Percutaneous coronary intervention (PCI) continues to serve an important role in the management of ischemic heart disease. More than 1 million cardiac catheterizations and more than 500,000 PCIs are performed every year in the United States, and millions more are performed worldwide. The vascular site of access, however, has evolved over the years. After initially occurring via the classic brachial artery cutdown approach in the 1970s, based on the innovation of the Judkin’s technique, the field quickly moved toward the percutaneous femoral approach, which is currently the most commonly employed arterial vascular access worldwide for PCI. Despite this important advance, as many of the providers and patients who have been part of this technique know all too well, the femoral approach is fraught with its own shortcomings and complications. The field was calling for a new approach, and the world turned its attention to the radial artery. Ever since the introduction of radial coronary angiography in 1989 by Lucian Campeau—quickly followed by radial PCI in 1992 by Ferdinand Kiemeneij—the use of radial coronary angiography and PCI has steadily increased over the years worldwide and more recently has gained increasing favor in the United States. Many centers have made radial access the primary access site for routine cardiac catheterization, including those that require PCI. Over the past 5 years, there has been a rapid uptake in the employment of radial access for coronary interventions. As of 2012, 15.3% of PCIs in the United States were performed via a transradial approach. The benefits observed by using the transradial as opposed to the transfemoral approach have been increasingly studied across many of the high-volume centers. Multiple studies have shown a consistent advantage of the radial approach for diagnostic and interventional procedures over the femoral approach in regard to key periprocedural adverse outcomes, such as bleeding or major access site complications. The radial artery seems to be the ideal choice for arterial catheterization because there is usually a redundant “ischemic protective” dual blood supply to the wrist and hand, there are no major nerves at risk of injury, and the radius provides a resistant surface on which to achieve hemostasis at the completion of the case. Because the technique of transradial catheterization is relatively new in the United States, many senior invasive cardiologists and interventionists who trained prior to the rise in popularity are now learning the radial technique from some of the more experienced junior operators coming out of recent training programs. Ball et al demonstrated the presence of a learning curve with improving rates of PCI success and decreased fluoroscopy time along with decreased contrast use as transradial PCI operators become more experienced (particularly > 50 cases). The European Society of Cardiology recently updated its guidelines to state that radial arteries should be the default access site for PCI, including in high-risk acute coronary syndromes. As with any paradigm shift in medicine, we may be close to the tipping point of a major disruptive change in what is considered the standard access approach for cardiac catheterizations and coronary interventions in the United States. **BLEEDING/VASCULAR COMPLICATIONS** Access site hematomas large enough to require transfusion have been linked to an increased risk of adverse events, including mortality. Numerous observational studies and randomized trials have compared the radial artery approach for PCI to the femoral and/or brachial artery approach and have consistently demonstrated statistically significant improvements in bleeding and vascular complications. **From Femoral to Radial: An Ongoing Paradigm Shift** Updates on improving outcomes and reducing complications. **BY ROHAN R. WAGLE, MD, AND RALPH BRINDIS, MD, MPH, MACC, FSCAI**
significant reductions in bleeding and access site complications with the radial approach.10-14 A large meta-analysis performed by Jolly et al15 of 23 randomized trials between 1994 and 2007 compared outcomes between the radial and femoral approaches to PCI (Figure 1). Major bleeding occurred significantly fewer times when the radial approach was used compared to the femoral approach, with an odds ratio of 0.27 (95% confidence interval, 0.16–0.45; P < .01).

With the growing obesity epidemic in the United States, there is some concern about the safest approach for PCI in obese patients to reduce vascular complication rates. Cox et al16 performed a retrospective review of 5,234 cardiac catheterizations and demonstrated higher trends of radial artery access and femoral vascular closure devices in the obese population. Between the observed radial and femoral groups, there was a statistically significant reduction in the rates of vascular complications in obese and nonobese patients with the transradial approach.

**OUTCOMES IN ACUTE CORONARY SYNDROME**

There have been multiple randomized trials, observational studies, and meta-analyses comparing the outcomes of transradial and transfemoral approaches to PCI in acute coronary syndrome (ACS). In 1997, Mann et al17 first studied in a randomized fashion the outcomes of radial artery access compared to femoral artery access in patients diagnosed with ACS. There were significantly less access site bleeding complications in the radial group compared to the femoral group, in addition to fewer hospitalization days and reduced hospital costs without any increase in mortality, coronary artery bypass grafting (CABG), or myocardial infarction (MI). In 2009, Sciachbasi et al18 studied 1,305 patients from 2003 to 2006 with high-risk, non–ST-elevation ACS who presented to multiple Italian hospitals and either underwent PCI via the transfemoral (863 patients) or transradial approach (307 patients). There was no significant difference in mortality or reinfarction up to 1 year after the initial procedure between the two groups. Furthermore, despite being more likely to have received thienopyridines or glycoprotein IIb/IIIa inhibitors, patients in the radial group had significantly less bleeding than those in the femoral group.

