



REVIEW

The Transradial Approach for Cardiac Catheterization and Percutaneous Coronary Intervention: A Review

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Abstract

Cardiac catheterization and percutaneous coronary intervention play an important role in the management of coronary artery disease. Although the transfemoral approach has been the traditionally dominant method, there has been an increased utilization of the transradial approach. Multiple observational studies and randomized clinical trials have shown fewer bleeding complications, reduced morbidity and mortality, improved quality of life, and better economic outcomes when the transradial approach is utilized when compared to the transfemoral approach. Despite its many benefits, utilization of this approach in certain countries including the United States has been less than optimal due to a lower adoption rates mostly driven by lack of training opportunities and decreased awareness of clinical benefits of the transradial approach. In this review, the history, observational trends, efficacy, and technical aspects of transradial cardiac catheterization and percutaneous coronary intervention are discussed.

Keywords: transradial vascular access; cardiac catheterization; percutaneous coronary intervention

Introduction

Cardiac catheterization and percutaneous coronary intervention (PCI) play an important role in the diagnosis and treatment of coronary artery disease. The transfemoral approach to cardiac catheterization has been the dominant technique utilized by interventional cardiologists in the past decades. However, the transradial approach has emerged as an effective alternative since the first successful coronary angiography and PCI using this method were performed in 1989 and 1993 respectively [1–3]. The transradial approach

has become increasingly popular in light of multiple studies which suggest advantages of this vascular access site over the transfemoral approach; including, reduced access site bleeding, lower rates of vascular complications, early sheath removal, improved patient comfort, fast recovery, and decreased costs [4]. Despite these advantages, the transradial approach has been associated with longer procedure times, a prolonged learning curve, higher crossover rates, and inability to use large bore sheaths, which has led to variability in its adoption worldwide [5–7]. Both the ACC/AHA/SCAI and European guidelines include a class IIA recommendation for transradial approach to decrease access site complications [8, 9].

In this review, the history, observational trends, efficacy, and technical aspects of transradial cardiac catheterization and PCI will be discussed.

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History

Initial attempts at central arterial catheterization and coronary angiography via the radial artery were first reported by Radner in 1948 [10]. Although there was interest in the transradial approach, equipment related limitations led to a shift of most catheter-based procedures at the time, to larger vessels. The radial artery remained a site for monitoring arterial pressure [1]. Early PCI in the 1970s were performed using larger 9F guiding catheters [11]. Campeau was the first to report successful coronary angiography using a transradial approach in 1989, with successful PCI performed by Kiemeneij in 1993 utilizing smaller 6F guiding catheters [2, 3]. There were early enthusiastic adopters and as utilization grew, improvements in patient comfort and reduction in bleeding complications were noted.

The Problem with Access

Bleeding complications after both diagnostic and interventional cardiac catheterization are most commonly related to the access site and are associated with significantly higher morbidity, mortality and cost [12–15]. One large study has reported that major bleeding occurred in 2.8% of all patients hospitalized for acute myocardial infarction [16]. Intracranial bleeding and gastrointestinal bleeding are well acknowledged potentially fatal events, however, bleeding complications related to the access site have been historically viewed as benign complications. Studies conducted by Doyle et al. and Yatskar et al. have shown that major femoral bleeding complications after cardiac catheterization including major hematoma, external bleeding, and retroperitoneal bleeding are associated with an increased short and long term mortality [12, 17]. Consequently, femoral access site bleeding complications should not be disregarded. It has been reported that using a transradial instead of a transfemoral approach is the most effective method of reducing major bleeding [18].

