applied following sheath removal, and with a pulse oximeter placed over the index finger, manual ipsilateral ulnar occlusion was performed, and the hemoband was loosened until radial patency was confirmed with the return of plethysmographic signal, or until bleeding occurred. The hemoband was left on for 2 hours, with hourly checks on patency. In he conventional compression group, the hemoband was applied as usual following sheath removal, and those who had flow-limiting compression (confirmed using a Barbeau's test) were recorded to have "occlusive hold".

At 24-hour follow-up, 27 patients (12%) in the occlusive hold group developed plethysmographic evidence of radial occlusion, compared with 11 patients (5%) in the patent hemostasis group (59% reduction in occlusion, $p < 0.05$). At 30-day follow-up, the incidence was 7% vs.

Factors		*Comments*	*Reference*
Patient-related	DM	DM predisposes to RAO as shown in a large study of predictors of RAO, using a regression model	46. Zhou YJ, Zhao YX, Cao Z et al. Zhonghua Yi Xue Za Zhi 2007; 87: 1531-4.
	Female gender	RAO is more frequent in females as shown in a large study of predictors of RAO, using a regression model	46. Zhou YJ, Zhao YX, Cao Z et al. Zhonghua Yi Xue Za Zhi 2007; 87: 1531-4.
	Low BMI	Low body weight patients are at significantly higher risk of RAO	51. Pancholy SB. Am J Cardiol 2009; 104: 1083-5.
Procedural-related	Anticoagulation	Heparin was shown to be crucial in reducing incidence of RAO, with a dose-dependent beneficial effect. No difference in magnitude of effect between IV and IA route of administration	45. Lefevre T, Thebault B, Spaulding C et al. Eur Heart J 1995; 16: 293. 46. Zhou YJ, Zhao YX, Cao Z et al. Zhonghua Yi Xue Za Zhi 2007; 87: 1531-4
	Size of sheath and catheters	Ratio of sheath outer diameter to inner diameter of radial artery is indirectly proportionate to incidence of RAO. The bigger lower the ration (i.e. the bigger the sheath), the higher the incidence of RAO.	46. Zhou YJ, Zhao YX, Cao Z et al. Zhonghua Yi Xue Za Zhi 2007; 87: 1531-4 52. Saito S, Ikei H, Hosokawa G, Tanaka S. Catheter Cardiovasc Interv 1999; 46: 173-8
	Successive cannulation	Incidence of TRA dropouts increases as successive punctures were performed due to narrowing and occlusion of the radial artery, probably as a function of repeated punctures	53. Sakai H, Ikeda S, Harada T et al. Catheter Cardiovasc Interv 2001; 54: 204-8.
	Occlusive hemostasis	Use of occlusive hemostasis, and duration of radial artery compression post-procedure is an independent predictor of RAO. Patent hemostasis reduces incidence of RAO.	46. Zhou YJ, Zhao YX, Cao Z et al. Zhonghua Yi Xue Za Zhi 2007; 87: 1531-4. 51. Pancholy SB. Am J Cardiol 2009; 104: 1083-5.

Table 2: Predisposing factors to Radial Artery Occlusion.

1.8% respectively (with 75% reduction in radial occlusion with the patent hemostasis, p<0.05). The lower incidence at 30 days indicates spontaneous recanalization of some occlusions.

This study showed that patent hemostasis is highly effective in reducing the incidence of RAO after trans-radial catheterization, without compromise to hemostasis, and should therefore be adopted as routine to minimize incidence of RAO.

Sheathless Guiding Catheters & Bilateral Radial Access for Chronic Total Occlusions (CTO)

In today's practice, the majority of trans-radial interventions are performed using 5F or 6-F catheters [57]. It has previously been shown that most patients have an internal radial artery diameter, which is larger than the 2.52 mm external diameter of the 6F introducer sheath. Historically, the only limitation for trans-radial access had been inability to use large (7-F or 8-F guiding catheters), but with miniaturization of equipment, in today's practice virtually any intervention can be performed through 6-F catheters.. Still 31.7% of men and 59.5% of women have a smaller radial artery diameter than the outer diameter of 6Fr sheath (smaller than 2.52mm), as demonstrated in a cohort of 1191 Korean patients, using 2-dimentional ultrasound measurement of radial artery before and after transradial procedures [30].

More recently, the advent of sheathless guiding catheters has added to the armamentarium available for radial access interventions. These have a hydrophilic coating, and negate the need for an introducer sheath. For the same size puncture, sheathless guides provide a larger internal diameter (2.06 mm for a 7.5-F), which is effectively smaller in outer diameter than a 6-F sheath, thus allowing for larger equipment to be introduced through this route for interventions.

Dedicated sheathless guiding catheters offer a very smooth transition between the dilator and the guiding catheter itself. As discussed, due to their design and larger inner diameter they offer the choice to operators to still use radial access for complex procedures even in patients with very small radial arteries. Although it has been postulated that the creation of a smaller radial artery hole and smooth transition with the guiding catheter would reduce the risks of RAO, this remains largely unproven.