In 2011, Jolly et al19 reported the results of the RIVAL study, a large, multinational, multicenter, randomized trial that enrolled 7,021 patients with ACS and compared outcomes with radial and femoral access. There was no significant difference in mortality, MI, stroke, or non–CABG-related major bleeding at 30 days between the two approaches (Figure 2). However, presence of a large hematoma and pseudoaneurysm needing closure was statistically more common in the femoral group compared to the radial group. Additionally, high-volume radial access centers were noted to have better outcomes and lower crossover rates than centers with lower volumes. Interestingly, femoral access was not superior to radial access at high-volume femoral centers. Patients with ST-elevation myocardial infarction (STEMI) undergoing radial access for PCI showed a reduced incidence of the previously mentioned primary and secondary outcomes when compared to those undergoing femoral access.

In 2012, Mehta et al20 reanalyzed the initial RIVAL registry and divided the patients into those presenting with STEMI and those with non-STEMI, only to find that patients with STEMI who underwent radial access were less likely to experience the primary outcome of death, MI, stroke, or non–ST-elevation myocardial infarction (STEMI) undergoing radial access for PCI showed a reduced incidence of the previously mentioned primary and secondary outcomes when compared to those undergoing femoral access.

In the most recently published analysis of the National Cardiovascular Data Registry (NCDR) in 2013, Feldman et al21 examined 294,769 patients undergoing PCI for STEMI between 2007 and 2011 and compared transradial and
transfemoral approaches, showing that there was no difference in the procedural success rates between these two groups, along with a lower adjusted risk of bleeding and a lower adjusted risk of in-hospital mortality with the transradial approach. In this report from the NCDR CathPCI registry, there were < 1% of STEMI patients who underwent primary PCI via transradial access in 2007, whereas > 6% of STEMI patients underwent transradial access in 2011. The demonstration of a slow but steady rise in transradial access, both in its growing popularity and the increasing operator comfort by United States interventionists while appreciating the importance of rapid door-to-balloon time, is a testimony of the advantages of the transradial technique (Figure 3).

INCIDENCE OF RADIAL ARTERY OCCLUSION
Radial artery occlusion (RAO) is the most common complication after transradial catheterization. This phenomenon had previously been described in 1973 in the critical care literature when Bedford et al22 first published the results of approximately 100 patients undergoing radial artery cannulation for invasive hemodynamic monitoring and showed that prolonged cannulation times increased the risk of catheter-related thrombus formation (25% occlusion rate with cannulation < 20 h; 50% occlusion rate with cannulation between 20–40 h). Since then, it has been shown that repeated cannulations23,24 larger introducer sheath size,24,25 and decreased ratio of arterial diameter to sheath26 have been associated with a higher incidence of RAO with transradial catheterizations. Heparinization during the procedure has been linked to a lower incidence of RAO, as well as improved sheath duration and patent hemostasis rates, with transradial catheterization,27 but this remains a complication even in the hands of experienced operators.

In 1997, Stella and Kiemeneij et al28 studied the incidence of clinical RAO in 563 patients undergoing transradial catheterization with PCI and found the occurrence rate to be 5.3% prior to discharge. At 1-month follow-up, approximately 50% of the patients with clinical RAO showed evidence of spontaneous recanalization. Hemostasis was achieved in all of these patients by application of occlusive tourniquets for 30 to 60 minutes with gradual release of pressure, followed by a pressure bandage for 4 to 6 hours.

