Transradial Approach to Cardiovascular Interventions: An Update

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Abstract

Keywords

- radial artery
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- vascular complications
- cost-benefit analysis
- worldwide adoption
- feasibility studies

Background Since the first cardiac catheterization in 1929, the procedure has continually evolved with advances in understanding, capabilities, and ease of operation. Though historically performed by cut down of the brachial artery, cardiologists soon learned that transfemoral access was both easier to perform and more efficacious with regard to patient outcome. In the last 20 years, the transradial approach has been adopted, and is being utilized with increasing frequency.

Methods We conducted a survey of literature published concerning safety, efficacy, cost-effectiveness, and global uptake of transradial catheterization with specific attention to how transradial interventions compare with transfemoral interventions.

Results This review of literature indicates that when performed by an experienced interventionalist, radial catheterization is as effective as femoral catheterization and has additional benefits of shorter length of hospital stay and reduced patient costs. Transradial access is superior to transfemoral access in some, but not all, clinical scenarios; in addition, it is an effective alternative for catheterization in patients contraindicated for transfemoral procedures. Adoption of radial access in the United States is at a faster rate than previously expected, though rate of use varies drastically worldwide.

Conclusion The transradial approach is an excellent option for carrying out cardiovascular interventions, and will be adopted by more cardiologists in the upcoming years.

The history of cardiac catheterization began in 1711 with an equine biventricular catheterization and progressed through the centuries.¹ In 1929, German physician Forssmann boldly performed a right heart catheterization on himself, and subsequently shared the 1956 Nobel Prize in Medicine with Columbia University physicians Cournand and Richards for the development of cardiac catheterization.¹ The actions of these medical pioneers paved the way for modern interventions of the heart and coronary arteries, prompting the advent of interventional cardiology.¹ In 1989 Campeau was able to perform the first diagnostic cardiac catheterization via the radial artery, and in 1993 Kemeneij and Laarman were able to complete a radial access percutaneous coronary

artery intervention, a procedure involving angioplasty and stenting.²

With regards to arterial access site, the femoral artery and radial artery are routinely selected. For patients in whom radial and femoral access is impossible, the brachial method is sometimes employed, though less desirable due to the risk of complications, including neuropathy.^{3,4} Rarely, experienced operators opt for axillary entrance.³ Unfortunately, major weaknesses of catheter-based procedures are the risks of acute vessel closure, restenosis, bleeding, and pseudoaneurysm.^{1,3} Overall analysis of complications in 200,000 patients undergoing diagnostic cardiac catheterization indicates that less than 1% of patients experience vascular complications

such as thrombosis, pseudoaneurysms, or bleeding requiring transfusion.³ Much research in the last 30 years has been devoted to determining which access site is best suited for particular patients and circumstances; as technological advances expand the boundaries of possibilities, this work continues.

In spite of the efficacy of femoral catheterizations for cardiac procedures, vascular bleeding complications give rise to increased morbidity and duration of hospitalization, especially when aggravated by aggressive anticoagulation and antiplatelet treatment.^{5,6} The femoral approach has been compared with the radial approach for both diagnostic and interventional procedures in multiple randomized trials and observational studies. An important advantage of the radial artery is that unlike the brachial and femoral arteries, it is not an end artery, so even in the event of occlusion, blood from collateral arteries will prevent ischemia of the territory that it supplies. Current literature suggests lower rates of vascular and neurological complications in radial access procedures since the artery is more compressible, facilitating sheath removal, and not immediately associated with a nerve. Numerous studies also report earlier patient discharge, earlier time to ambulation, patient preference for the procedure, and a shorter recovery period associated with radial access.⁷ A potential complication with the procedure is radial artery occlusion, which hinders future radial access and use of the artery for dialysis fistulas and bypass grafts.⁸ The reported rates of radial artery occlusion vary widely, spanning 5 to 40% depending on institution and study specific protocol.^{9,10} However, hand ischemia is largely preventable if the patient's ulnar supply to the palmar arch is assessed before the procedure by Allen test.⁸

We aim to review praxes and trends of transradial catheterization procedures across the globe, paying particular attention to metrics of cost-effectiveness, procedural safety, complications, and effectiveness across a variety of clinical scenarios.

