

REVIEW ARTICLE

Access-site Complications of the Transradial Approach: Rare But Still There

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Abstract: In the past decade, the Transradial Approach (TRA) has constantly gained ground among interventional cardiologists. TRA's anatomical advantages, in addition to patients' acceptance and financial benefits, due to rapid patient mobilization and shorter hospital stay, made it the default approach in most catheterization laboratories.

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Access-site complications of TRA are rare and usually of little clinical impact, thus, they are often overlooked and underdiagnosed. Radial Artery Occlusion (RAO) is the most common, followed by radial artery spasm, perforation, hemorrhagic complications, pseudoaneurysm, arterio-venous fistula, and even rarer complications, such as nerve injury, sterile granuloma, eversion endarterectomy or skin necrosis. Most of them are conservatively treated, but rarely, surgical treatment may be needed and late diagnosis may lead to life-threatening situations, such as hand ischemia or compartment syndrome and tissue loss. Additionally, some complications may eventually lead to TRA failure and switch to a different approach.

On the other hand, it is the opinion of the authors that non-occlusive radial artery injury, commonly included in TRA's complications in the literature, should be regarded more as an anticipated functional and anatomical cascade, following radial artery puncture and sheath insertion.

Keywords: Transradial approach, access-site complications, radial artery occlusion, coronary interventions, pseudoaneurysm.

1. INTRODUCTION

In the past decade, the Transradial Approach (TRA) has constantly gained ground among interventional cardiologists. In the USA alone, TRA rose from 1.2% in 2007, to 16.1% in 2012 [1]. In Europe, TRA has gradually been adopted as the default procedure in most catheterization laboratories [2, 3], as shown by several national registries [4-8]. The aforementioned transition from the Transfemoral Approach (TFA) to TRA has obviously occurred due to several advantages of the latter one.

Regarding anatomy, the dual vascular perfusion of the hand, both by the radial and the ulnar artery, secures it from ischemia in case of radial artery occlusion. Also, the absence of nerves and joints across the superficial course of the radial artery, minimizes access-site complications [9, 10]. Additionally, TRA is associated with fewer bleeding complications. A notable number of TFA catheterizations (3-6%) will be complicated with hemorrhage; 1% of them will be major ones, requiring hospitalization, blood transfusion, or even surgery, further worsening short-term outcomes and long-term prognosis [11]. Bleeding complications in TRA occur

in <2% of the procedures, while the need for blood transfusion is extremely rare [12]. Furthermore, TRA allows earlier patient mobilization, increasing patients' comfort and acceptance of the procedure [13-15]. Earlier mobilization leads to earlier patient discharge, thus reduction in hospital costs and health-care system burden [13, 16].

According to the literature, TRA complications occur rarely, while most of them have a benign course and are of limited clinical importance. As a result, it seems that some of them are often overlooked, underdiagnosed, and left untreated [17, 18]. However, awareness of TRA complications, as well as prompt diagnosis and, in some cases, timely treatment, are of utmost importance in terms of both patients' safety and procedural success.

The present review will examine the full spectrum of TRA complications, in terms of predisposing factors, frequency of occurrence, clinical presentation, diagnosis, and treatment, while Non-Occlusive Radial Artery Injury (NO-RAI), as a result of arterial cannulation, will be separately assessed.

2. COMPLICATIONS

2.1. Radial Artery Occlusion (RAO)

RAO is the most common adverse event following TRA, with an incidence of 1-12% in contemporary registries

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[19-22]. *Stella et al.*, studied a cohort of 563 patients who underwent TRA for Percutaneous Coronary Interventions (PCI), demonstrating that 5.3% of them were diagnosed with RAO at hospital discharge [23]. RAO usually occurs early (within 24 hours) after TRA, while in almost half of the cases, there is spontaneous recanalization within 3 months [21, 24]. Non-occlusive stenosis of the radial artery is apparent in 31% of patients within 48h of TRA and in 28% of them later on, based on Doppler ultrasound data analysis [25].

Radial artery patency after TRA is crucial to secure access for future TRA procedures or even allow arteriovenous fistula formation for patients with end-stage renal disease undergoing dialysis [19, 26, 27]. It can also be used as a bypass graft, although carefully evaluated when an ipsilateral TRA procedure has preceded [28].

Many mechanisms have been proposed for the pathogenesis of RAO, including impaired blood flow due to the sheath insertion, as well as perioperative vascular tissue injury. A combination of the above leads to thrombus formation and occlusion of the vessel [19, 25, 27]. Furthermore, multiple puncture attempts seem to result in spasm and thickening of the medial intima layer, leading to remodeling of the vascular wall and raised thrombogenicity [21, 29-31]. Imaging techniques, including Doppler ultrasound, angiography, and optimal coherence tomography (OCT), along with pathological studies, seem to support thrombus formation as the leading cause of RAO [31-35].

RAO is usually asymptomatic, due to the dual perfusion of the hand, by both the radial and ulnar arteries, through the superficial and deep palmar arches. As a result, RAO is often overlooked and underdiagnosed, while no further treatment is sought [35, 36]. In some patients, though, functional disability of the hand, paresthesia or persistent pain may occur [25]. Acute hand ischemia following RAO is extremely rare, leading, in most cases, to tissue loss and amputation, irrespective of the treatment. Hand ischemia usually occurs in critically ill patients in need of prolonged hemodynamic monitoring through the radial artery or patients with severe comorbidities [28, 37, 38].

