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ISCHEMIC HEART DISEASE (D MUKHERJEE, SECTION EDITOR)

Radial Artery Versus Saphenous Vein Grafts in Coronary Artery Bypass Surgery: a Literature Review

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Abstract

Purpose of Review Coronary artery bypass grafting is a preferred strategy for complete coronary revascularization in patients who have multi-vessel coronary artery disease, left ventricular dysfunction, and/or diabetes. Both arterial (internal thoracic artery/radial artery) and venous grafts are utilized to bypass the obstruction in native vessels. Despite having radial arterial grafts as a preferred second conduit for bypass, venous grafts are more commonly used.

Recent Findings We review the existing literature and report the preferred conduit based on a recently published meta-analysis of 6 randomized controlled trials. The analysis concluded that radial artery grafts are associated with fewer adverse cardiac events and better graft patency at 5 years of follow-up.

Summary Although saphenous vein grafting is the most commonly used conduit in addition to ITA, current data suggests that total arterial bypass (using RA conduit in addition to ITA) may be the better strategy. Both the US and European consensus guidelines advocate for the use of arterial over SV grafting for most patients.

Keywords Saphenous venous graft · Radial artery graft · Coronary artery bypass grafting · CABG · Graft patency · Graft failure

Introduction

Despite widespread use of effective medical therapy aimed at atherosclerotic risk factor modification [1], coronary artery disease (CAD) remains the leading cause of morbidity and mortality in the USA. Coronary artery bypass grafting (CABG) is the preferred strategy for complete revascularization of multi-vessel coronary artery disease [2]. In patients with left main disease, advanced age, diabetes, and reduced left ventricular ejection fraction (EF), CABG has been shown to improve survival and lower the rates of major adverse cardiac events (MACE) [3] when compared to the medical therapy in stable CAD patients. At the time of surgical revascularization, both arterial and/or saphenous vein grafts (SVG) can be used to bypass native coronary artery stenosis or occlusion. However, due to improved outcomes and superior patency of internal thoracic artery (ITA) grafts compared with vein grafts, there has been a significant increase in the use of ITA as the bypass

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conduit of choice (from 88% in 2000 to 95% in 2009) [4–7]. Nevertheless, the use of arterial grafts has extended beyond ITA to include radial artery (RA), gastroepiploic artery (GEA), and inferior epigastric artery (IEA) grafting.

Although complete arterial revascularization seems theoretically advantageous, SVG continue to be the most widely used conduits in CABG with an average of 2 grafts per procedure [8]. SVG have been shown to have inferior patency as compared to arterial conduits with occlusion rates as high as 25% after the first year post-CABG and 75% over 10 years [8, 9]. From the clinical standpoint, vein graft failure is associated with increased risk of composite endpoint of death, myocardial infarction (MI), and repeat revascularization at 4 years [8]. Given the outlined issues with venous conduits, some surgeons elect to use arterial grafts (specifically RA) instead of SVG. In this review, we aim to discuss and inform clinicians of the current evidence supporting the use of RA conduits over venous grafts in patients undergoing CABG.

Radial Artery Grafts

Shortly after their introduction in the early 1970s, the use of RA grafts was abandoned. This was largely due to poor patency rates, which were thought to be secondary to arterial spasm, endothelial denudation, and graft hyperplasia [10]. Revival of RA graft use ensued two decades later after it was found that the long-term patency rates with RA grafts were significantly higher than previously reported [11]. In their 1992 publication, Acar et al. reported > 90% patency after a mean follow-up of 9 months, among 104 consecutive patients treated with RA grafts in addition to ITA [11]. One major contributor to the improvement in RA graft patency was the ability to reduce the incidence of RA spasm—thought to be the main cause of graft failure. Prevention of spasm was achieved by using the atraumatic "no-touch" technique during harvesting and the use of pharmacologic dilation as opposed to the more traumatic mechanical dilation, as well as optimal use of systemic vasodilator therapy during the postoperative course [12]. Furthermore, rates of graft occlusion can be lowered if RA grafting is used to bypass more severe coronary artery lesions. Use of RA conduits in less severe coronary artery stenosis is prone to spasm and subsequent graft failure because of competitive flow [13].