Transradial Access Safety and Efficacy

Transradial access for cardiac catheterization and percutaneous coronary intervention (PCI) reduces risks of access site bleeding and vascular complications without compromising the success and range of possibilities already associated with modern day PCI.¹¹ These benefits initially came at the cost of increased access site crossover and decreased procedural success rates; over time, the procedure was refined to minimize hazards and further increase patient comfort.¹¹ Bertrand and coworkers compiled a meta-analysis of 10 randomized, controlled trials evaluating the effectiveness of the radial versus the femoral approach in primary PCI. They found correlations between the radial approach and improved survival and reduced vascular complication rates, in addition to a trend suggesting a reduction in major bleeding events following radial access.¹² Another meta-analysis of 12 studies compared outcomes of transradial and transfemoral PCI, and found significant reductions in mortality, periprocedural major bleeding, and risk of adverse effects such as death,

stroke, and myocardial infarction with the radial approach.¹³ However, conclusions from the RIVAL (Radial Vs femoral Access for coronary intervention) trial, the largest randomized controlled trial comparing radial and femoral procedures, found no difference in incidences of major bleeding, myocardial infarction, stroke, and death between the two.¹⁴ Although the RIVAL study enrolled over 7,000 patients with acute coronary syndrome undergoing coronary angiography or PCI, Rao and Krucoff clarify these findings to properly contextualize the results. Bleeding events in the RIVAL trial were largely unrelated to the access site, and radial access was demonstrated to reduce major vascular complications.¹⁵ In addition, benefits of the radial procedure were most clearly seen in centers that had high levels of experience with radial procedures.¹⁵ Finally, there was an association between radial access and reduced mortality among patients with STEMI (ST-segment elevation myocardial infarction), who were most likely enrolled at centers with marked radial proficiency.¹⁵

Radial procedures take approximately 2 minutes longer to complete than femoral procedures, though due to the reductions in short term mortality, this method is the favored approach in primary PCI.¹² Some studies suggest that radial procedures are not associated with higher radiation exposure for the patient, though others maintain that they are associated with a substantial increase in exposure, albeit still below the threshold for deterministic effects.^{16,17} A third opinion maintains that once operator expertise is accounted for, there is no difference in patient radiation exposure across the two access sites.¹⁸ Rao and Krucoff affirm this finding and reconcile many of these differences by maintaining that radial access is only superior to femoral access when both the operator and facility have attained procedural proficiency.¹⁵ To achieve proficiency, they advocate for adoption of a "radial first" approach among cardiologists and the catheterization laboratory team, and encourage cardiologists to seek formal radial-specific training.¹⁵ Although it appears that the completion of 50 procedures is sufficient to overcome the learning curve, they provide information illustrating that efficiency and outcomes improve with experience; after an operator has completed about 300 to 350 cases, each case is typically completed under 20 minutes, the sheath insertion time is under 5 minutes, and the rate of failure is under 5%.¹⁵ Until operators are performing at an experienced level, transradial procedures have higher rates of failure, take longer to complete, and are associated with increased radiation exposure.¹⁵

Risk Reduction

The risk for adverse bleeding effects is greatly reduced if a radial procedure is performed by an experienced operator, in the context of STEMI, or at a high-volume radial center.¹¹ There is also evidence in support of anticoagulation agents, which reduce access site bleeding in transradial but not transfemoral procedures.¹¹ When examining access site bleeding complications, data remains controversial when comparing femoral procedures with a closure device to radial procedures; some data maintains rates are comparable, though there is evidence that rates of access site bleeding is

up to sixfold greater with femoral procedures even when a closure device is utilized.^{5,19} However, the femoral closure device makes femoral access comparable to radial access with regard to procedure length, time until patient mobility, and time until the patient can maintain an upright position.¹⁹

