

Radial Artery Use and Reuse

Preserving radial patency after transradial catheterization procedures.

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The transradial approach for cardiac catheterization and percutaneous coronary intervention (PCI) has demonstrated significant benefits when compared with the traditional femoral approach by way of predictable reductions in access-site bleeding and vascular complications, as well as through decreased time to ambulation, shortened length of hospital stay, enhanced patient comfort, and greater patient preference.¹⁻⁴ Recent data from a number of studies, including the very large RIVAL (Radial Versus Femoral Access for Coronary Intervention) and MATRIX Access (Minimizing Adverse Hemorrhagic Events by Transradial Access Site and Systemic Implementation of angioX) trials, have also suggested differential benefits in high-risk patient subsets, most notably an association between transradial primary PCI in the ST-elevation myocardial infarction population and reduced mortality.²⁻⁴

As a natural consequence of the resultant surge in global radial adoption, the safety and feasibility of repeated use of the radial artery have been brought into question. Prime among the safety concerns is radial artery occlusion (RAO), which remains an important limitation of the technique and is often cited by operators as a hindrance to even greater adoption of this approach. In this article, we discuss practical issues related to prevention, detection, and treatment of RAO, as well as evidence-based best practices of particular relevance to treating patients who undergo repeated use of

the radial artery for catheter-based procedures.

INCIDENCE, PATHOPHYSIOLOGY, AND RISK FACTORS FOR RAO

RAO has been reported in clinical investigations to occur after transradial catheterization with variable incidence, ranging from < 1% to 10% in the majority of contemporary studies, although some investigators have found substantially higher rates.⁵⁻⁸ Whatever the reported incidence in studies, there is general agreement that the true incidence of RAO in clinical practice may be even higher, given that its occurrence is usually asymptomatic and because spontaneous recanalization in the days to weeks after radial access approaches 50%. This results in systematic underestimation when assessment of radial patency is deferred until postdischarge follow-up or not performed at all based on the absence of symptoms.^{5,8} The rate of symptomatic RAO

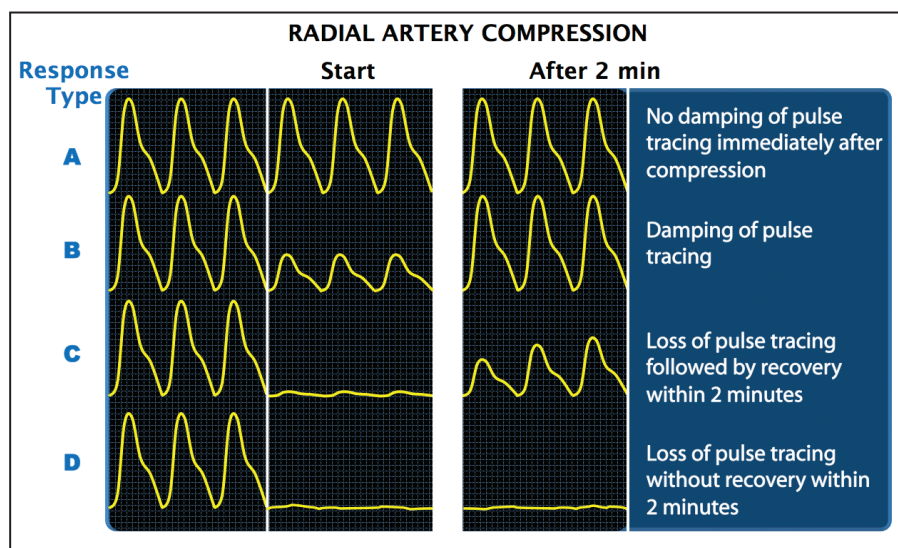


Figure 1. The four patterns of ulnopalmar arch patency assessed by plethysmography and pulse oximetry as described by Barbeau et al. In 1,010 patients, the various response types occurred in the following proportions (left hand, right hand): type A: 14.3%, 17.1%; type B: 75.2%, 73.7%; type C: 5.4%, 5.2%; and type D: 5.1%, 4%.⁹

in the RIVAL study was a mere 0.2%, although it may be safely assumed that the overall rate of acute RAO was probably somewhat higher.³ Importantly, the presence of a palpable pulse does not definitively exclude RAO, as some patients may manifest segmental stenosis with some residual flow, whereas others with complete occlusion of the radial artery may have return of pulsatile flow to the segment of vessel distal to the occlusion via carpal or palmar arch collaterals.⁵ Although it could be argued that the definitive diagnosis of RAO requires Doppler ultrasound assessment of the radial artery, plethysmographic assessment of blood flow to the thumb during ulnar compression (the so-called reverse Barbeau test) serves as a reasonable surrogate test.^{5,8,10}