The frequency of bleeding complications is significantly higher in the setting of ST-elevation myocardial infarction. One study conducted using the CathPCI registry noted that bleeding complications in the ST-elevation myocardial infarction (STEMI)

subgroup were more than twice as likely when compared to the non-ST elevation myocardial infarction (NSTEMI) subgroup and close to 4 times as likely in comparison to patients undergoing PCI electively [19]. The same study provided a few explanations for this. Firstly, the STEMI subgroup had lower utilization of the transradial approach in comparison to the NSTEMI and elective PCI subgroups. Secondly, the STEMI subgroup was more aggressively anticoagulated. Lastly, there was higher utilization of intraaortic balloon pumps, which have been associated with a larger bleeding risk [20].

In addition to the morbidity and mortality associated with post PCI bleeding, a significant economic impact can also be noted. One study by Kugel-mass et al. showed vascular complications had an added cost of approximately \$6400 and added close to 3 days of hospitalization [14]. Studies comparing transfemoral and transradial approaches have shown significantly lower hospital costs with the transradial approach. An early study published in 1999 showed that among patients undergoing diagnostic cardiac catheterization, the transradial approach was associated with savings of \$290 per case [21]. It is likely that these savings were due to decreased procedural complications and shorter hemostasis times. The savings would be expected to be higher in the case of PCI due to the more aggressive utilization of antiplatelet and anticoagulant agents. Disadvantages of the transradial approach include longer procedure times and higher crossover rates. The question that needed to be answered was whether the potentially higher costs of longer procedure times and higher crossover rates were counterbalanced by fewer complications. According to a systematic review conducted by Mitchell et al., which accounted for these variables, the transradial approach was favored in all conditions tested and resulted in a \$275 less cost per patient [5]. Another reason for the economic advantages of the transradial approach is the increased likelihood of same day discharge. One study involving over 100,000 Medicare beneficiaries showed that same day discharges occur in only 1.25% of elective PCI cases. A significantly higher proportion of those patients underwent PCI using the transradial approach [22]. Studies have shown that same day discharge after uncomplicated elective transradial PCI leads to a relative cost reduction of 50% [23].

Transradial catheterization is also associated with increased patient comfort. From the time when early studies were published, there has been strong patient preference for transradial catheterization and an improved post procedure quality of life has been noted in comparison to the transfemoral approach. One small study has shown transradial PCI led to reduced pain, and improved physical health and walking ability [21]. Results from the OCEAN RACE trial also showed that the transradial approach is associated with improved psychological outcomes and fewer mobility-related problems [24]. The RIVAL trial also demonstrated

that when patients were asked regarding their preference for subsequent procedures, transradial was the more frequent choice [25]. The transradial and transfemoral approaches are compared in Table 1.

Trends in Utilization

Despite the many advantages of the transradial approach, its adoption varies significantly across the United States and internationally. The use of the transradial approach was adopted quickly in Europe and Asia. Studies have reported that a significant num-

Table 1 Comparison of Transradial and Transfemoral Access.

	Radial access	Femoral access
Anatomy		
Vessel caliber	2–3 mm	6–10 mm
Vascular course	Variable	Constant
Vessel depth	Constant, superficial	Variable, related to body habitus
Adjacent neurovascular structures	No	Yes
Technical features		
Success rates	Marginally lower than for femoral access	Marginally higher than for radial access
Procedure length	Comparable	Comparable
Contrast load	Comparable	Comparable
Fluoroscopy time	Marginally longer than for femoral access	Marginally shorter than for radial access
Choice of sheath sizes	Limited	Unrestricted
Learning curve	Longer	Shorter
Crossover to alternative arterial access	Higher than for femoral access	Lower than for radial access
IMA graft cannulation	Variable	Simple
Complications		
Access-site bleeding	Lower than for femoral access	Higher than for radial access
Access-vessel occlusion	Approximately 5%	Rare
Access-site pseudoaneurysm	0.05%	Up to 5%
PCI Outcomes		
Rate of MACE	Comparable	Comparable
Patient comfort		
Patient preference	Higher than for femoral access	Lower than for radial access
Time to ambulation	Immediate	4–6 h
Same day discharge	More likely	Less likely
Healthcare utilization		
Cost	Lower	Higher
Length of hospital stay	Shorter than for femoral access	Longer than for radial access

IMA, internal mammary artery; MACE, major adverse cardiac events; PCI, percutaneous coronary intervention.