Simultaneous bilateral radial arterial access can also be utilized when treating a chronic total occlusion (CTO) of a coronary artery, to allow for bilateral coronary injections, and retrograde approach to intervention through the contralateral coronary circulation via collaterals [58].

Acknowledgements

Dr. OF. Bertrand is a research-scholar of the Quebec Foundation for Health Research. Dr. E. Abdelaal is supported by the Laval University Radial Research & Education Fund.

Disclosures

This review was conducted with internal funds and did not receive external sources of funding. There is no conflict of interest to disclose.

References

1. Mueller RL, Sanborn TA (1995) The history of interventional cardiology: cardiac catheterization, angioplasty, and related interventions. Am heart j 129: 146-172.
2. Cournand A (1975) Cardiac catheterization; development of the technique, its contributions to experimental medicine, and its initial applications in man. Acta Med Scand Suppl 579: 3-32.
3. Liljestrand G. Le, prix Nobel en (1956). Stockholm: Nobel Foundation.
4. Seldinger SI (1953) Catheter replacement of the needle in percutaneous arteriography; a new technique. Acta radiol 39: 368-76.
5. Hurst J (1985) History of cardiac catheterization. In: King SB, Douglas J, eds. Coronary arteriography and angioplasty. McGraw-Hill:5-6.
6. Dotter CT, Judkins MP (1964) Transluminal Treatment of Arteriosclerotic Obstruction. Description of a New Technic and a Preliminary Report of Its Application. Circulation 30: 654-670.
7. Hurst JW (1986) The first coronary angioplasty as described by Andreas Gruentzig. Am j cardiol 57: 185-186.
8. Campeau L (1989) Percutaneous radial artery approach for coronary angiography. Cathet Cardiovasc Diagn 16: 3-7.
9. Kiemeneij F, Laarman GJ, de Melker E (1995) Transradial artery coronary angioplasty. Am Heart J 129: 1-7.
10. Mann T, Cowper PA, Peterson ED, Cubeddu G, Bowen J, et al. (2000) Transradial coronary stenting: comparison with femoral access closed with an arterial suture device. Catheter Cardiovasc Interv 49: 150-156.
11. Choussat R, Black A, Bossi I, Fajadet J, Marco J (2000) Vascular complications and clinical outcome after coronary angioplasty with platelet IIb/IIIa receptor blockade. Comparison of transradial vs transfemoral arterial access. Eur Heart J 21: 662-667.
12. 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.
13. Chase AJ, Fretz EB, Warburton WP, Klinke WP, Carere RG, et al. (2008) Association of the arterial access site at angioplasty with transfusion and mortality: the M.O.R.T.A.L study (Mortality benefit Of Reduced Transfusion after percutaneous coronary intervention via the Arm or Leg). Heart 94: 1019-1025.
14. Manoukian SV, Feit F, Mehran R, Voeltz MD, Ebrahimi R, et al. (2007) Impact of major bleeding on 30-day mortality and clinical outcomes in patients with acute coronary syndromes: an analysis from the ACUITY Trial. J Am Coll Cardiol 49: 1362-1368.
15. Bertrand OF, Larose E, Rodes-Cabau J, Gleeton O, Taillon I, et al. (2009) Incidence, predictors, and clinical impact of bleeding after transradial coronary stenting and maximal antiplatelet therapy. Am Heart J 157: 164-169.
16. Mehran R, Pocock SJ, Stone GW , Clayton TC, Dangas GD, et al. (2009) Associations of major bleeding and myocardial infarction with the incidence and timing of mortality in patients presenting with non-ST-elevation acute coronary syndromes: a risk model from the ACUITY trial. Eur heart J 30: 1457-1466.
17. Mamas MA, Ratib K, Routledge H, Fath-Ordoubadi F, Neyses L, et al. (2012) Influence of access site selection on PCI-related adverse events in patients with STEMI: meta-analysis of randomised controlled trials. Heart 98: 303-311.
18. Levine GN, Bates ER, Blankenship JC (2011) ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention: Executive Summary A Report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Society for Cardiovascular Angiography and Interventions. Journal of the American College of Cardiology 58: 2550-2583.
19. Johnson D, Ellis H (2005) Pectoral girdle and upper limb. In: Standring S, ed. Gray's Anatomy. New York: Elsevier Churchill Livingstone:799-942.
20. McCormack LJ, Cauldwell EW, Anson BJ (1953) Brachial and antebrachial arterial patterns; a study of 750 extremities. Surg Gynecol Obstet 96: 43-54.
21. Sargon M, Celik HH (1994) Proximal origins of radial and common interosseous arteries. Kaibogaku Zasshi 69: 406-409.
22. Sahin B, Seelig LL (2000) Arterial, neural and muscular variations in the upper limbs of a single cadaver. Surg radiol anat 22: 305-308.
23. Haerle M, Hafner HM, Dietz K, Schaller HE, Brunelli F (2003) Vascular dominance in the forearm. Plast Reconstr Surg 111: 1891-1898.
24. Moore KL, Dalley AF (1999) Upper Limb. Clinically oriented anatomy. 4 ed. Philadelphia: Lippincott Williams & Wilkins.
25. Bataineh ZM, Habbal O, Moqattash ST (2009) Variations in the superficial palmar arch of the hand. Ital J Anat Embryol 114: 11-20.
26. Edwards EA (1960) Organization of the small arteries of the hand and digits. Am J Surg 99: 837-846.