Evaluation of radial arterial patency, post TRA, can be performed either by clinical tests, including palpation and the reverse Barbeau test, or by Doppler echo. According to a meta-analysis by Hahalis *et al.*, Doppler echo should be the preferred method for diagnosing RAO, as it enables the evaluation of the cause (*e.g.* direct visualization of thrombus) as well as the blood flow through the vessel (Fig. 1). On the contrary, clinical tests run a high risk of both false negative and false positive results [35, 39, 40]. Laser Doppler, an emerging, non-invasive technique, using low-power laser beams, seems superior to conventional Doppler vascular ultrasound, since it achieves a detailed mapping of the whole hand and digits perfusion, without skin contact, and avoiding artifacts [41].

Female sex [42-49], peripheral arterial disease [43, 49], smoking, and diabetes mellitus [21, 50] are predisposing factors for RAO. The significance of age, on the other hand, is

unsure, due to controversial outcomes in several studies [42, 51-54]. Interestingly, higher rates of RAO are seen in patients without a history of arterial hypertension or with low blood pressure perioperatively [44, 45, 55, 56]. Furthermore, patients on statin therapy, probably due to statins' pleiotropic effects, have lower RAO incidence [45, 57].

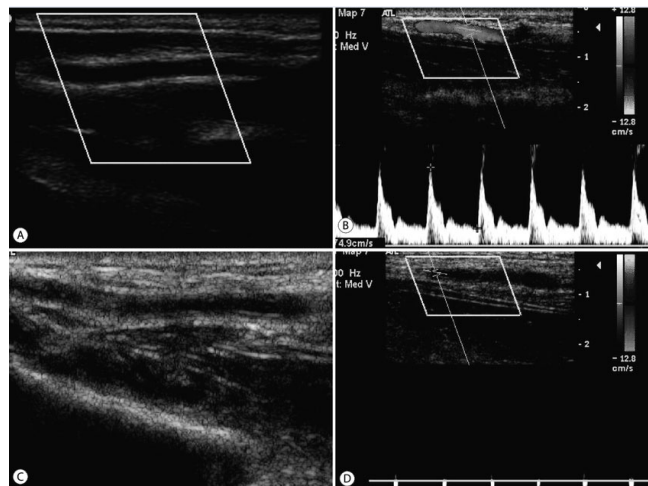


Fig. (1). A normal radial artery, with an intact lumen (A) and normal, biphasic wave-form in the doppler echo (B) pre-procedurally. After a TRA procedure, the presence of thrombus is indicated by increased echogenicity inside the vessel lumen (C), while blood flow is absent (D) (TRA: Transradial Approach) [40]. (*A higher resolution / colour version of this figure is available in the electronic copy of the article.*)

Different perioperative variables also seem to affect RAO incidence. Multiple (>1) puncture attempts increase the risk for RAO, probably due to pain leading to arterial spasm [51, 56, 58-61]. Peripheral puncture of the radial artery (0-1 cm from the styloid process) also promotes RAO [62]. Large-sized sheaths, along with poor anticoagulation, extended and occlusive post-procedural radial binding also seem to increase RAO rates [59, 63-65]. Concerning the hemostatic technique, graded-pressure, bracelet-like hemostatic devices are superior both to fixed-pressure binding bands [66] and improvised wrist bandaging [67]. On the other hand, manual compression after coronary angiography did not seem to have an impact on RAO incidence, compared to mechanical one with the use of graded-pressure pneumatic devices, as shown in the MEMORY study. Notably, total hemostasis duration in the manual group was significantly shorter [22, 68]. Finally, data on the association between total TRA procedure duration and RAO incidence have been controversial [44, 55, 63, 64, 67, 70] (Table 1).

Adequate anticoagulation (at least 50 Units/kg or 5.000 Units of unfractionated heparin either intravenously or intra-arterially) [71] in combination with patent hemostasis (preservation of anterograde flow through the artery during compression) [42, 50] and short compression protocols are the mainstay for the preservation of radial artery patency [72]. Simultaneous ulnar artery compression during patent

Table 1. Predisposing factors of RAO, according to current literature.

PREDISPOSING FACTORS OF RAO	
Patient-Related	
Advanced age*	Pancholy <i>et al.</i> [41], Hahalis <i>et al.</i> [39], Politi <i>et al.</i> [51]
Lower age*	Abdelaal <i>et al.</i> [52], Uhlemann <i>et al.</i> [42], Lee <i>et al.</i> [53]
Female sex	Pancholy <i>et al.</i> [41], Uhlemann <i>et al.</i> [42], Tuncez <i>et al.</i> [46]
Low body weight - BMI	Pancholy <i>et al.</i> [41], Plante <i>et al.</i> [68], Tuncez <i>et al.</i> [46], Levin <i>et al.</i> [47], Dangoisse <i>et al.</i> [48]
Renal dysfunction	Lisowska <i>et al.</i> [44]
Peripheral arteriopathy	Uhlemann <i>et al.</i> [42], Dangoisse <i>et al.</i> [48]
Diabetes mellitus	Nagai <i>et al.</i> [21]
Smoking	Cubero <i>et al.</i> [49]
No statin therapy	Honda <i>et al.</i> [56]
Absence of arterial hypertension – Low peri-procedural blood pressure	Aykan <i>et al.</i> [43], Levin <i>et al.</i> [47], Roghani <i>et al.</i> [54], Buturak <i>et al.</i> [55]
Procedure - related	
Multiple puncture attempts - Spasm	Rathore <i>et al.</i> [57], Hahalis <i>et al.</i> [39], Buturak <i>et al.</i> [55] Aminian <i>et al.</i> [58], Kotowycz <i>et al.</i> [59], Costa <i>et al.</i> [60]
Distal puncture (0-1 cm from the styloid process)	Bi <i>et al.</i> [61]
Long procedural time*	Aykan <i>et al.</i> [43], Roghani <i>et al.</i> [54], Tian <i>et al.</i> [62], Dharma <i>et al.</i> [63]
Short procedural time*	Plante <i>et al.</i> [68] Kwan <i>et al.</i> [69]
Large sheaths	Uhlemann <i>et al.</i> , Honda <i>et al.</i> , Dahm <i>et al.</i>
Insufficient anticoagulant therapy – Low ACT values	Rathore <i>et al.</i> [57], Politi <i>et al.</i> [51], Aykan <i>et al.</i> [43], Levin <i>et al.</i> [47]
Non-patent hemostasis	Pancholy <i>et al.</i> [41, 72], Kwan <i>et al.</i> [69], Cong <i>et al.</i> [66]
Prolonged hemostasis protocols	Aminian <i>et al.</i> [58], Tian <i>et al.</i> [62], Dharma <i>et al.</i> [63], Yan <i>et al.</i> [64]
No use of nitrates intra-arterially	Dharma <i>et al.</i> [63]
GPIs use	Aminian <i>et al.</i> [58]