a. Advantages: In patients without a suitable ITA, RA conduit represents a reasonable alternative. Given its relatively superficial course, RA is an excellent choice for harvesting at the time of bypass surgery. RA is typically harvested from the non-dominant arm, using either an open or endoscopic approach with an ultrasonic scalpel [14]. The usual length (> 20 cm) and diameter (2–3 mm) of the harvested RA conduit allows the surgeon to bypass virtually any coronary artery [12]. Furthermore, its thick muscular wall allows it to be easily anastomosed to both the aorta and the native coronary artery. Unlike SVG, RA graft is preconditioned to high arterial pressure which can explain the superior results associated with its use. Additional benefit of RA use over SVG is the avoidance of ambulatory dysfunction, which is a frequent complication associated with saphenous vein grafting [15]. Furthermore, graft disease is uncommon in RA grafts, a phenomenon that is found commonly in SVG within 5 years of surgery [16].
b. Pitfalls: Although harvesting of the RA rarely results in motor dysfunction or compromised perfusion, sensation abnormality attributable to nerve damage has been described as the most common complication, affecting up to one-third of all patients [17]. Nevertheless, great care needs to be taken to ensure that adequate collateral circulation is present in the ipsilateral forearm prior to RA harvesting. Methods established to confirm the patency of collateral circulation via ulnar artery include Allen's test, arterial Doppler testing, and oximetric plethysmography [18]. Aside from patency of the ulnar artery, other factors which can pose a challenge to using RA as a bypass conduit include visualization of RA plaque on ultrasound, presence of arterio-venous fistula for hemodialysis access, history of trauma, native RA disorders (i.e., vasculitis), and/or previous RA cannulation. Due to the histologic composition of RA as a single-layer elastic lamina with multiple fenestrations, there is a significantly higher prevalence of atherosclerosis in RA as compared to ITA [19]. Finally, the highly dense muscle cell composition of the RA renders it very sensitive to systemic vasopressor administration and to external trauma. [19, 20].

Saphenous Venous Graft

Despite the inferior patency rates of saphenous vein grafts, SVG conduits are utilized in most bypass surgeries, especially in those patients who undergo repeat CABG or have poor arterial conduits. Saphenous vein is a large superficial vein which courses through the medial aspect of the lower extremity and drains into the common femoral vein at the level of the femoral head. Compared to arterial conduits, SVG are thin walled, large in caliber, and have an ill-defined laminar layer. Sparse amount of smooth muscle cells, presence of valves, and abundance of vasa vasorum make these conduits structurally and functionally different from arterial conduits [21].

a. Advantages: In patients who have limited amounts of available graft conduits (i.e., patients with prior bypass surgery, presence of peripheral artery disease, or an arterio-venous fistula for hemodialysis access), single SVG can be used to achieve multi-vessel revascularization. These sequential grafts, which have a single proximal aortic anastomosis and multiple distal coronary anastomoses (m-SVG), are preferred over (s-SVG) grafts in which one SVG has only a single distal coronary anastomosis. Furthermore, the use of sequential vein grafting techniques allows for shorter surgical procedure times and more significant improvement in hemodynamics as well as a more complete revascularization. Interestingly, however, recent data suggest that patients undergoing bypass with s-SVG have superior 1-year graft patency rates and improved clinical outcomes as compared to patients receiving m-SVG [22].

b. Pitfalls: Large caliber, thin walls, and ill-defined elastic lamina make SVG more prone to ischemic injury, lipid deposition, and atherosclerosis as compared to RA grafts [21]. Given their high compliance and the natural adaptation to low pressure, exposure of SVG conduits to arterial pressures can lead some conduits to undergo early graft failure.