Modified from Byrne RA, Cassese S, Linhardt M, et al. Vascular access and closure in coronary angiography and percutaneous intervention. *Nat Rev Cardiol* 2013;10(1):27–40.

ber of PCI procedures performed in Japan (60%), France (55%), Canada (50%), Spain (43%), the United Kingdom (35%), India (32%), Italy (25%), Germany (25%), China (25%) and Poland (22%) are performed via the transradial approach [26, 27]. Caputo et al. report that an estimated 20% of PCI procedures worldwide are performed transradially. This number increases to 29% if the United States is excluded from the estimate [27]. The low utilization of this approach in the United States is confirmed by a few studies. One study conducted using the National Cardiovascular Data Registry from 2004 to 2007 showed that only 1.32% of all PCI procedures were performed using the transradial approach [6]. Results from a subsequent study using 2007–2012 data from the same registry showed that utilization of this approach has increased from 1.2% in the first quarter of 2007 to 16.1% in the third quarter of 2012 and accounts for 6.3% of all PCI procedures

performed during the study period [28]. The same study also noted that the transradial approach was more frequently utilized in teaching hospitals and in the northeast region of the United States. Another study conducted by Baklanov et al. from the same registry noted that in the setting of STEMI, the utilization of transradial PCI increased from 0.9% to 6.4% between 2007 and 2011. The study also noted that the transradial approach was associated with a longer median door-to-balloon time but at the same time had lower risk of bleeding and in-hospital mortality rates [29]. A study conducted by Hannan et al. noted that the utilization of the transradial approach for PCI in the setting of STEMI, increased from 4.9% to 11.9% between 2009 and 2010 in the state of New York [30]. Figure 1 illustrates the trends in utilization of the transradial approach for PCI from the National Cardiovascular Data Registry between years 2007 and 2012 [28].

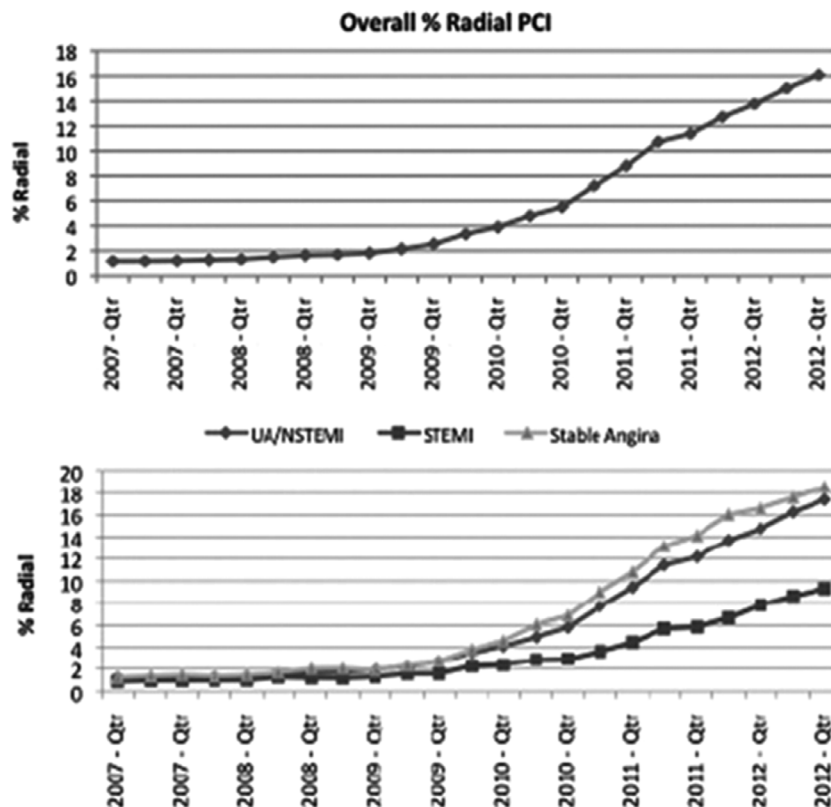


Figure 1 Trends in Utilization of the Transradial Approach for PCI from the National Cardiovascular Data Registry between 2007 and 2012.