Despite the increased adoption, there are still tasks that must be addressed regarding both technique of the radial procedure and its implementation.²⁰ Of four important issues, the first is access site bleeding, has the potential to evolve into forearm hematoma and compartment syndrome if not monitored properly.²⁰ The next, radial artery injury and occlusion, can be reduced with smaller sheath size, appropriate anticoagulation, and allowing the patient to remain in a state of patent hemostasis following the procedure.²⁰ The third remaining challenge encompasses minimizing radiation exposure for both the patient and the operator, and the fourth suggests that implementation of a successful radial program in a hospital setting is dependent on operators with both sufficient proficiency at completing the radial procedure and capability of timely femoral bailout if needed.²⁰

Economic Considerations

Two important factors to consider for patient care are cost of a procedure and the quality of life that follows. In 1999, Cooper et al found that in patients undergoing diagnostic cardiac catheterizations, radial procedures are not only less expensive than femoral procedures for the hospital, but also are generally preferred by patients and associated with an improved quality of life following the procedure.²¹ The economic analysis prospectively measured bed costs inclusive of nursing utilization, catheterization laboratory costs, pharmacy costs, and all other expenses; the 14% (approximately \$300) reduction in costs with the transradial method was largely due to the shortened duration of hospital stay.²¹ This allowed for fewer direct hospital costs and lower bed and pharmacy costs.²¹ The catheterization laboratory costs were equal across both groups.²¹ This model bases conclusions on comparing transradial procedures to transfemoral procedures without the use of a closure device, and assumes that a transfemoral procedure with the use of a closure device would be more expensive, due to the added cost of the closure device itself.²¹ Over time, further cost reduction may be expected with transradial access due to decreased laboratory costs as operator experience increases and specialized equipment is designed for radial procedures is introduced, as well as the option for performing other procedures through radial access sites.²¹

Approximately a decade later, Roussanov et al performed a similar cost-effectiveness study comparing radial and femoral access for diagnostic catheterization procedures. Unlike the Cooper et al analysis, this investigation includes transfemoral procedures both with and without closure devices and used an economic analysis that evaluated costs associated with specific aspects of each procedure.⁷ The overall result was that the transradial procedure was more cost-effective than both transfemoral procedures, through transfemoral procedures with a closure device were less expensive than those

without.⁷ The more detailed findings of expense itemizations indicate that when comparing the radial group to either femoral group, the access cost was higher in the radial group, though the catheter cost, contrast cost, and recovery cost was lower.⁷ The total cost savings per patient undergoing the transradial approach was approximately \$77 to \$180.

A final cost-benefit study presented is a 2012 systematic review of 14 published randomized, controlled trials by Mitchell et al, who used a stochastic simulation model of per-case costs and considered procedure and hemostasis time, costs of repeating the procedure at an alternative site if the first attempt failed, and the inpatient hospital costs associated with complications arising from the procedure.²² They found that the radial approach was approximately \$275 less per patient from the hospital perspective, a number similar to the Cooper et al study published years before. The cost discrepancy in the Roussanov et al study may be due to the fact that it was not randomized or prospective, and operator discretion in access site chosen may have skewed the data.⁷ Unlike the Cooper et al study, which credits decreased hospital stay for the reduction in overall cost, the Mitchell et al analysis attributes the cost savings to a reduction in complication costs with the transradial approach relative to the transfemoral approach.²² This model also extrapolates projective conclusions. For example, despite the radial procedure taking an average of 1.5 minutes longer than the femoral procedure, the radial procedure would need to increase to 20 minutes longer than the femoral procedure for the added cost of catheterization laboratory time to wholly offset other cost differences and make femoral procedures less expensive than radial ones.²² Alternatively, reducing the rates of transfemoral complications by 60% with no accompanying reduction in transradial complication rates would also make transfemoral access the more economic choice.²² Although the authors did not include studies involving femoral closure devices in their systematic review, they suggest that femoral closure devices make transradial and transfemoral procedures equivalent with regards to rates of vascular complications. The transradial approach would be \$1.18 more expensive than the transfemoral approach with a vascular closure device, with the added cost from transradial access site failure.²² However, if the complication rate of the transradial method is reduced by only 0.1%, the transradial procedure becomes \$18 less than the transfemoral procedure with vascular closure device per case, indicating that miniscule reductions in complication rates yield savings.²²