Abbreviations: RAO: Radial Artery Occlusion, BMI: Body Mass Index, ACT: Activated Clotting Time, GPIs: IIb-IIIa Gluco-Protein Inhibitors. (*) Predisposing factors of RAO with controversial literature data.

hemostasis of the radial artery is promising, according to recent data [73, 74]. In case RAO has occurred, several therapeutic interventions have been reported in the literature. Recanalization of the radial artery can be achieved either with retrograde, through a more distal part of the artery [33, 34] or antegrade angioplasty, through the brachial or femoral artery [75, 76]. In a small case series by Jaradat *et al.*, four patients with symptomatic RAO underwent radial angioplasty along with abciximab infusion. Radial artery patency was achieved and retained in all four of them [77]. Four-week treatment with enoxaparin or fondaparinux in symptomatic patients with RAO achieved high rates (87%) of recanalization [78]. Finally, prompt (within 3-4 hours post TRA), hourly, occlusive compression of the ipsilateral ulnar artery in conjunction with a bolus of 5.000 Units of heparin [79] has shown promising results.

2.2. Radial Artery Spasm

Radial artery spasm during TRA, although benign in course, can result in abandoning the approach. Traumatic insertion and rough manipulation of catheters seem to be the cause in most circumstances. It usually manifests as pain or discomfort of the patient, as well as the inability to further advance or manipulate catheters. It is more prominent among women and accounts for 5-10% of the complications following TRA. Small and tortuous radial arteries, use of

large-sized catheters, and low operator experience predispose to the complication [80]. Spasm may result in catheter entrapment alongside the upper limb vasculature [36]. In a randomized study, Rathore *et al.* demonstrated a correlation between the use of non-hydrophilic coated sheaths and radial artery spasm prevalence, compared with the use of hydrophilic ones. On the contrary, no relation was found between the length of the sheath and the incidence of the complication [58].

Vasodilators, such as nitrates and calcium channel blockers, have been shown to effectively prevent, as well as treat, radial artery spasm (Fig. 2). As medial intima of the radial artery is regulated by $\alpha 1$ adrenergic receptors, the use of these drugs favorably alters this pathway. Other drugs, such as nitroprusside, nicorandil, diltiazem, magnesium sulphate, phentolamine, and molsidomine, are rarely used [81, 82]. In recent research, the use of dinitrate isosorbide *via* subcutaneous injection, along with local anesthesia (1% lidocaine solution), may facilitate the TRA procedure [83]. Last but not least, use of hydrophilic catheters seems to prevent the occurrence of spasm [58, 84].

In conclusion, gentle catheter manipulation by adequately experienced operators, as well as by default use of spasmolytic agents (nitrates, verapamil or both), are of utmost importance both for preventing the complication as well as removing entrapped catheters in case spasm occurs.

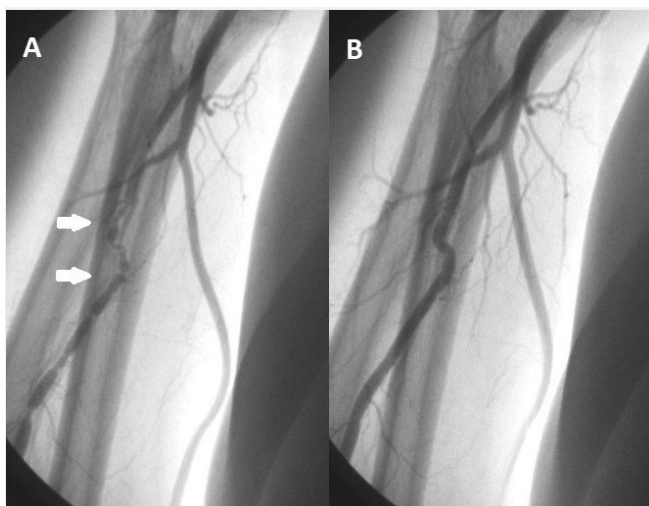


Fig. (2). Severe, diffuse spasm (white arrows) of the radial artery (A), which resolves after intra-arterial administration of spasmolytic agents (B). (A higher resolution / colour version of this figure is available in the electronic copy of the article).

2.3. Arterial Perforation

Arterial perforation, typically implicating the radial or brachial artery, is quite rare, accounting for 0.1-1% of TRA access-site complications. It is most prominent in elderly women, who usually have narrow and tortuous arteries. If not early recognized and promptly treated, arterial perforation clinically manifests as an arm or forearm hematoma (Fig. 3) of various severity, ranging from unimportant localized hematoma to compartment syndrome, threatening upper limb viability [85-87].