PCI, percutaneous coronary intervention; UA, unstable angina; NSTEMI, non-ST elevation myocardial infarction; STEMI, ST-elevation myocardial infarction.

Obtained from Feldman DN, Swaminathan RV, Kaltenbach LA, Baklanov DV, Kim LK, Wong SC, et al. Adoption of radial access and comparison of outcomes to femoral access in percutaneous coronary intervention: an updated report from the national cardiovascular data registry (2007–2012). *Circulation* 2013;127:2295–306.

Randomized Clinical Trials

Multiple randomized clinical trials have been conducted to compare transradial and transfemoral approaches. The RIVAL trial randomly assigned patients with acute coronary syndromes who underwent PCI to either transradial or transfemoral approaches. Findings showed no differences in patients with NSTEMI, however, in STEMI patients, the transradial approach reduced mortality, myocardial infarction, stroke, and non-coronary bypass graft-related major bleeding. One confounding factor for RIVAL was that operator experience with transradial PCI was greater in the STEMI group when compared to the NSTEMI group; this could be a possible explanation for the lack of positive findings in the NSTEMI group [31]. The recently conducted MATRIX trial randomized a total of approximately 8400 patients with acute coronary syndromes, both STEMI and NSTEMI, who underwent PCI across multiple centers to either femoral or radial approaches. Results showed that the transradial approach was associated with a net reduction in adverse clinical events including major bleeding and all-cause mortality [32]. The SAFE-PCI for Women trial, which randomized female patients to transradial or transfemoral approaches showed conflicting results [33]. A total of 1787 were recruited at 60 sites. Findings of the study showed that the radial approach did not significantly reduce bleed-

ing or vascular complications in women undergoing PCI. However, when results for both diagnostic and interventional procedures were combined, there were better outcomes for the transradial approach. The conflicting findings from this trial may also be explained by its early termination due to a lower than expected rate of bleeding and vascular complications. Investigators reported that the originally planned sample size would not be able to show a difference between approaches. RIFLE-STEACS was a multicenter study involving 1001 patients with STEMI randomized to transradial or transfemoral approaches for PCI, which noted that the transradial approach was associated with fewer adverse clinical events, shorter hospital stay, as well as lower overall morbidity and cardiac mortality [34]. Table 2 summarizes the findings of randomized clinical trials involving the transradial approach.

Technical Aspects

Despite the many benefits of the transradial approach, it should be emphasized that it is not always feasible, as many technical aspects need to be considered. In most cases, there is an anastomosis between ulnar and radial arteries, with the predominant blood supply being provided by the ulnar artery [37]. However, the vascular anatomy of the hand can have significant variability, making hand

Table 2 Randomized Trials Related to the Transradial Approach.

Randomized trials	Summary of findings
RIVAL [24, 31]	Transradial approach reduced mortality, myocardial infarction, stroke, and non-coronary bypass graft related bleeding in STEMI patients.
MATRIX [32]	Net reduction in adverse clinical events including major bleeding and all-cause mortality in both STEMI and NSTEMI when transradial approach was utilized.
SAFE-PCI [33]	Transradial approach did not significantly reduce bleeding or vascular complications in women undergoing PCI better outcomes noted when data for diagnostic and interventional procedures combined.
RIFLE-STEACS [34]	In patients with STEMI, transradial approach had fewer adverse clinical events, shorter hospital stay, as well as lower overall morbidity and cardiac mortality.
TALENT [35]	Left radial approach when compared to right, was associated with a lower fluoroscopy time and radiation dose, especially in older patients, and had a shorter learning curve.
OCEAN RACE [24]	Transradial approach associated with improved psychological outcomes and fewer mobility-related problems.
RADAR [36]	Allen test results are not required to identify patients in whom the transradial approach can be safely utilized.