The primary pathophysiologic mechanism underlying RAO appears to be thrombosis, with contributions from endothelial injury and inflammation, intimal or medial dissection, and spasm.^{5,8} Radial sheath insertion may result in lasting injury to the vessel even in the absence of RAO, as borne out by intravascular imaging studies demonstrating localized vascular trauma immediately afterward and intimal thickening, as well as vessel narrowing upon reaccess.⁵ Additionally, many weeks after radial access, flow-mediated radial artery dilation and response to vasodilator challenge are both diminished.⁵ The clinical implications of these observations are that radial reaccess may become technically more difficult even after an uneventful initial procedure, and further, that use of the previously accessed radial artery as a conduit for coronary artery bypass surgery may be unfavorable.

Anatomic and clinical variables that predict RAO include a larger ratio of sheath size to radial artery diameter, longer radial cannulation time, omission or underdosing of anticoagulation, omission of spasmolytic agents, and the duration and intensity of radial compression after the procedure.^{5-8,10-13} It should be noted that variability in the methodology and time frame for RAO assessment hampers direct comparisons across the individual studies that have yielded these observations.

TECHNICAL AND PHARMACOLOGIC CONSIDERATIONS AT THE TIME OF RADIAL ACCESS

We have previously detailed technical considerations that should guide safe and effective radial access.¹⁰ Confirmation of dual arterial supply to the hand was historically regarded as a prerequisite to obtaining a measurement of radial artery blood gas and is still commonly performed before radial artery harvesting for coronary artery bypass grafting.¹⁴ Although the neces-

sity of this step before transradial catheterization has been debated by the international medical community on the basis of scant supportive evidence, its observance has become commonplace in the United States. On a purely pragmatic level, confirmation of dual arterial supply (implying not only a patent ulnar artery, but also palmar arch patency) serves as a measure of reassurance that digital ischemia is unlikely even in the event of confirmed RAO.

Until recently, this step had been performed using a modified approach to that described first in 1929 by Dr. Edgar V. Allen, who offered his initial recommendations on the basis of three patients with thromboangiitis obliterans.¹⁵ However, a number of authors have since demonstrated that the modified Allen's test lacks adequate sensitivity, specificity, predictive accuracy, or reproducibility to be considered clinically satisfactory.^{14,16} The implementation of more objective plethysmographic metrics has thus become the de facto standard in assessment of dual arterial supply and patency of the ulnopalmar arches. Perhaps the most commonly employed of the current methodologies was described in its final form by Barbeau and colleagues just over a decade ago. In total, 1,010 patients underwent assessment of ulnopalmar arch patency via modified Allen's test, plethysmography, and pulse oximetry with the clamp sensor applied to the thumb.⁹ Plethysmography tracings were recorded after 2 minutes of continuous radial compression and results categorized as types A through D (Figure 1), representing varying degrees of ulnopalmar arch patency and presumably also the presence or absence of recruitable palmar collaterals. It was found that on average, > 95% of subjects manifested sufficient dual arterial supply (response types A–C) in one or both arms to allow safe proceeding with radial access.⁹

Although no specific preparatory step or choice of equipment used to gain access has been definitively shown to reduce RAO, it is widely recognized that multiple puncture attempts increase the propensity for radial spasm, and as mentioned previously, an overlay of spasm may contribute to RAO risk.^{5,8,10} Therefore, it may be inferred that technical iterations of radial access and subsequent sheath/catheter manipulations that minimize vessel spasm may offer some benefit with respect to RAO risk. Recent confirmation of this concept came from a prospective, randomized study by Dharma and colleagues, which found that 500 µg of intra-arterial nitroglycerin delivered through the sheath at the conclusion of the procedure was associated with a significant decrease in RAO assessed via ultrasound at 1 day postprocedure compared to placebo.¹⁷