In case a guidewire has been successfully advanced proximally to the lesion, the rupture site can be sealed with the use of longer sheaths, guiding catheters or balloon inflations (Fig. 4). Although perforation may occasionally lead to TRA failure and switching to TFA, some series have indicated the feasibility of proceeding transradially. As there are no reported long-term complications, several operators, nowadays, suggest the continuation of the procedure itself, as it may be beneficial for perforation sealing and arterial reconstruction [85, 88, 89]. After completion of the procedure, an arterial angiogram must be performed. In case the rupture has not resolved, protamine infusion, external pressure using a sphygmomanometer, or prolonged balloon inflations may be needed. Compression bandages or even manual compression proximally to the rupture site may be additionally used, while angioplasty with a graft-stent may be the last resort, in case everything else fails. Surgical consultation may rarely be needed.

If a guidewire cannot be proximally advanced, the operator must proceed with protamine infusion as well as external pressure with the use of a sphygmomanometer or compression bandages. Prolonged balloon inflations through an alternative, antegrade access may also be applied. In this case, the procedure usually has to stop and an alternative ap-

proach must be performed after the perforation site has been effectively sealed [90, 91].

Compartment syndrome is a very rare and critical complication, with an incidence of 0.004%, where urgent surgical treatment with fasciotomy is essential [92]. It is caused by abrupt pressure increase inside the limb leading to nerve, artery, and muscle compression, resulting in ischemia and tissue loss [93, 94]. Acute pain, edema and pallor, along with paresthesia of the upper limb, are diagnostic of the complication. In most cases, compartment syndrome results from a rough catheter and wire manipulation during TRA, which causes arterial perforation and consequent hematoma in the upper limb, which may not be detected promptly. Thus, gentle movements of wires and catheters, as well as low-threshold in radial arteriography when guidewires or catheters are not easily advanced, can prevent unnecessary complications [36].

2.4. Pseudoaneurysm of the Radial Artery

Pseudoaneurysm of the radial artery is a very rare complication, with a prevalence of 0.1% [87]. It usually occurs after multiple radial puncture attempts, excessive anticoagulation, use of large-sized sheaths, or, rarely, contaminated catheters. In most cases, patients present days or even weeks after the procedure, with a palpable, pulsatile mass in the ipsilateral wrist or forearm that may or may not be painful (Fig. 5) [95]. Doppler echo confirms the diagnosis, demonstrating the typical, bidirectional, laminar blood flow through the neck of the lesion. Surgical treatment, either with excision of the pseudoaneurysm or even ligation of the radial artery, may be needed. However, less invasive treatment methods, like echo guided compression of the pseudoaneurysm, transcutaneous thrombin injection [92], or compression with an air-filled wrist band, have also been reported [96]. Early diagnosis and prompt treatment of this complication are of great importance, as further progression may lead to arterial rupture or impaired blood supply of the hand [36].

2.5. Nerve Injury

Radial, medial or ulnar nerve injury is extremely rare during TRA, since their anatomical course is distal to the traditional puncture site. It can be caused after multiple puncture attempts. Subtle ipsilateral index finger hypoesthesia may occur, with a benign and self-limiting course. A more serious, though very rare, form of nerve injury is Complex Regional Pain Syndrome (CRPS). It is characterized by pain, edema, restricted limb mobility, and vasomotor instability. All reported cases were conservatively treated, sympathetic blockage being included, with symptoms gradually subsiding. CRPS is a critical complication, as it may result in persistent disability [97-99].

2.6. Sterile Granuloma

In 2003, the formation of a sterile granuloma as a complication after TRA was first reported. Chronic inflammation



Fig. (3). Brachial artery perforation during transradial catheterization, not timely diagnosed, resulting in a large arm – forearm hematoma. (*A higher resolution / colour version of this figure is available in the electronic copy of the article*).

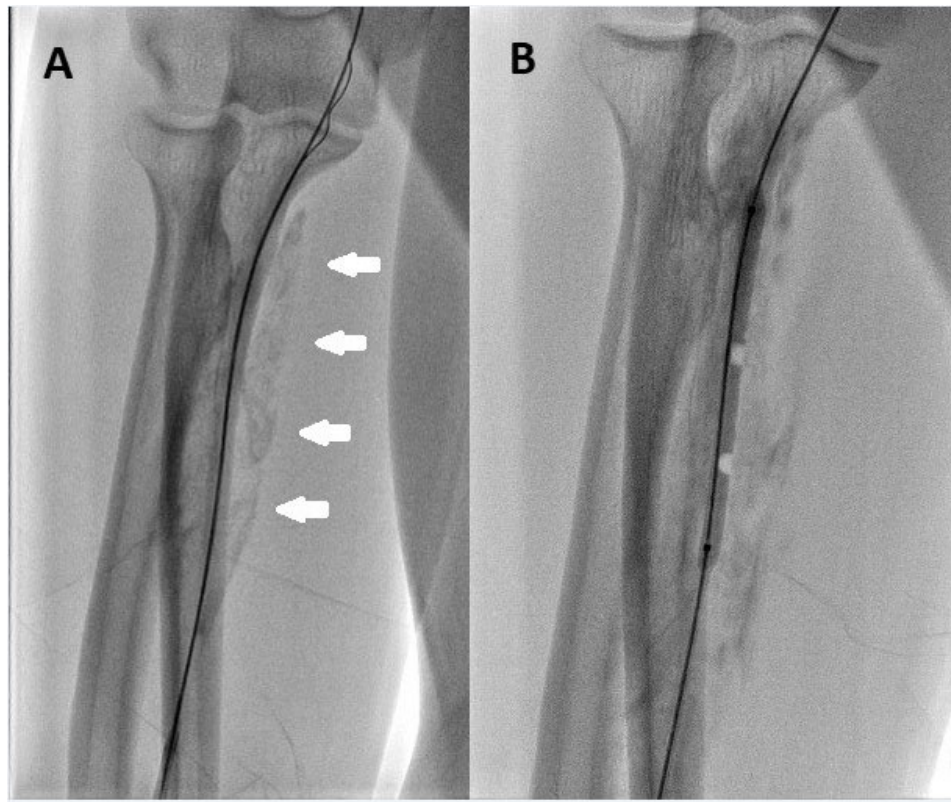


Fig. (4). Radial artery perforation with contrast agent extravasation after infusion (white arrows). The true arterial lumen is indicated by the guidewire course (A). Perforation was promptly diagnosed and effectively sealed with a long balloon dilatation (B). (*A higher resolution / colour version of this figure is available in the electronic copy of the article*).