Comparison of RA Grafts with SVG in Observational Studies

Survival benefit associated with CABG in high-risk patients is predominantly determined by graft patency. Several observational studies utilizing angiography have shown that RA conduits have superior patency over SVG at a short- and long-term follow-up. RA grafts, either used separately or as composite grafts, have also been shown to have equivalent patency to other arterial grafts [23]. In one of the earliest retrospective studies, Acar et al. [11] showed RA conduits to have 100% patency at 2 weeks following revascularization and 93.5% patency at 9 months of follow-up, thus establishing RA as a reasonable substitute for IMA. In a more recent report, the long-term patency (10 years of follow-up) and perfect patency (widely patent vessel without irregularity, stringed, or occlusion) of the RA grafts were 91.6% and 88% versus 67.1% and 53.4% for SVG, respectively [24]. The most important determinant of patency in this study was the severity of target vessel stenosis, whereas there was no association between patency and either target vessel location or use of calcium channel blockers [24]. In a prospective review of 175 consecutive patients who underwent bypass grafting by a single surgeon, there were no RA harvest site hematoma or infection. Transient dysesthesia occurred in 2.6% patients with no death reported. In the follow-up of 3 months, patency rate exceeding 95% was observed via elective coronary angiography [25]. Zacharias and colleagues evaluated the comparative outcomes between RA or SV grafts as an additional conduit for patients undergoing CABG with LIMA to LAD grafting. In this study, which had similar distribution of demographics and operative characteristics between the two groups, RA grafting was associated with superior estimated survival (92% vs. 87%, $p < 0.03$) at 6 years of follow-up as compared with SVG [26]. In a short- and mid-term follow-up in a Japanese Institute [27], no adverse effects were noted after CABG with RA grafting. The cumulative graft patency rate was 93% after 1.5 years of angiographical follow-up with graft calculated patency rates at 1, 2, and 3 years of 98.2%, 91%, and 86.2%, respectively [27]. “String sign,” a marker of diffuse severe occlusion of RA graft was found in 13 patients in a mean follow-up of 13 years [27].

Whereas some reports found RA grafts to be superior to SVG, others found either similar or superior patency and outcomes with the use of SVG. In a 5-year follow-up of 50 asymptomatic patients who underwent bypass surgery with at least one RA graft, coronary angiography was performed to determine graft patency and presence of narrowing, graft patency rates were 100% for LIMA, 94% for RIMA, 89% for RA, and 92% for SV grafts [28]. Within the cohort of 62 patients with RA conduits, “String sign” (diffusely narrowed and diseased RA graft) was found in 7 patients (11%). In an angiographic review of 310 patients who underwent CABG using IMA, SVG, and RA conduits between 1996 and 2011 at Cleveland Clinic and presenting with signs and symptoms of ischemia, RA graft patency was found to be 51% as compared to 64% in SVG ($p = 0.0016$) and 91% in LIMA grafts ($p = 0.0001$) [29]. Interestingly, within the subsets of patients with RA grafts, women had lower patency as compared to their male counterparts 38% versus 56%, respectively. Lower RA graft patency rates in this study were attributed to increased vasoreactivity, intimal hyperplasia, atherosclerosis, and graft dependence on high level of blood flow. Major limitation of this study was the fact that only those patients with active ischemia were studied, thereby introducing significant selection bias. Summary of these results illustrates that there is substantial variability within the non-randomized literature, and therefore equipoise regarding superiority of RA over SVG conduits. Although RA grafts appear to have superior patency rates and outcomes in some reports, these same endpoints are better in the SVG arm of other studies.

Randomized Controlled Trials Comparing RA and SV Conduits

To date, six RCTs have been conducted to address the inconsistent results of the non-randomized studies regarding the superiority of RA versus SV grafts (Table 1). Radial Artery Patency and Clinical Outcomes (RAPCO) trial was the first single-center RCT published in 2003 which compared patency rates and event free survival between RA, RIMA, and SV grafts after CABG over a 10-year follow-up [35]. In group 1, RA grafts were compared to RIMA grafts in patients under 70 years of age, whereas in group II RA grafts were compared with SVG in patients 70 years and over. Graft patency estimates after 5 years were 95% (RA) vs. 100% (RIMA), $p = 0.40$ in group 1, and 87% (RA) vs. 94% (SVG), $p = 0.50$ in

Table 1 Characteristics of all randomized controlled trials comparing radial artery grafts with saphenous vein grafts

Study	Total RA[1] graft patients	Total SVG patients	Time to Angiography (years)	Follow-up (years)	Primary outcomes	Results
Petrovic et al. (2015) [30••]	100	100	8	6	Composite of cardiovascular mortality, non-fatal myocardial infarction, and need for repeat myocardial revascularization	Revascularization with 2 arterial conduits offers better mid-term event-free survival than a single arterial graft
Yoo et al. (2012) [31]	35	25	5.8	0.7	Immediate postoperative morbidity and mortality, 1-year postoperative CT angiography results	No differences in immediate postoperative morbidity and mortality were observed.
RAPS (2012) [32••]	269	269	8.4	7.7	Functional graft occlusion by invasive angiography	Radial arteries are associated with reduced rates of functional and complete graft occlusion compared with SVG
RSVP (2008) [33•]	82	60	5.5	5.5	Angiographic graft patency 5 years postoperatively	RA patency is significantly better than SVG patency and comparable to that of internal artery grafts
Stand-in-Y (2008) [34]	204	205	3.3	3.5	In-hospital outcomes (mortality rate and morbidity), 2-year freedom from all-cause death, and adverse cardiac event-free survival	Revascularization with 2 arterial grafts showed better event-free survival than a single arterial graft
RAPCO (2003) [35]	113	112	5	5	Graft patency and cardiac event-free survival	RA graft does not have superior patency than right internal mammary artery or SVG