Multiple investigators have demonstrated a correlation between higher ratios of sheath outer diameter to inner radial diameter and the risk of RAO.^{5,11-13}

Saito et al studied 250 consecutive Japanese patients using ultrasound and found that after treatment with nitrates, mean internal radial diameter measured 10 mm proximal to the styloid process (corresponding to the likely site of sheath insertion) was 3.1 ± 0.6 mm in men and 2.8 ± 0.6 mm in women.¹¹ Given that the external diameter of a 6-F sheath is 2.52 mm, at least 14% of men and 27% of women in this cohort had a radial caliber smaller than this.¹¹ Sheathless radial guide systems have outer diameters roughly 1.5 F smaller than the analogous sheath capable of accommodating a guide catheter of the same caliber.¹⁸ Although use of these systems intuitively seems like a potential opportunity to minimize radial trauma and therefore RAO, this remains to be proven.⁸ Shifting routine practice to the use of smaller standard sheaths and catheters, especially for diagnostic procedures, may, however, be a step toward reducing the incidence of RAO.

After use of smaller sheaths and achieving patent hemostasis (subsequently described), routine use of parenteral anticoagulation shortly after radial access remains one of the most established and evidence-based practices in transradial intervention. Spaulding et al first described decreasing rates of asymptomatic RAO with increasing heparin doses in 415 patients undergoing catheterization via left radial approach: 71% RAO without unfractionated heparin, 24% in patients receiving 2,000 to 3,000 units of heparin, and 4.3% in patients receiving 5,000 units of heparin ($P < .05$).¹³ Subsequently, multiple other groups have confirmed the value of anticoagulation in RAO prevention with larger versus smaller doses; these, as well as weight-adjusted doses (most often 50 to 70 units/kg of unfractionated heparin) and anticoagulation combined with selective use of transient ulnar artery compression, have all independently demonstrated value in limiting RAO.^{1,5,8,19} Bivalirudin anticoagulation may be a reasonable substitute in patients unable to receive heparin products or in the case of planned PCI.^{5,8} Additional studies are necessary to plot out the anticoagulant dose range that strikes the optimal balance between RAO

prevention and short hemostasis time/avoidance of radial hematomas.

RAO AVOIDANCE STRATEGIES AT THE TIME OF HEMOSTASIS

The radial approach achieves its margin of safety over the femoral approach with respect to access site bleeding and vascular complications primarily through its superficial location and ease of compression.¹ Excessive pressure or duration of compression, however, may contribute to RAO, as the precedent stasis of blood in the compressed radial artery is unlikely to be associated with any premonitory symptoms. There is strong evidence to support the practice of maintaining antegrade radial artery blood flow during the period of hemostasis, known as *patent hemostasis*.^{5,8}

In the PROPHET (Prevention of Radial Artery Occlusion-Patent Hemostasis Evaluation Trial) study, patients were randomized to standard (untitrated) radial compression using a radial compression device versus compression titrated using plethysmography with ulnar compression to maintain flow in the radial artery with surface hemostasis.²⁰ The titrated (patent hemostasis) group showed evidence of significantly lower rates of RAO at both 24-hour and 30-day time points.²⁰ Importantly, PROPHET also reconfirmed prior observations suggesting that independently of RAO