ischemia a possible complication. Studies have suggested that radial artery access can lead to vessel occlusion in 0.8–30.0% of cases [38]. Thus, it may be beneficial to confirm the integrity of palmar arches, prior to utilizing the transradial approach. Guidelines from both the European Society of Cardiology and the Society for Cardiac Angiography and Interventions recommend testing for the integrity of blood supply to the hand prior to utilizing the transradial approach for cardiac catheterization. In 1929, the Allen test was introduced to evaluate the blood supply to the hand in patients with Buerger disease. This test is performed by compressing the radial and ulnar arteries simultaneously while the patient clenches his/her fist, which causes the patient's hand to blanch. Next, the patient is asked to unclench his/her fist while the ulnar artery is released. Return of normal color to the patient's hand is thought to indicate the presence of adequate collateral circulation. The Allen test has since been modified in several ways to test circulation prior to radial artery access [39]. Whether or not this test predicts the likelihood of ischemic complications after transradial access is a controversial issue, with some studies suggesting that many centers no longer utilize it [36]. An international survey, showed that hand circulation is assessed in most cases however no prior testing is performed in 23.4% of cases [7]. Results from the RADAR trial suggest that normal Allen test results are not required to identify patients in whom the transradial approach can be safely utilized [36]. Thus far, a large number of patients have undergone transradial access without Allen testing and only a minimal number of cases of hand ischemia have been reported [40–42]. Therefore, it is important to emphasize that abnormal Allen test results should not exclude patients from undergoing procedures utilizing the transradial approach.

Both left and right radial arteries can be utilized as access for cardiac catheterization and PCI. The decision of which side to use can depend largely on physician preference. Comfortable positioning for both patient and physician is essential to performing safe and successful procedures. The TALENT study reported that the left radial approach was associated with a lower fluoroscopy time and radiation dose, especially in older patients [35]. This may be attributable to more tortuosity of the right subclavian artery and radial loops, making navigation more

difficult [43]. The findings being amplified in older patients are likely due to increased atherosclerosis, tortuosity and calcification. Another reason for increased difficulty in catheter navigation on the right is that the right subclavian artery does not directly feed into the aortic root. Right-sided catheters have to pass through both the right subclavian as well as the brachiocephalic trunk prior to accessing the aortic root. In contrast, the left subclavian artery arises directly from the aortic root allowing for easier navigation. One recent meta-analysis of randomized trials noted that right radial access was associated with a significantly larger risk of crossover to femoral access when compared to left. However, no significant overall differences were present in terms of procedural time, contrast use, fluoroscopy time, or major complications [44]. Although increased procedure time, fluoroscopic time and radiation exposure have been demonstrated with the transradial approach, studies have shown that this significantly decreases with operator experience [25, 45].

The manipulation of catheters to navigate vasculature and engage coronary arteries can be more challenging from a transradial approach. Regular guidewires with a J shaped tip (3 mm radius) can often be larger than the diameter of the radial artery leading to spasm. A better choice for the navigation of small and sometimes tortuous vessels is a guidewire with a smaller J tip (1.5 mm radius). Utilizing hydrophilic angle-tipped wires can be associated with accidental perforation of small arterial branches, especially in the anticoagulated patients. As a result, close fluoroscopic guidance is required when these wires are utilized. It is essential for instruments not to be advanced against resistance due to the smaller diameter of the arteries in the upper extremity. Thinner 0.014-inch guidewires and smaller catheter sizes can be utilized to navigate radial ulnar loops and tortuosity with subsequent exchange with the standard 0.035-inch guidewire when it has been advanced past the brachial artery.