RA radial artery, *SVG* saphenous vein graft

group 2. The event-free survival at 5 years was 91% (RA) vs. 82% (RIMA), $p = 0.70$ in group 1, and 85% (RA) vs. 89% (SVG), $p > 0.90$ in group 2. Therefore, the 5-year interim results did not support the superiority of RA graft over either SV or RIMA grafts in terms of graft patency or clinical outcomes [35]. In another single-center prospective study, 142 patients were randomized to receive either RA or SVG conduits for aortocoronary bypass grafting of the native left circumflex artery [33•]. After 5 years post-CABG, 98.3% of RA and 86.4% of SV ($p = 0.04$) grafts were found to be patent on follow-up angiography. RA was superior to SVG in terms of perfect patency and absolute patency. Limitations of this study included a small patient sample size, imbalance of clinical characteristics between the two groups, male predominance, and lack of angiographic follow-up in a significant number of patients. In a subsequent RCT published by Nasso and colleagues in 2009 [34], 815 patients with coronary artery disease and planned to undergo surgical revascularization were randomized into 4 groups, e.g., LIMA-LAD and RIMA for secondary vessel grafting, RIMA-LAD and LIMA for secondary grafting, LIMA-LAD and RA for secondary grafting, and LIMA-LAD and SVG for secondary grafting. Among the 4 surgical strategies, all the 3 approaches that utilized arterial conduits for secondary vessel grafting had comparable cardiac and overall survival at 40 months. However, adverse cardiac event-free survival was significantly lower in the single arterial conduit (with SVG used for secondary vessel grafting) group as compared to the double arterial bypass groups. This was irrespective of which second arterial graft (LIMA, RIMA, or RA) was used. Lack of consistent angiographic follow-up was the major limitation of this study.

In a randomized study of 60 elderly patients (age > 70 years old) scheduled to undergo off-pump CABG, clinical outcomes and graft patency (by computed tomography–CT angiography) were compared between patients receiving either RA or SV grafts [31]. After a 1-year follow-up, there was no significant difference in terms of graft patency or overall clinical outcomes (in-hospital and postoperative mortality) between the two groups. Assessment of graft patency using CT angiography was a novel approach as compared to traditional invasive coronary angiography. The study was limited by its short-term follow-up (mean of 8 months). In an RCT conducted by Petrovic and colleagues, 200 relatively young patients (mean age 57 years) with significant coronary artery disease were randomized to surgical revascularization with either LIMA and RA or LIMA and SVG conduits [30••]. After 8 years of follow-up, there was no significant difference in either the absolute survival or clinical outcomes (i.e., MI, need for percutaneous coronary intervention, or redo surgery). Within the cohort of patients that underwent coronary angiography for ischemia, RA patency rate was 92% as compared with 86% for SVG ($p = 0.65$). Despite the limitation of being a single-center study with a relatively small patient population, the trial was important in demonstrating equivalent clinical outcomes for both the arterial and venous grafts after a long-term follow-up (8 years).

Finally, the Radial Artery Patency Study (RAPS), which was the first multi-center trial to compare arterial and venous surgical conduits, randomized 510 patients from 9 centers in Canada to receive either RA or SV grafting at the time of CABG [32••]. The primary endpoint was angiographic evidence of functional graft occlusion (Lack of Thrombolysis in Myocardial Infarction flow grade 3); secondary endpoint was the rate of complete graft occlusion (Thrombolysis in Myocardial Infarction flow grade 0). After a mean follow-up of 7.7 years, the frequency of functional graft occlusion (12% vs. 19.7%, $p = 0.03$) and complete graft occlusion (8.9% vs. 18.6%, $p = 0.002$) was significantly lower in patients undergoing RA as compared to SV grafting, respectively. Recent meta-analysis of all RCTs to date (total of 1036 patients) showed RA to be the preferred conduit as compared to SVG. RA grafting was associated with lower rates of major adverse cardiac events (HR 0.67, $p = 0.01$) and higher patency rates at 5 years of follow-up (HR 0.44, $p = < 0.001$). Although no difference in mortality was found between RA and SV conduits, RA use was associated with lower incidence of MI (HR 0.72, $p = 0.04$) and rates of repeat revascularization (HR 0.50, $p = < 0.001$) [36].