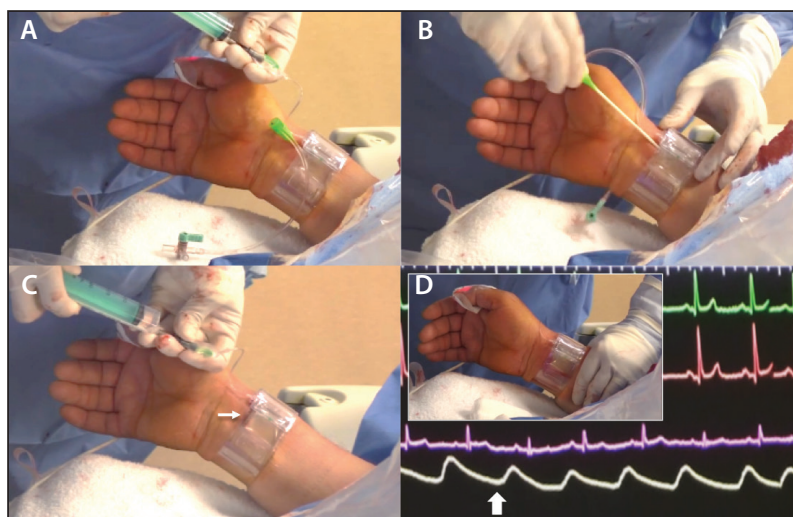


Figure 2. Patent hemostasis. The radial compression band is applied to the site of the sheath insertion and inflated to occlude radial flow (A). The sheath is removed from the body (B). Air is slowly removed from the compression band until blood return is seen under the band (arrow; C). The band is inflated with 1 to 2 mL more of air until cessation of oozing. Ulnar compression is performed (inset; arrow denotes start of ulnar compression), and plethysmography reveals a mildly blunted but pulsatile waveform, consistent with patent hemostasis of the radial artery (D).

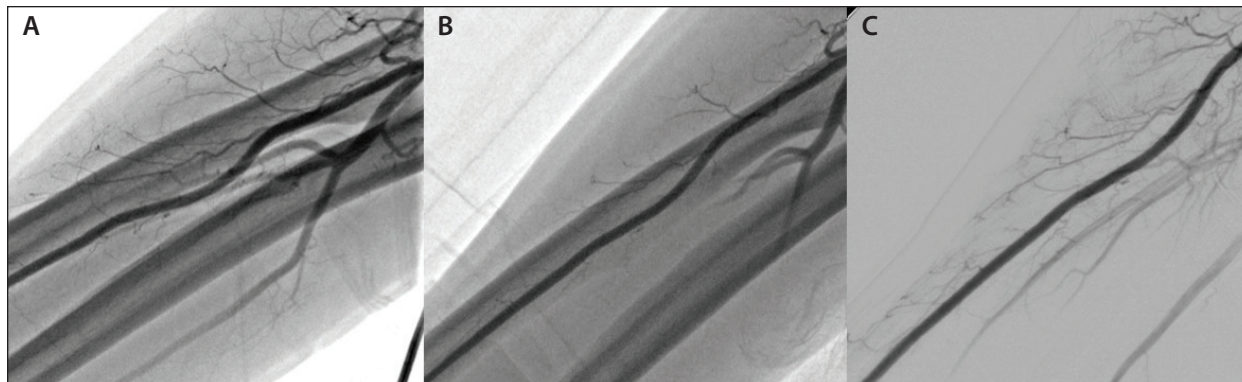


Figure 3. Radial reuse. Panels A through C demonstrate patency of the right radial artery in a patient who had three angiograms via a right radial approach (each separated by a 12- to 14-month interval). Each time, radial patency was confirmed before discharge via reverse Barbeau test, and on angiography, the vessel is noted to be without stenosis or overt evidence of vascular injury. This patient has had two subsequent angiograms via a transradial approach.

avoidance strategies, a significant proportion of early RAO resolves spontaneously: 40.7% of initial RAO in the traditional compression group and 63.6% of initial RAO in the patent hemostasis group had recanalized by the 1-month follow-up.^{5,8,20}

In the RACOMAP (Radial Compression Guided by Mean Artery Pressure Versus Standard Compression with a Pneumatic Device) study, investigators fashioned a manometer apparatus attachment to the TR Band radial compression device (Terumo Interventional Systems) and compared mean arterial pressure (MAP)-guided radial compression with standard 15-mL inflation of the TR Band device.²¹ A dramatic reduction in RAO seen 24 to 72 hours after sheath removal in the patients randomized to MAP-guided hemostasis (1.1% vs 12%; $P = .0001$) prompted early termination of the study after interim data analysis at 50% ($n = 351$) recruitment.²¹ Another 400-patient retrospective analysis found that 2 hours of radial artery compression was associated with a twofold lower rate of early RAO (at 24 hours after sheath removal) as compared with 6 hours of compression (5.5% vs 12%; $P = .025$).²² Once again, a sizeable proportion of patients with early RAO had spontaneously recanalized by the time of the 30-day follow-up. Step-by-step details of patent hemostasis are provided in Figure 2.