27. Al-Turk M, Metcalf WK (1984) A study of the superficial palmar arteries using the Doppler Ultrasonic Flowmeter. J Anat 138: 27-32.

28. Brzezinski M, Luisetti T, London MJ (2009) Radial artery cannulation: a comprehensive review of recent anatomic and physiologic investigations. Anesth analg 109: 1763-1781.

29. Lo TS, Nolan J, Fountzopoulos E, Behan M, Butler R, et al. (2009) Radial artery anomaly and its influence on transradial coronary procedural outcome. Heart 95: 410-415.

30. 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.

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

32. 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.

33. Pancholy SB, Coppola J, Patel T (2006) Subcutaneous administration of nitroglycerin to facilitate radial artery cannulation. Catheter cardiovasc interv 68: 389-391.

34. Ouadhour A, Sideris G, Smida W, Logeart D, Stratiev V, et al. (2008) Usefulness of subcutaneous nitrate for radial access. Catheter Cardiovasc Interv 72: 343-346.

35. Kiemeneij F, Vajifdar BU, Eccleshall SC, Laarman G, Slagboom T, et al.(2001) Measurement of radial artery spasm using an automatic pullback device. Catheter Cardiovasc Interv 54: 437-441.

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

37. He GW, Yang CQ (1996) Use of verapamil and nitroglycerin solution in preparation of radial artery for coronary grafting. Annals Thoracic surgery 61: 610-614.

38. Varenne O, Jegou A, Cohen R, Empana JP, Salengro E, et al. (2006) Prevention of arterial spasm during percutaneous coronary interventions through radial artery: the SPASM study. Catheter Cardiovasc Interv 68: 231-235.

39. Biondi-Zoccai GG, Moretti C, Omede P, Sciuto F, Agostoni P, et al. (2011) Intra-arterial lidocaine versus saline to reduce peri-procedural discomfort in patients undergoing percutaneous trans-radial or trans-ulnar coronary procedures. Acta Cardiol 66: 9-14.

40. Hildick-Smith DJ, Lowe MD, Walsh JT, Ludman PF, Stephens NG, et al. (1998) Coronary angiography from the radial artery--experience, complications and limitations. Int J Cardiol 64: 231-239.

41. Hildick-Smith D, Lowe M, Petch M, Ludman P (2000) Radial coronary angiography and stenting. Heart 83: 584-585.

42. Kiemeneij F, Fraser D, Slagboom T, Laarman G, van der Wieken R. (2003) Hydrophilic coating aids radial sheath withdrawal and reduces patient discomfort following transradial coronary intervention: a randomized double-blind comparison of coated and uncoated sheaths. Catheter Cardiovasc Interv 59: 161-164.

43. 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.

44. 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.

45. Lefevre T, Thebault B, Spaulding C (1995). Radial artery patency after percutaneous left radial artery approach for coronary angiography. The role of heparin. Eur Heart J 16: 293.

46. Zhou YJ, Zhao YX, Cao Z, Fu XH, Nie B, et al. (2007) Incidence and risk factors of acute radial artery occlusion following transradial percutaneous coronary intervention. Zhonghua Yi Xue Za Zhi 87: 1531-1534.

47. 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.

48. 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.

49. Singh A, Edasery D, Noor A, Bhasin N, Kaplan B, et al. (2011) Use of low-dose heparin with bivalirudin for ad-hoc transradial coronary interventions: experience from a single center. J Invasive Cardiol 23: 101-104.

50. Venkatesh K, Mann T (2006) Transitioning from heparin to bivalirudin in patients undergoing ad hoc transradial interventional procedures: a pilot study. J Invasive Cardiol 18: 120-124.

51. 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.

52. 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.

53. Sakai H, Ikeda S, Harada T, Yonashiro S, Ozumi K, et al.(2001) Limitations of successive transradial approach in the same arm: the Japanese experience. Catheter Cardiovasc Interv 54: 204-208.

54. Sanmartin M, Gomez M, Rumoroso JR, Sadaba M, Martinez M, et al. (2007) Interruption of blood flow during compression and radial artery occlusion after transradial catheterization. Catheter Cardiovasc Interv 70: 185-189.

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

56. 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.

57. Bertrand OF, Rao SV, Pancholy S, Jolly SS, Rodés-Cabau J, et al. (2010) Transradial approach for coronary angiography and interventions: results of the first international transradial practice survey. JACC Cardiovasc Interv 3: 1022-1031.

58. Wu CJ, Fang HY, Cheng CI, Hussein H, Abdou SM, et al. (2011) The safety and feasibility of bilateral radial approach in chronic total occlusion percutaneous coronary intervention. Int heart J 52: 131-138.