In 2008, Pancholy et al29 addressed concerns regarding the method of achieving hemostasis as a potential cause of RAO by comparing patent hemostasis with traditional occlusive hemostasis after transradial catheterization. Patent hemostasis (plethysmographic confirmation of radial artery patency with occlusion of ulnar artery) achieved a 59% relative risk reduction in RAO in the study population of 480 patients undergoing transradial catheterization. This method of hemostasis has been the biggest leap forward in addressing issues with RAO, but it continues to be a concern with transradial catheterization. With the proper technique, operators can achieve an RAO rate of < 1%.30 There is only one reported case of critical hand ischemia after transradial cardiac catheterization, but this patient also had a pre-existing occluded ulnar artery.31

RADIATION EXPOSURE
Radiation exposure to the patient and the operator has been studied in multiple trials comparing transradial versus transfemoral cardiac catheterizations. In 2013, Jolly et al32 demonstrated that more experience for both femoral and radial operators was important in reducing radiation exposure. Furthermore, high-volume centers had the least amount of radiation exposure despite which method of access was employed. Most trials have used fluoroscopy time as a surrogate for radiation exposure, although this...
assumption seems to be more accurate for assessing radiation exposure to patients than it does to operators.

In a review article in 2012, Rao et al\textsuperscript{33} summarized the results of 16 randomized trials in which fluoroscopy or dosimetry data were compared and concluded that the transradial approach to angiography led to an approximate 1- to 2-minute increase in fluoroscopy time in most trials. Between the two techniques, operator radiation exposure during the transradial approach without the use of a movable floor shield was associated with a 100% increase in operator exposure compared to the transfemoral approach.\textsuperscript{34} Exposure to patients was not affected, which raises the question of whether operators were standing closer to the radiation source during radial procedures. When a floor shield was utilized, operator radiation exposure during the transradial approach was reduced to less than that with the transfemoral approach.\textsuperscript{35}

Sciahbasi et al\textsuperscript{36} performed the first trial comparing operator radiation exposure between the left and right radial approaches for PCI and found that fluoroscopy times, as well as radiation exposure to the body, shoulder, and thyroid, were similar between the two approaches, whereas exposure to the left wrist was slightly less when the left radial artery was used. Two subsequent studies showed that left radial access was associated with lower radiation exposure to the operator with similar success rates and procedural duration time compared with right radial access.\textsuperscript{37,38} The radiation exposure during all of these studies was well below the accepted limits of exposure to patients or operators. The increased radiation exposure in transradial cases seems to be linked to the diagnostic portion of the case, suggesting that the increase in fluoroscopy time may be due to the observed difficulties of passing the first wire initially across the subclavian artery and into the aortic root. With the use of exchange-length wires during the remainder of the procedure, there seems to be no further increase in fluoroscopy time during the PCI portion of these cases. The use of a lead drape has been suggested to reduce the amount of radiation exposure to the operator during transradial cases.\textsuperscript{39}

**ECONOMICS OF THE TRANSRADIAL APPROACH**

Many countries outside of the United States, including Spain, the United Kingdom, France, Canada, and Japan, perform 40% to 50% of their PCIs via the transradial approach.\textsuperscript{40} With the ever-increasing costs of health care in the United States and an evolution toward bundled payment models, length of hospital stay after PCI has attracted the attention of hospital administrators.

Jabara et al\textsuperscript{41} observed all transradial PCIs in a single-center tertiary care hospital between 2004 and 2007 and found that complications were rare (5.3% event rate), and none occurred between 6 and 24 hours postprocedure. Thus, it is rare that early complications would prevent early discharge, and those complications occurring after 24 hours would have been unaffected by routine next-day discharge. Brayton et al\textsuperscript{42} recently published a meta-analysis in which seven randomized controlled trials employing transradial access for PCI in 60.8% of the cases demonstrated no difference in death, MI, target lesion revascularization, major bleeding, or vascular complications between same-day discharge and routine overnight observation.

At the London Chest Hospital, the development of a dedicated “radial lounge,” where patients recover after transradial access for angiography or PCI, has been shown to facilitate same-day discharges and has favorably affected in-patient bed capacity.\textsuperscript{43} Amin et al\textsuperscript{44} studied the health care costs of PCI hospitalization and found transradial PCI to be associated with a total cost savings of $830 over transfemoral PCI. Most of the cost difference was from postprocedural savings, especially in the population at highest risk for bleeding and mortality.

**CONCLUSION**

The transradial approach to cardiac catheterization and PCI has seen much advancement since its inception in 1992. Although radial access seems to be advantageous compared to femoral access when it comes to bleeding events, vascular complications, and even mortality, there are issues with radial artery catheterizations that are still left to be studied and understood in greater depth. It seems evident that operator experience is directly proportional to procedural success, and radiation exposure and contrast usage seem to be dependent on this learning curve as well.