Over 1 million diagnostic cardiac catheterizations are performed in the United States each year, and the additive effects of total savings could be used to increase the budget for nursing units to combat the shortage of cardiac trained nurses in catheterization facilities, benefit the health care system at a national level or influence local decisions regarding whether a local hospital should switch to a radial program.^{7,22} Therefore, though pervasive acceptance of the transradial method would require an initial cost investment for retraining interventional cardiologists, substantial reductions in cost and morbidity make this a worthwhile venture.²¹

Clinical Applications

Certain clinical presentations are better suited to radial access procedures, while others are better suited to femoral access procedures. In some cases, the access site does not make a significant impact in the outcome, and is best left to operator discretion. Cases representative of each category will be outlined in the following discussion.

There are three clinical presentations that are unaffected by whether the patient received a transradial or transfemoral procedure: patients presenting with silent cerebral infarcts following aortic stenosis, patients with PCI-related ischemic strokes, and patients who have complex arterial bends. Silent cerebral infarcts are more likely following catheterizations, though occurrence is independent of whether the catheterization was performed radially or femorally.²³ Silent cerebral infarcts are caused by microembolisms, and there is a higher infarct risk in patients who are either tall or have a low transvalvular gradient.²³ Rates of PCI-related stroke did not differ following a radial versus femoral procedure, though factors that increased likelihood of a PCI-related stroke include: more contrast use, larger catheter size, and previous rotational atherectomy.²⁴ Finally, arterial bends vary by patient, and are not characteristic of approach site, though bends in peripheral arteries do interfere with catheterization.²⁵ Around 25% of the population has moderate to severe bends that complicate procedures and add to risk of atherosclerosis and arterial elongation.²⁵ Smaller sheath size is ideal in both radial and femoral procedures, and novel 4F catheters have proven to be successful in both without access site complications, artery occlusion, stent dislodgement, or inadequate contrast opacities.²⁶

There are two patient populations in which the femoral access site is favored over the radial access site—children under the age of 2 and critically ill patients. In children less than 2 years old, arterial injuries require immediate treatment with microvascular techniques.²⁷ Risks associated with small vessel caliber, vessel spasms, and tissue necrosis make practitioners hesitant to perform arterial reconstructions. In a study of nine cases, five were performed with femoral access. However, eight of nine children still sustained iatrogenic injuries related to operative transection or catheter manipulation.²⁷ In the critically ill, complication rates were not affected by peripheral vascular disease, greater age, and increased procedure length, although rates of complications were associated with difficulties in percutaneous and surgical cut down insertion of radial catheters.²⁸

A final note on transfemoral procedures deals with the use of femoral closure devices. When a femoral closure device was used, whether complication and access site bleeding rates are equivalent to those with radial procedures remains contestable, though procedure length, time until patient mobility, and time until the patient could maintain an upright position were similar across the two.^{15,19} However, patients consider transradial procedures to be more comfortable than transfemoral procedures both with and without the closure device.²⁹

There is a growing number of scenarios for which radial access ought to be indicated, and a substantial number of

presentations that can benefit from unusual utility of the radial artery. Both single studies and large meta-analyses indicate that radial procedures are just as safe and feasible as femoral procedures for STEMI following thrombolysis, and are associated with lower incidences of bleeding events and vascular complications.^{30,31} In addition, the procedures are associated with shorter time to ambulation, with no significant difference in procedure length.^{30,31}

Octogenarians with left main disease can be treated through transradial procedures, which have the same long-term results as transfemoral procedures, though fewer bleeding risks and access site complications.³² In octogenarians, the radial approach is associated with a high rate of conversion to alternative approaches, though is safe and effective for primary and rescue PCI.³³ Moreover, radial artery access is a feasible, safe, and effective approach for high speed rotational atherectomy in all patients, and is associated with a lower risk of major bleeding complications compared with the femoral approach.³⁴