CABG Conduit Guidelines and Contemporary Practice

Despite the US and European guidelines endorsing complete arterial revascularization in patients requiring CABG, SVG are still commonly used as second conduit in the USA as well as in Europe. As per 2011 American College of Cardiology (ACC)/American Heart Association (AHA) guidelines [37], complete arterial revascularization should be considered in patients < 60 years of age (class IIb). RA grafts are preferred when grafting left-sided arteries (left circumflex and LAD) with severe stenosis (> 70%) and right-sided artery (RCA) when there is critical stenosis (> 90%) (class IIb). According to the joint 2014 focused guideline update from Society of Thoracic Surgeons (STS)/American Association of Thoracic Surgeons/AHA/ACC, bilateral ITA should be considered in patients who are at low risk of sternal complications (class IIa, level of evidence–LOE B) [38]. As an adjunct to LIMA, RA graft should be considered as second conduit when target vessel has severe stenosis, especially in patients with higher risk of sternal complications (i.e., patient who are obese and/or have diabetes mellitus) (class IIa, LOE B) [38]. Use of pharmacological agents is also recommended in the pre-operative and peri-operative period to reduce the incidence of RA spasm (class IIb, LOE B). In 2014 guideline, European Society of Cardiology (ESC) and the European Association for Cardiothoracic Surgery (EACTS) recommended bilateral ITA grafting in patients younger than 70 years of age (class IIa, LOE B) [36]. RA grafting is a reasonable alternative for patients with significant coronary artery stenosis who have a contraindication to bilateral ITA harvesting (i.e., obese, older females, and diabetics) (class I, LOE B) [39]. Total arterial revascularization was recommended in patients with reasonable life expectancy (class IIa, LOE B) and in patients with poor vein quality independent of age (class I, LOE C).

Conclusion

In the current era, CABG remains to be the treatment modality of choice for patients with complex multi-vessel coronary artery disease, left main disease, and in patients with diabetes. Both arterial and venous conduits are part of a surgeon's armamentarium at the time of surgery. Although saphenous vein grafting is the most commonly used conduit in addition to ITA, current data suggests that total arterial bypass (using RA conduit in addition to ITA) may be the better strategy. Both the American and European consensus guidelines advocate for the use of arterial over SV grafting for most patients. Nevertheless, in some patients (such as those who are older, diabetic, obese), SV grafting may be preferable. Therefore, the ultimate revascularization strategy for a given patient should be derived following a multidisciplinary heart team discussion as well as consideration of the individual's risk factors and preferences.

Compliance with Ethical Standards

Conflict of Interest Hafeez Ul Hassan Virk, Vladimir Lakhter, Muhammad Ahmed, Brian O' Murchu, and Saurav Chatterjee declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Ulrich MR, Brock DM, Ziskind AA. Analysis of trends in coronary artery bypass grafting and percutaneous coronary intervention rates in Washington state from 1987 to 2001. Am J Cardiol. 2003;92:836–9.
2. Serruys PW, Morice M, Kappetein AP, Colombo A, Holmes DR, Mack MJ, et al. Percutaneous coronary intervention versus coronary-artery bypass grafting for severe coronary artery disease. N Engl J Med. 2009;360:961–72.
3. Yusuf S, Zucker D, Peduzzi P, et al. Effect of coronary artery bypass graft surgery on survival: overview of 10-year results from