Other limitations of the transradial approach are related to smaller diameter of the radial in comparison to the femoral artery. One study involving patients that underwent radial artery ultrasonography showed that it has a mean size of approximate 2.5 mm [46]. This makes 6F sheaths, which are

2 mm in diameter the largest that can be properly utilized. In most cases, PCI can be adequately performed with guide catheters of this size. However, in some instances involving complex coronary artery disease such as bifurcating lesions or situations requiring dual stent techniques, larger catheters can become necessary. Reports have indicated that a sheathless technique can be safely utilized to allow for larger guiding catheters up to 7–8F in size [47]. There have been efforts to miniaturize the catheter size for transradial catheterization and intervention in order to decrease radial artery occlusion, facilitate navigation, and improve patient comfort with less spasm. A study conducted by Masutani et al. has demonstrated the successful and safe use of a “slender system” in which 0.010-inch guidewires are utilized along with 3-F catheters for the purposes of treating complex lesions [48, 49]. Future studies and improvements in the transradial technique need to be conducted to refine this method further and reduce limitations.

Learning Curve and Operator Volume

The significant learning curve associated with the transradial approach has been well described in the literature. A meta-analysis conducted by Jolly et al. reported a high procedure failure rate among inexperienced physicians utilizing the transradial approach, however, in experienced operators success rates were comparable to transfemoral approach [50]. Several studies have shown a strong association between operator volume and outcomes with the transradial approach. One substudy of the RIVAL trial showed a strong correlation between institutional volumes and outcomes with the transradial approach but no such relationship was demonstrated with the transfemoral approach [51]. A study conducted by Ball et al. showed that a minimum case volume of 50 is required to achieve acceptable outcomes and odds of failure of this approach decrease significantly with increases in operator volume [52]. Another study utilizing the CathPCI registry showed that operators experienced with the transradial approach are more likely to utilize it in higher risk patients [53]. Approaches from the right radial artery can be significantly more challenging

when compared to the left due to the right subclavian artery not feeding directly into the aortic root as well as other factors that have been mentioned previously. For newer operators, the left radial approach may be best during their learning phase. Investigators of the TALENT trial also reported that among trainees, a left radial approach was associated with a much shorter learning curve with reductions in access and fluoroscopy times as operator volume increased [35]. To summarize, these findings highlight the significant learning curve associated with the transradial approach and emphasize the impact of experience on the outcomes associated with this approach.

Radiation Exposure

As mentioned previously, there have been concerns regarding increased radiation exposure for both patients and operators, which may have contributed to the suboptimal utilization of the transradial approach. In a meta-analysis and systematic review conducted by Plourde et al., the transradial approach was associated with a small yet significant increase in radiation exposure by 1–2 min for both diagnostic and interventional procedures [54]. Recent studies have shown that this gap is much smaller, with the transradial approach adding about 30 s in fluoroscopy time [54]. It is possible that this reduction is due to the advent of dedicated devices for the transradial approach, improvement in techniques, and an increase in operator experience. It has been consistently demonstrated that the increased radiation dose and fluoroscopy times significantly decreases with operator experience, and no differences in radiation exposure are observed when expert operators perform transradial procedures [25, 45, 54].

Conclusion

In conclusion, although the transfemoral approach to PCI has been traditionally dominant, there is an increasing utilization of the transradial approach. In light of significant benefits shown by observational studies as well as randomized clinical trials including fewer bleeding complications, reduced morbidity and mortality, improved quality of life, as well as better economic outcomes; the transradial

approach has surpassed the transfemoral approach to become the dominant method for performing PCI in some countries. Its utilization in other countries like the United States remains suboptimal due to a prolonged “learning curve”, longer procedure times, and a higher crossover rate, mostly among older operators that did not receive transradial training and are unwilling to change their practices. Further efforts need to be made to increase its uti-

lization as well as refine this method and reduce limitations for the purposes of improving patient outcomes and comfort while simultaneously reducing costs.

Conflict of Interest

The authors declare no conflict of interest.

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