Patients contraindicated for transfemoral procedures due to lower limb or aortoiliac vascular disease are a very high-risk group, and transradial catheterizations can be successfully performed on them without a high risk of major complications.^{35,36} Restrictions of radial access as alternatives for transfemoral procedures are largely due to the size of the radial artery, which may be inadequate to handle equipment of larger diameters, or constraints from catheter lengths, which may be unable to reach vessels distal to the external and common iliac arteries in taller patients.³⁶ However, these obstacles are sometimes navigable via use of the left radial artery and selection of a more proximal puncture site on the artery.³⁶

Though femoral access predominates in treating patients with cardiogenic shock due to the need for mechanical assistance, radial access has been demonstrated to be beneficial due to the reduction in bleeding complications from anticoagulants and antiplatelet medications.³⁷ Radial access is equally effective as femoral access in patients with previous coronary artery bypass graft, for coronary bypass angiography and intervention, and also associated with fewer access site complications and decreased duration of hospitalization.³⁸ For bilateral cardiac catheterization with simultaneous cardiac biopsy, transradial access is technically feasible, which offers an alternative method of cardiac biopsy in the patient population contraindicated for femoral procedures.³⁹ Although not previously evaluated, recent findings indicate that the radial method is safe and effective for rescue PCI with glycoprotein inhibitor following failed thrombolysis.⁴⁰

Females and obese patients are two noteworthy populations for radial access procedures. Females are more likely to have access site complications such as pseudoaneurysms with the femoral approach, so improving sheath removal techniques or considering the radial approach is suggested.⁴¹ Failure rates of both radial and femoral procedures are higher in females, perhaps because of their smaller artery size.⁴² There is an obesity paradox associated with transradial procedures, meaning that obese patients have fewer vascular complications than nonobese patients following the

procedure.⁴³ Interestingly, the complication rate following transradial procedures was no more frequent in morbidly obese patients than in obese and nonobese populations, and both the transradial approach as well as the transfemoral approach followed by use of a femoral closure device were found to be safe and effective means for evaluating coronary heart disease in the morbidly obese.⁴⁴ These methods are preferred to noninvasive testing in the morbidly obese, which is often inconclusive and sometimes misleading.⁴⁴

Worldwide Adoption

Despite the benefits of radial access, it currently accounts for less than 10% of PCI's performed in the United States, though it is the primary access route for procedures in several European countries, Asian countries, and Canada. Recent trends suggest that the interest and adoption of the radial technique is occurring at a faster rate than previously suggested.^{11,25} Though worldwide, radial access is used in about 20% of PCI procedures, the rates of uptake vary greatly by country.⁴⁵ Norway, Malaysia, and Bulgaria are areas with rates of radial use exceeding 70%.^{36,45} Radial access is in approximately 50% of cases in Canada, and 15% in Central and South America. Rates of radial uptake are lowest in America, Africa, and the Middle East.^{36,45} Likely culprits for its unpopularity deal with the steep learning curve associated with procedural proficiency, the lack of a defined training protocol for rising physicians in the field, the lack of available resources, as well as unresolved concerns regarding procedural failure, radiation exposure, and radial artery occlusion.¹¹

Individual studies have been conducted in multiple countries comparing the efficacy of the radial and femoral approach. Transradial interventions were independently associated with improved clinical outcomes in studies conducted in Scotland, Brazil, India, Turkey, and Spain.^{46–50} There were conflicting reports regarding the procedure in China. Hou et al found that transradial interventions in Chinese patients with acute myocardial infarctions had comparable success to transfemoral interventions with fewer access site complications, though Xia et al suggest that the success rate is lower in radial procedures and that the radial approach could prolong the reperfusion time.^{51,52}