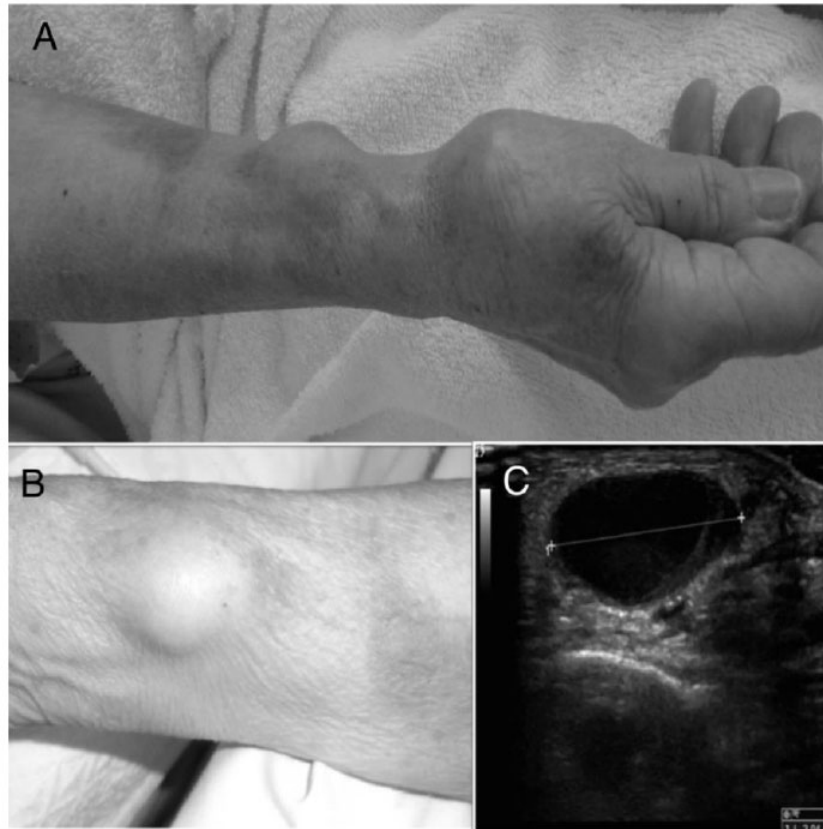


Fig. (5). Radial artery pseudoaneurysm, presenting as a large, pulsatile mass over the puncture site after TRA (A, B), confirmed by 2-D echo (C) (TRA: Transradial Approach, 2D: 2-Dimensional) [95]. (A higher resolution / colour version of this figure is available in the electronic copy of the article).

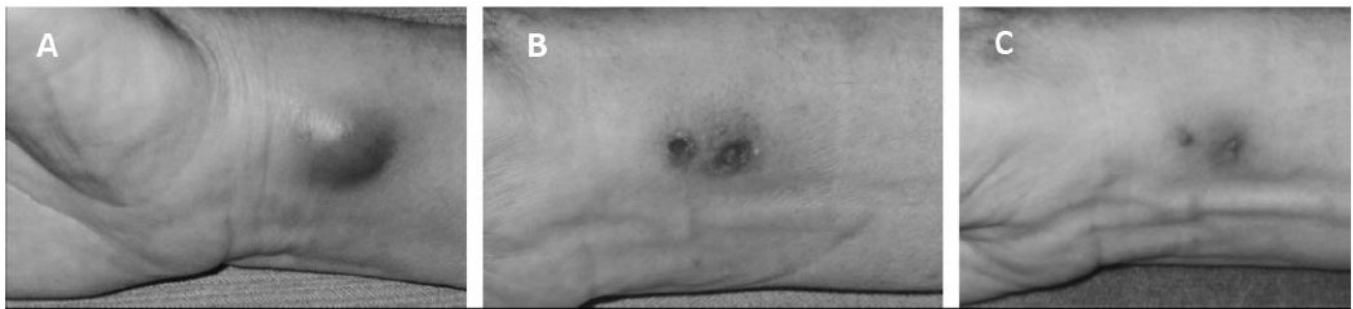


Fig. (6). Sterile granuloma leading to abscess formation after TRA with the use of a hydrophilic sheath (A), gradually resolving after drainage and high-dose steroid treatment (B, C) (TRA: Transradial Approach) [102]. (A higher resolution / colour version of this figure is available in the electronic copy of the article).

and fibrosis, combined with giant cell aggregation around the foreign body, were found in the pathological study. According to a single-center registry, it has an incidence of 2.8% with the use of hydrophilic sheaths, while it has never been reported when non hydrophilic-coated sheaths are used [99, 100]. Patients typically present 2-3 weeks after TRA, with a local foreign-body reaction or even abscess formation, when the initial empirical antibiotic course has no ef-

fect. Abscess drainage, in conjunction with analgesic – anti-inflammatory therapy for symptoms relief, including steroids, seem to shorten the complication's course (Fig. 6) [101, 102]. In a recent registry from the United Kingdom, a total of 76 cases of sterile granulomas have been documented [103]. Remarkably, all reported cases have been correlated with Cook® hydrophilic sheaths alone [104].