RADIAL ARTERY REUSE

The recent uptick in transradial procedures being performed in the United States and the world over has thrust the question of radial reaccess into the spotlight. Long before global radial adoption reached its current heights, however, the Japanese radial reaccess experience yielded important insights on this topic. In 2001, Sakai et al reported on 812 patients undergoing 1,539

transradial procedures (2 to 7 procedures per patient) over a 3-year period.²³ Despite the predominant use of 5-F sheaths, technical failure of radial access (dropout from the study cohort) increased from 3.5% of men and 7.9% of women at the time of the second radial procedure to 10% of the remaining men and 20% of remaining women at the time of the third radial procedure, and to 30% of remaining men and 50% of remaining women at the fifth radial reaccess attempt.²³ Although severe spasm, faint or absent pulse, hematoma formation, and failed puncture were all cited as reasons for dropout, the authors concluded that the primary mechanism of technical failure at the time of radial reaccess attempts was due to vessel narrowing or occlusion.

A more recent retrospective analysis from the Quebec Heart-Lung Institute found a 93% success rate for second-time radial reaccess.²⁴ Linear regression analysis estimated a 5% failure rate associated with each successive attempt with an approximately 60% rate of success with eight or more attempts in the same radial artery.²⁴ Although the reason for technical failure was clinically assessed RAO in all patients, remarkably, all patients with RAO in this analysis were asymptomatic. It has been our center's experience that with observance of the aforementioned best practices, the radial artery is routinely preserved for several successful reaccess attempts (Figure 3).

TREATMENT OF RAO

Although RAO is generally a benign event, there have been isolated cases of RAO-associated digital ischemia, including a published case in which RAO ensued in a patient whose ulnar artery was erroneously assessed as patent by plethysmography.²⁵ In that particular

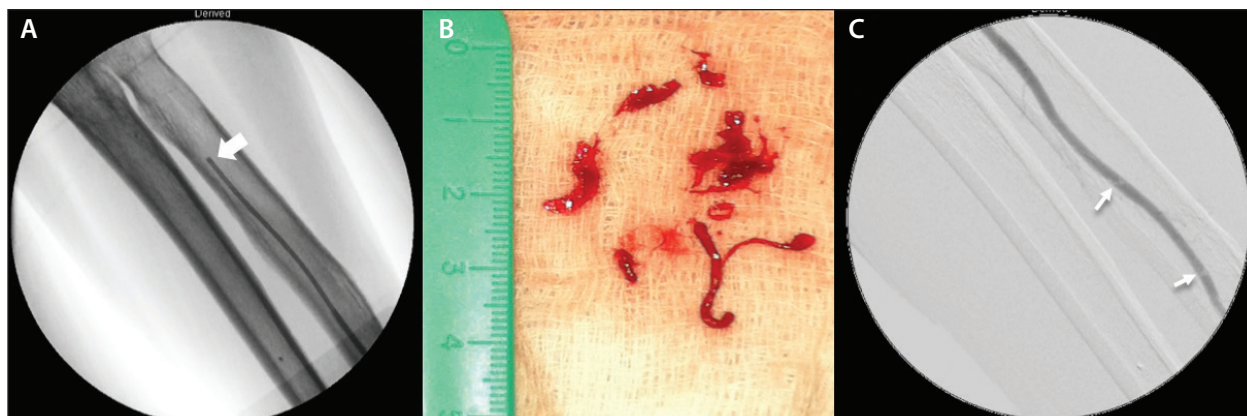


Figure 4. Aspiration thrombectomy of an acutely occluded radial artery. The left radial artery was suspected to be acutely thrombosed at the conclusion of an uncomplicated peripheral angiogram on the basis of absent arterial waveform from the sheath, inability to draw back blood, and severe blunting of a previously pulsatile plethysmography waveform. A 5-F straight, nontapered Glidecath (Terumo Interventional Systems) was introduced through the 5-F radial sheath (A), and the length of the radial artery was aspirated, taking care to stop short of the brachial bifurcation in order to minimize risk of embolization into the ulnar artery. Organized thrombus was removed (B) after several aspiration passes with restoration of flow in the radial artery (C). Arrows indicate small mobile pieces of adherent thrombus residual in the radial artery. Additional heparin was given before sheath removal. The radial artery was confirmed to be patent by reverse Barbeau test at 1-month follow-up.