randomised trials by the Coronary Artery Bypass Graft Surgery Trialists Collaboration. Lancet. 1994;344:563–70.
4. ElBardissi AW, Aranki SF, Sheng S, O'Brien SM, Greenberg CC, Gammie JS. Trends in isolated coronary artery bypass grafting: an analysis of the Society of Thoracic Surgeons adult cardiac surgery database. J Thorac Cardiovasc Surg. 2012;143:273–81.
5. Taggart DP, D'Amico R, Altman DG. Effect of arterial revascularization on survival: a systematic review of studies comparing bilateral and single internal mammary arteries. Lancet. 2001;358:870–5.
6. Zacharias A, Schwann TA, Riordan CJ, et al. Late results of conventional versus all-arterial revascularization based on internal thoracic and radial artery grafting. Ann Thorac Surg. 2009;87:19–26 e2.
7. Lytle BW, Loop FD, Cosgrove DM, Ratliff NB, Easley K, Taylor PC. Long-term (5 to 12 years) serial studies of internal mammary artery and saphenous vein coronary bypass grafts. J Thorac Cardiovasc Surg. 1985;89:248–58.
8. Lopes RD, Mehta RH, Hafley GE, for the PREVENT IV Investigators, et al. Relationship between vein graft failure and subsequent clinical outcomes after coronary artery bypass surgery. Circulation. 2012;125:749–75.
9. Bjork VO, Ekestrom S, Henze A, Ivert T, Landou C. Early and late patency of aortocoronary vein grafts. Scand J Thorac Cardiovasc Surg. 1981;15:11–21.
10. Curtis JJ, Stoney WS, Alford WC, et al. Intimal hyperplasia: a cause of radial artery aortocoronary bypass graft failure. Ann Thorac Surg. 1975;20:628–35.
11. Acar C, Jebara VA, Portoghese M, Beyssen B, Pagny JY, Grare P, et al. Revival of the radial artery for coronary artery bypass grafting. Ann Thorac Surg. 1992;54:652–60.
12. Verma S, Szmitko PE, Weisel RD, Bonneau D, Latter D, Errett L, et al. Should Radial Arteries Be Used Routinely for Coronary Artery Bypass Grafting? Circulation. 2004;110:e40–6 originally published August 2, 2004.
13. Maniar HS, Sundt TM, Barner HB, Prasad SM, Peterson L, Absi T, et al. Effect of target stenosis and location on radial artery graft patency. J Thorac Cardiovasc Surg. 2002;123:45–52.
14. Kobayashi J. Radial artery as a graft for coronary artery bypass grafting. Circ J. 2009;73:1178–83.
15. Cohen G, Tamariz MG, Sever JY, Liaghati N, Guru V, Christakis GT, et al. The radial artery versus the saphenous vein graft in contemporary CABG: a case-matched study. Ann Thorac Surg. 2001;71:180–6.
16. Hagiwara H, Ito T, Kamiya H, Akita T, Usui A, Ueda Y. Mid-term structural change in the radial artery grafts after coronary artery bypass grafting. Ann Thorac Surg. 2004;77:805–11.
17. Siminelakis S, Karfis E, Anagnostopoulos C, Toumpoulis I, Katsaraki A, Drossos G. Harvesting radial artery and neurologic complications. J Card Surg. 2004 Nov-Dec;19(6):505–10.
18. Parolari A, Rubini P, Alamanni F, Cannata A, Xin W, Gherli T, et al. The radial artery: which place in coronary operation? Ann Thorac Surg. 2000;69:1288–94.
19. Chen XJ, Chen X, Xie D, Meng F, Shi K, Xu M. Radial artery as conduit is safe and effective in coronary bypass surgery in the elderly single-central results from 326 patients. Circ J. 2009;73: 1049–54.
20. Chardigny C, Jebara VA, Acar C, et al. Vasoreactivity of the radial artery: comparison with the internal mammary artery and gastroepiploic arteries with implications for coronary artery surgery. Circulation. 1993;88(suppl II):II115–27.
21. Thiene G, Miazzi P, Valsecchi M, Valente M, Bortolotti U, Casarotto D, et al. Histological survey of the saphenous vein before its use as autologous aortocoronary bypass graft. Thorax. 1980;35: 519–22.
22. Mehta RH, Ferguson TB, Lopes RD, Hafley GE, Mack MJ, Kouchoukos NT, et al. Saphenous vein grafts with multiple versus single distal targets in patients undergoing coronary artery bypass surgery: PREVENT IV trial. Circulation. 2011;124(3):280–8.
23. Calafiore AM, Di Mauro M, D'Alessandro S, et al. Revascularization of the lateral wall: long-term angiographic and clinical results of radial artery versus right internal thoracic artery grafting. J Thorac Cardiovasc Surg. 2002;123:225–31.