2.7. Arteriovenous Fistula

Arteriovenous fistula formation, an extremely rare complication, may manifest as persistent pain and edema in the puncture site, with a pulsatile thrill or a visible, dilated superficial vein (Fig. 7) [105]. This complication is rarely encountered since radial artery runs a superficial course, surrounded by veins of a rather small diameter. Surgical treatment may be necessary in selected cases [36].

2.8. Hemorrhage and Transfusion

TRA reduces the incidence of hemorrhagic complications, by as far as 73%, compared to the TFA, as shown in a recent meta-analysis [104]. Blood transfusion was only required in 3 among 1959 patients with hemorrhage [106-112]. Radial catheterization is associated with less major bleeding events and a lower rate of ischemic incidents [104].

2.9. Eversion Endarterectomy

Eversion endarterectomy is an extremely rare complication following TRA. In a single published case report, it occurred after a rough removal attempt of a long sheath during an intense spasm, in a 75-year-old female patient, following successful PCI through right TRA (Fig. 8). The prolapsing part of the radial artery was surgically removed with local excision. Neither hemorrhagic nor long term functional complications occurred, since the ipsilateral ulnar artery adequately supplied the palmar arches [113].

2.10. Skin Necrosis

Access-site skin necrosis after TRA is extremely rare. In a recently published case report, Tsiafoutis *et al.* described the occurrence of skin necrosis after prolonged compression of the radial artery, in a 65-year-old male patient after 2 PCIs within 5 days *via* the right radial artery, in terms of staged revascularization. Adequate hemostasis was hard to achieve, since the patient was under triple antithrombotic treatment (aspirin, clopidogrel and oral anticoagulant). Necrotic lesion appeared 5 days after discharge, it was surgically excised and the area was covered with a regional flap. Radial artery patency was preserved, while no long-term complications have been reported [114]. Non-surgical treatment after a careful clinical evaluation is an additional option, as demonstrated in two unpublished cases of patients who had undergone PCI through the right radial artery. Both patients remained asymptomatic and skin necrosis was only diagnosed one and three months post-PCI, respectively (Fig. 9 A and B), during scheduled hospital visits. Conservative treatment was favored in both patients, while no further complications were noted.

3. NON-OCCLUSIVE RADIAL ARTERY INJURY (NORAI)

It is very common in the literature for NORAI to be included among the access-site complications of TRA [36, 115]. However, it is the opinion of the authors of this article

that NORAI should not be regarded as an accidental complication, but rather as an anticipated anatomical and functional cascade, triggered by the unavoidable arterial wall injury during puncture and sheath insertion, that leads to intimal hyperplasia and vessel remodeling. The use of intravascular ultrasound (IVUS) technique in patients after cardiac catheterization through TRA has consistently demonstrated intimal hyperplasia, leading to an actual reduction of the lumen's mean diameter [29]. A recent OCT study demonstrated acute radial injury in the majority of patients after TRA (intimal rupture in 67% and medial dissections in 36%) as well as substantial intimal thickening, being more prominent after repeat TRA procedures [31]. Additionally, a vasodilatory reserve of the radial artery has been shown to be significantly impaired 9 weeks post-TRA [116], although a small study advocates its recovery after 1 year [117].

These anatomical and functional modifications seem to affect the radial artery's quality as a by-pass graft. Small observational registries had indicated reduced early patency rates, when radial arteries had been previously used for TRA procedures [26]. Moreover, a histopathological study of radial grafts that had been previously used for TRA, demonstrated findings of significant inflammation and hyperplasia in the distal part of the vessel, where the sheath had been inserted, while the media of the proximal part remained intact [118]. These observations impose the need for meticulous evaluation of radial arteries as by-pass grafts, when an ipsilateral TRA procedure has preceded. Furthermore, use of the same radial artery for repeat TRA interventions should be considered, in order to preserve the contralateral radial artery as a by-pass graft, in case surgical revascularization is required.

4. THE DISTAL TRANSRADIAL APPROACH (D-TRA) THROUGH THE ANATOMICAL SNUFFBOX (AS)

Over the past few years, D-TRA through the AS has emerged as an alternative to conventional TRA (C-TRA). The AS, also known as the radial fossa, is a triangular depression on the lateral side of the hand's dorsum, being most apparent during the extension of the ipsilateral thumb. It is located over the scaphoid and trapezium carpal bones, while its triangular borders are defined by the styloid process of the radius (proximally), tendon of the extensor pollicis longus (medially) and tendons of the extensor pollicis brevis and abductor pollicis longus (laterally) (Fig. 10) [119, 120].

Left D-TRA, as initially shown by *Kiemeneij*, is a feasible alternative to left C-TRA. Its main advantage is increased patient's and operator's comfort, since the patient's hand is placed in a more natural position, over his left groin and closer to the operator, during the procedure [121]. Although most data come from the left D-TRA [121-123], recent outcomes indicate the feasibility and safety of the right D-TRA as well [124]. On the other hand, the main disadvantages of this novel approach seem to be the challenging and more time-consuming puncture of this peripheral artery, as