case, Rhyne and Mann describe successful use of coronary angioplasty equipment and technique to restore patency of a recently occluded radial artery with complete resolution of the presenting symptoms of hand ischemia.²⁵ Such cases notwithstanding, RAO is usually asymptomatic and corrects itself spontaneously in perhaps as many as 50% of cases. Nevertheless, most RAO cases do not mandate definitive therapy beyond reassurance, observation, and analgesia in the event of forearm discomfort, which may be a manifestation of the arterial inflammation that accompanies thrombosis.^{5,8} Rarely, a short course of anti-inflammatory medications may also be required for symptomatic relief, although its impact on vessel recanalization is not known.^{5,8} It is understandable, however, that dedicated radial operators would want to maximize radial patency, if for no reason other than to preserve the vessel for future reaccess attempts.

Therapies aimed at recanalization of RAO may be broadly divided into pharmacotherapy and mechanical strategies. In a prospective nonrandomized study, Zankl et al treated patients with symptomatic RAO with 4 weeks of either enoxaparin or fondaparinux and observed a second cohort of asymptomatic RAO patients without administering any specific therapy.²⁶ At the 1-month follow-up evaluation, the rate of radial patency was significantly higher in the anticoagulated patients than in those who were managed conservatively (87% vs 19%; $P < .01$).²⁶ Caution should be

exercised in the interpretation of this study, however, given that it was nonrandomized, the rate of spontaneous recanalization was numerically lower than most published series, and further, that the two groups of patients clearly differed with respect to symptoms, which suggests some unquantified anatomic or pathophysiologic differences between the groups and likely prompting differential therapies beyond anticoagulation.

Bernat et al reported that a higher dose of anticoagulant plus short-term ulnar compression favorably influenced recanalization rates in patients with documented RAO despite short compression times and use of patent hemostasis technique.¹⁹ The reported incidence of RAO 5 to 6 hours after sheath removal was 5.9% in patients randomized to 2,000 units of unfractionated heparin versus 2.9% in the 5,000-unit group ($P = .17$). In those patients with RAO, the Terumo TR Band used for initial hemostasis was reapplied over the ulnar artery for 1 hour, and radial patency was reassessed. The final incidence of RAO was 4.1% in the group receiving 2,000 units of heparin versus 0.8% in the group receiving 5,000 units of heparin ($P = .03$).¹⁹

Although various invasive mechanical approaches for radial recanalization have been described, routine use of these techniques, especially in patients with asymptomatic RAO, is generally not appropriate. Moreover, the decision to pursue radial angioplasty should take into account the thromboembolic risk involved, with

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regard to the possibility that a benign event could inadvertently be transformed into a clinically significant one if embolization to the ulnar or digital arteries occurs.²⁵ Finally, when thrombosis of the radial artery is apparent in the catheterization laboratory before sheath removal (as evidenced by absence of arterial waveform from the sheath, inability to draw back blood, and once spasm has been excluded), the authors have experience with aspiration thrombectomy through the sheath and successful recanalization of the radial artery (Figure 4).

CONCLUSION

The transradial approach to cardiac catheterization offers many proven benefits over the traditional transfemoral approach and is rapidly rising in popularity both globally and within the United States. RAO, while often asymptomatic and without any obvious clinical sequelae, remains an important drawback to transradial catheterization. Strategies proven to reduce RAO rates include use of lower-profile sheaths, anticoagulation during every case, use of a patent hemostasis technique after sheath removal, and limiting the number of times a given vessel is reaccessed. Less certain but likely beneficial interventions include intra-arterial administration of vasodilators, higher- versus lower-dose anticoagulation strategies, and shortening of compression time. Use of hydrophilic sheaths or sheathless guide systems may also be helpful (if unproven) adjuncts both aimed at minimizing trauma to the radial artery. In the event of RAO requiring immediate recanalization, short-term ulnar compression should be considered with or without the administration of additional anticoagulation before considering invasive options. With the observance of best practices and meticulous technique during and after the transradial procedure, maintenance of radial artery patency is achievable in the vast majority of patients. ■

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