Bertrand et al administered a worldwide international practice survey to about 1,100 interventional cardiologists across 75 countries.⁵³ The guide and diagnostic catheters used for transradial access are similar to those used for transfemoral access, indicating that specialized catheters for radial procedures are rarely utilized.⁵³ In almost 90% of cases, the right radial artery is selected for the case, and the procedure involves Judkins (Cordis Corporation, Bridgewater, NJ) catheters for left and right coronary angiographies and 6F right Judkins or standard extra backup guide catheters for right and left coronary artery PCI, respectively.⁵³ There is a significant amount of variation in specific avenues of transradial practice, implying a need for continued strategization to optimally facilitate transradial access and postprocedural artery patency.⁵³ Two findings of the survey indicate differences in radial procedures as they are performed in America

with how they are performed worldwide. In America, over 85% of physicians perform Allen or oximetry testing before the procedure, though dual-hand circulation testing is not standard worldwide.⁵³ Furthermore, in America, bivalirudin is the most frequently used antithrombotic agent, whereas heparin is the most frequently used agent worldwide.⁵³ Despite the evidence of its efficacy from multiple randomized clinical trials, it is truly amazing how the transradial approach has evolved over the last quarter century without the lack of overwhelming support from leaders in the mainstream medical industry.⁵⁴ Gilchrist maintains that the techniques have grown through a grassroots approach developed by pioneering individuals, and then spread through the support of local radial enthusiasts across the globe.⁵⁴

Remaining Challenges

Although the advantages of transradial access have been thoroughly delineated, there are many avenues for future research, advocacy, and education. In addition, to refining technique, improving patient safety, and clarifying discrepancies concerning advantageousness relative to alternative methods among the existing data, there is a great need to reduce risks of radial artery occlusion.⁵⁵ Radial artery occlusion is generally asymptomatic due to collateral flow from the ulnar artery. However, this is not always the case, as few patients, particularly those with susceptibility to radial artery thrombosis and arteritis, report forearm pain, loss of grip strength, and/or paresthesias.^{55,56} Rates of radial artery occlusion may be higher than previous data suggests, especially in patients who underwent a procedure with larger sheath size.⁵⁶ It remains unclear whether nonsteroidal anti-inflammatory agents and corticosteroids are effective at improving artery patency, and to what extent ulnar compression may be more effective than anticoagulation at improving radial artery patency.^{9,55} Rao and coworkers suggest that postprocedure assessment for radial artery occlusion ought to become an integral part of quality improvement programs in catheterization laboratories, though over 50% of respondents in the Bertrand practice patterns survey reported not assessing the radial artery occlusion before patient discharge.^{53,55}

From a pharmacologic standpoint, lack of preprocedure treatment with calcium channel blockers corresponds with a 30% chance of symptomatic radial artery spasm, though monumental support for one treatment regimen over another appears to be lacking.^{36,56} The difference in vasodilation among various calcium channel blockers is not significant, but varying off target effects have been documented.^{36,57} Furthermore, among antithrombotics administered to reduce rates of radial artery occlusion, effects of heparin, bivalirudin, and low-molecular-weight heparins are not understood. Optimal timing of administration remains unclear, as does the question of whether heparin is needed in patients who are already orally anticoagulated.³⁶

Finally, though the American College of Core Cardiology Training and Accreditation Council for Graduate Medical Education program requirements for graduate education in interventional cardiology both state that fellows should

demonstrate competence in performing transradial procedures, there is a lack of distinct standards defining competence, an established, training protocol for fellows, and published requirements for postgraduate training.³⁶

Conclusion

Clinical variables do not predict success of radial procedures reliably, though success rate is attributed to a different set of factors, including performing the procedure at a high-volume radial center and prioritizing high levels of operator expertise.^{15,58} Instances where the radial procedures were not successful were likely performed by inexperienced operators, or in scenarios where the patient had an obstructed peripheral artery.⁵⁸ Our review indicates that transradial procedures are equivalent if not superior to transfemoral procedures from perspectives of efficacy, safety, and cost-effectiveness, and have a wide range of endovascular uses. Moreover, the number of patients treated via radial access is likely to increase as the Center for Medicare and Medicaid Services (Baltimore, MD) considers "same-day" or outpatient PCI.^{36,58}

Summary

This review suggests a growing number of cardiologists are adopting the transradial approach to cardiovascular interventions. Following attainment of proficiency on the procedural learning curve, transradial access is superior to transfemoral access from multiple perspectives including patient safety, patient comfort, procedural efficacy, and cost-effectiveness; transradial catheterizations are suited to a variety of clinical scenarios as primary and alternate modes of intervention.

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