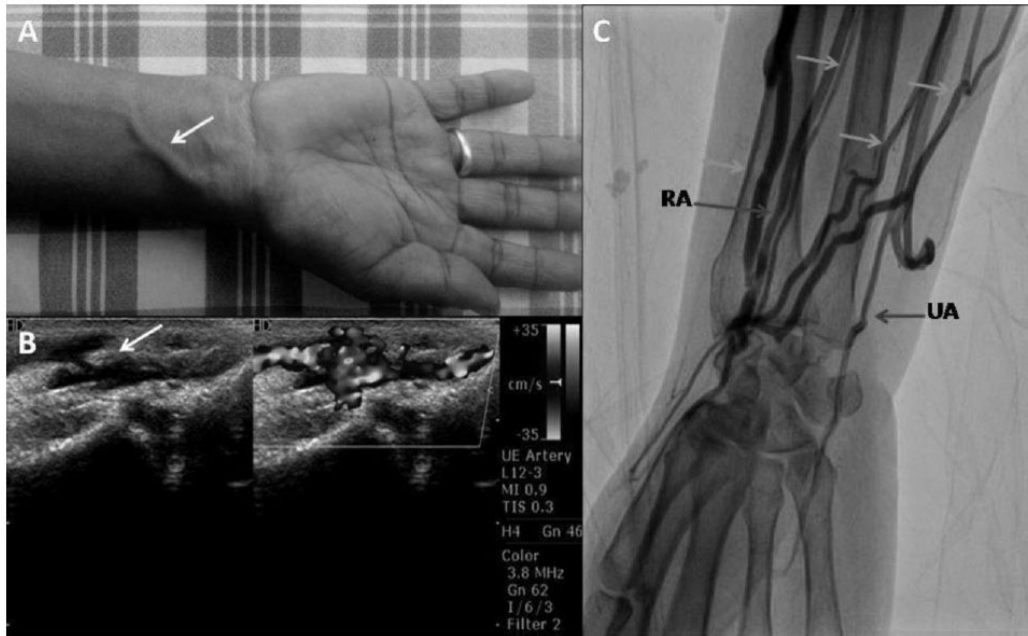


Fig. (7). Dilated superficial vein over the RA puncture site (A). Colour Doppler confirms the presence of a radial arteriovenous fistula (white arrow - B). Brachial artery angiography shows a radial arteriovenous fistula with multiple venous collaterals (Light gray arrows - C) (RA: Radial Artery, UA: Ulnar Artery) [105]. *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

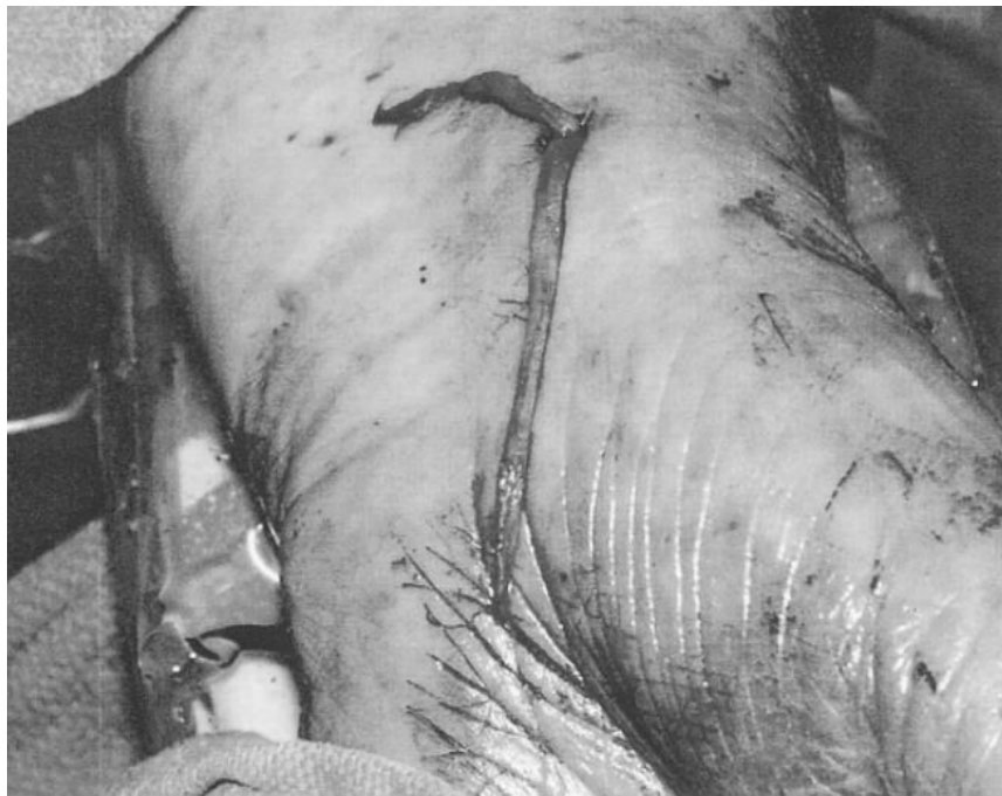


Fig. (8). Radial artery partially protruding through the arteriotomy site, after harsh sheath removal during intense arterial spasm [113]. *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