24. Possati G, Gaudino M, Prati F, Alessandrini F, Trani C, Glieca F, et al. Long-Term Results of the Radial Artery Used for Myocardial Revascularization. Circulation. 2003;108:1350–4 originally published September 15, 2003.
25. Brodman RF, Frame R, Camacho M, Hu E, Chen A, Hollinger I. Routine use of unilateral and bilateral radial arteries for coronary artery bypass graft surgery. J Am Coll Cardiol. 1996;28:959–63.
26. Zacharias A, Habib RH, Schwann TA, Riordan CJ, Durham SJ, Shah A. Improved Survival With Radial Artery Versus Vein Conduits in Coronary Bypass Surgery With Left Internal Thoracic Artery to Left Anterior Descending Artery Grafting. Circulation. 2004;109:1489–96 originally published March 29, 2004.
27. Amano A, Hirose H, Takahashi A, Nagano N. Coronary artery bypass grafting using the radial artery: mid-term results in a Japanese institute. Ann Thorac Surg. 2001;72:120–5.
28. Cameron J, Trivedi S, Stafford G, Bett JH. Five-year angiographic patency of radial artery bypass grafts. Circulation. 2004;110(Suppl. II):II-23–6.
29. Khot UN, Friedman DT, Pettersson G, Smedira NG, Li J, Ellis SG. Radial artery bypass grafts have an increased occurrence of angiographically severe stenosis and occlusion compared with left internal mammary arteries and saphenous vein grafts. Circulation. 2004;109:2086–91.
30.•• Petrovic I, Nezic D, Peric M, et al. Radial artery vs saphenous vein graft used as the second conduit for surgical myocardial revascularization: long-term clinical follow-up. J Cardiothorac Surg. 2015;10: 127 **This study indicates that revascularization with 2 arterial conduits offers better midterm event-free survival than a single arterial graft.**
31. Song S-W, Sul S-Y, Lee H-J, Yoo K-J. Comparison of the radial artery and saphenous vein as composite grafts in off pump coronary artery bypass grafting in elderly patients: a randomized controlled trial. Korean Circ J. 2012;42:107–12.
32.•• Deb S, Cohen EA, Singh SK, Une D, Laupacis A, Fremes SE. Radial artery and saphenous vein patency more than 5 years after coronary artery bypass surgery: results from RAPS (Radial Artery Patency Study). J Am Coll Cardiol. 2012;60:28–35 **This study indicates radial arteries are associated with reduced rates of functional and complete graft occlusion compared with SVG.**
33.• Collins P, Webb CM, Chong CF, Moat NE. Radial artery versus saphenous vein patency randomized trial: five-year angiographic follow-up. Circulation. 2008;117:2859–64 **This study shows radial artery patency is significantly better than SVG patency and comparable to that of internal artery grafts.**
34. Nasso G, Coppola R, Bonifazi R, Piancone F, Bozzetti G, Speziale G. Arterial revascularization in primary coronary artery bypass grafting: direct comparison of 4 strategies — results of the Stand-in-Y Mammary Study. J Thorac Cardiovasc Surg. 2009;137:1093–100.
35. Buxton BF, Raman JS, Ruengsakulrach P, Gordon I, Rosalion A, Bellomo R, et al. Radial artery patency and clinical outcomes: five-year interim results of a randomized trial. J Thorac Cardiovasc Surg. 2003;125:1363–71.
36. Gaudino M, Benedetto U, Fremes S, Biondi-Zoccai G, Sedrakyan A, Puskas JD, et al. Radial-artery or saphenous-vein grafts in coronary-artery bypass surgery. N Engl J Med. 2018;378:2069–77.
37. [Guideline]Aldea GS, Bakaeen FG, Pal J, Fremes S, Head SJ, Sabik J, et al. The Society of Thoracic Surgeons clinical practice guidelines on arterial conduits for coronary artery bypass grafting. Ann Thorac Surg. 2016;101(2):801–9.

38. [Guideline]Authors/Task Force members, Windecker S, Kolh P, Alfonso F, Collet JP, et al. 2014 ESC/EACTS Guidelines on myocardial revascularization: The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS) developed with the special contribution of the European Association of Percutaneous Cardiovascular Interventions (EAPCI). Eur Heart J. 2014;35(37):2541–619.
39. [Guideline]Hillis LD, Smith PK, Anderson JL, Bittl JA, Bridges CR, Byrne JG, et al. 2011 ACCF/AHA Guideline for Coronary Artery Bypass Graft Surgery: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. Circulation. 2011;124(23):e652–735.