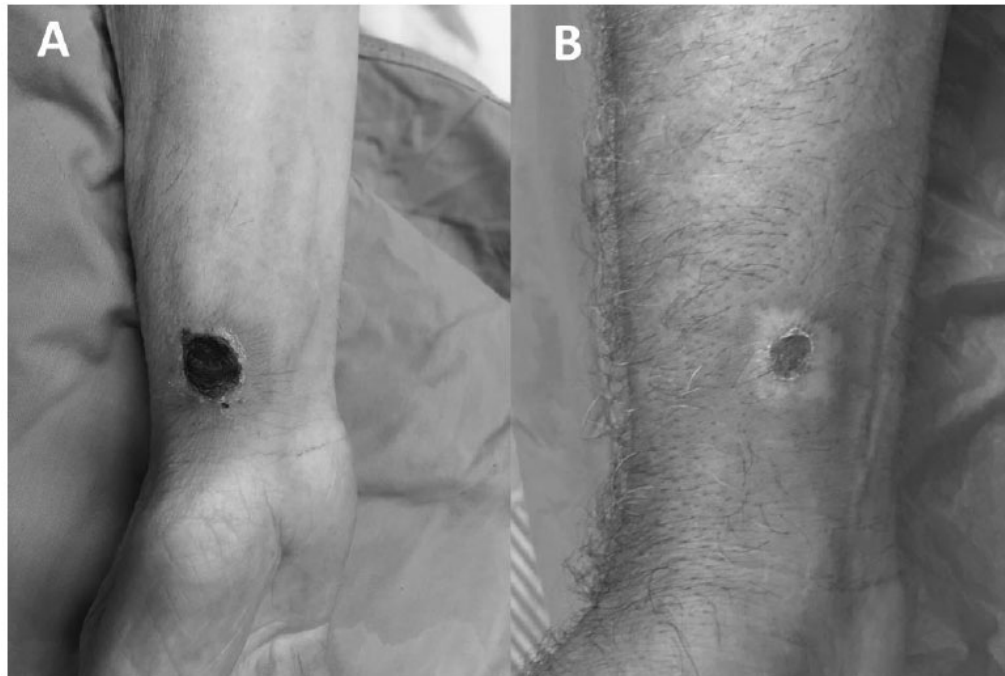


Fig. (9). Skin necrosis of the puncture site, in two separate patients, one (A) and three (B) months post - TRA PCI, respectively. After careful clinical evaluation, the lesion was conservatively treated in both, with no long-term adverse events (PCI: Percutaneous Intervention, TRA: Transradial Approach). *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*



Fig. (10). Graphical depiction of the anatomical snuffbox used in the distal TRA (TRA: Transradial Approach). *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

Table 2. Frequency, Clinical Presentation, and Treatment Options for the Access-Site Complications of TRA.

COMPLICATION	FREQUENCY	CLINICAL PRESENTATION	TREATMENT
Radial artery occlusion -Asymptomatic -Symptomatic -Ischemia	1-12% -Most common -Rare -XR	-No symptoms -Paresthesia, persistent pain -Pallor, pain, tissue loss	-Balloon angioplasty, abciximab, enoxaparin, fondaparinux, ulnar artery compression -Balloon angioplasty, abciximab, enoxaparin, fondaparinux, ulnar artery compression -Surgery, amputation
Spasm	5-10%	Pain, difficulty or inability to promote catheters	Spasmolytics (verapamil, nitrates)
Arterial perforation -Compartment syndrome	0.1-1% -0.004%	Forearm – arm hematoma -Acute pain, pallor, paresthesia	External pressure, balloon inflation, long sheaths, guiding catheters -Surgery
Pseudoaneurysm	0.1%	Palpable, pulsatile wrist mass	Surgery, compression, thrombin injection
Nerve injury -CRPS	XR -XR	Index finger hypoesthesia -Pain, edema, impaired mobility, vasomotor instability	Not needed -Conservative treatment, sympathetic blockage
Sterile granuloma	2.8% of Cook® hydrophilic sheaths	Wrist inflammation, abscess formation	Conservative wound care, abscess drainage
Arteriovenous fistula	XR	Pain, edema, pulsatile thrill	Compression, surgery
Hemorrhage	<2%	Hematoma, bleeding	Usually not needed (transfusion XR)
Eversion endarterectomy	XR	Partial prolapse of the radial artery wall after sheath removal	Surgical excision
Skin necrosis	XR	Necrotic lesion over the puncture site	Surgical excision or conservative treatment, after clinical evaluation

Abbreviations: CRPS: Complex Regional Pain Syndrome, TRA: Transradial Approach, XR: Extremely Rare.

well as higher failure rates [125, 126]. Additionally, the use of sheaths larger than 6 French in diameter may not be feasible in D-TRA.

Although multicenter, randomized trials comparing D-TRA and C-TRA are missing, for the time being, a recent meta-analysis has assessed the rates of complications in the two approaches [127]. Regarding access-site hematoma, radial artery spasm and dissection, no significant difference was observed between the two approaches. On the other hand, RAO rates were significantly lower in the D-TRA group (2.30% versus 4.86%, RR=0.51; 95% CI 0.32-0.81; p=0.004). Even rarer complications, such as pseudoaneurysm [128] and arterio-venous fistula formation [129], have been reported with D-TRA, but their true incidence is hard to estimate. Finally, D-TRA has been shown to protect from compartment syndrome [130]. However, since most cases of the syndrome result from arterial perforation of more proximal arterial branches, distant to the access-site, this advantage may be attributed to the experience of operators performing the D-TRA [115].

CONCLUSION

Over the past decade, TRA has constantly been gaining ground globally. Its feasibility, as well as its enhanced safety over the TFA, are now indicated by robust data. TRA's anatomical advantages, in addition to rapid patient mobilization, that improves quality of life and, eventually, leads to earlier hospital discharge cutting healthcare expenses, have led to its worldwide acceptance. Being the default approach in most catheterization laboratories (especially in Europe and Asia) has improved operators experience, while technological progress has led to the production of modern sheaths and catheters, dedicated to the TRA, reducing, even more, the occurrence of access-site complications. Thus, even the most

complex and demanding cases of both coronary and peripheral artery disease can be successfully managed through the TRA.

RAO is considered the “Achille’s heel” of TRA, since it impairs its repeatability, while it prevents the use of radial artery as a by-pass graft or for a fistula formation in patients with end-stage renal disease. Other complications, like arterial perforation, although rare, if not properly and promptly treated, can lead to TRA failure and switch to TFA.

All of the above highlight the need for the modern transradial interventionalist to be vigilant and fully aware of the wide spectrum of possible access-site complications in TRA procedures (Table 2); in order to prevent, timely recognize and effectively treat them. Although rarely accounted, they are still there, lurking in the shadows, ready to hurt TRA's safety and feasibility, which both have been so hard to gain Table 2.

CONSENT FOR PUBLICATION

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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