Chapter 7

Total Arterial Revascularization in Coronary Artery Bypass Grafting Surgery

Sean Maddock, Gilbert H. L. Tang, Wilbert S. Aronow and Ramin Malekan

Additional information is available at the end of the chapter

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1. Introduction

Coronary artery bypass graft (CABG) operations are one of the most commonly performed surgical procedures, with a worldwide prevalence of over 800,000 annually and more than 350,000 operations being performed in the United States each year [1]. The use of the left internal mammary artery (LIMA) is widely considered to be the gold standard for conventional CABG operations. Its use has been shown to result in a lower incidence of reintervention, fewer myocardial infarctions, a lower incidence of angina, and lower associated mortality rates than with the use of saphenous vein grafts alone. Also when compared to saphenous vein grafts, LIMA use has been shown to have greater long-term patency results [1, 2]. For patients with multivessel coronary disease undergoing what is usually referred to as conventional CABG, the LIMA is typically grafted to the left anterior descending (LAD) artery with saphenous vein grafts often used to bypass the remaining coronary occlusions. However, arterial conduits are now being more frequently used as choices for the second and third conduits in place of saphenous vein grafts to achieve total arterial revascularization (TAR) of the myocardium due to superior patency and long-term survival results. This article provides a review of TAR using the right internal mammary artery (RIMA) and radial artery as additional arterial conduits in conjunction with the LIMA as a first choice conduit. The reported benefits of TAR when compared to conventional CABG procedures using the LIMA and saphenous vein grafts are discussed.

2. LIMA use in CABG

The LIMA is widely considered to be the best conduit for CABG procedures. In a study of the Society of Thoracic Surgeons National Cardiac Database performed by Tabata *et al.*, data from 541,368 CABG surgeries taking place between 2002 and 2005 were analyzed. Among all procedures performed, 92.4% of patients had at least one IMA graft, and the frequency of LIMA usage by each hospital ranged from 48.0% to 100% with a median of 94% [3]. The presence of an IMA graft has also been identified as an independent predictor of survival and confers significantly better long-term survival rates than the use of saphenous vein grafts alone [2].

While anatomically identical to the LIMA, the RIMA is rarely used in CABG procedures, and is almost always used as part of bilateral internal mammary artery (BIMA) grafts when it is utilized. Despite several studies showing that BIMA use confers significantly improved clinical outcomes [4-6], between 2003 and 2005 the frequency of BIMA use was only 4% [3]. Reasons for not using the RIMA include increased operative time and perceived technical difficulty associated with the harvest, concern for perioperative morbidity and mortality, the possibility of reoperations for bleeding, sternal wound infection, and uncertainty as to whether there is a significant benefit with BIMA grafting [7, 8]

3. Outcomes of BIMA in CABG

Despite its low prevalence of use, many studies have shown that RIMA use in conjunction with the LIMA can confer significantly better clinical outcomes when compared to conventional CABG procedures with the LIMA and saphenous vein grafts.

Survival benefits of BIMA versus Single Internal Mammary Artery (SIMA)

Several observational, retrospective studies have found that there are significantly greater long-term survival benefits in patients who received BIMA grafting compared to SIMA grafting. Lytle *et al.* studied 10,124 elective CABG patients receiving either SIMA or BIMA grafts with or without any additional vein grafts in a retrospective, non-randomized study with a mean follow-up of 10 post-operative years. Hospital mortality rates were identical for the SIMA and BIMA groups (0.7%). However, over 12 years of post-operative follow up, survival rates for BIMA patients were significantly better than for SIMA patients (79.1% versus 71.6% respectively, $p < 0.001$) [9]. In a follow-up to the original study, which extended the mean post-operative follow up to 16.5 years, survival rates for BIMA and SIMA patients at 20 years were 50% versus 37% respectively ($p < 0.0001$), demonstrating a significant long-term survival advantage for patients receiving two internal mammary grafts compared to just one [10].

Nasso *et al.* aimed to determine whether or not there were significant benefits to using two arterial conduits rather than just a single arterial conduit. 815 patients were randomized to one of four revascularization strategies: *in situ* LIMA to LAD plus isolated RIMA Y graft, *in situ* RIMA to LAD plus *in situ* LIMA, *in situ* LIMA to LAD plus free radial artery, and *in situ* LIMA to LAD with saphenous vein grafts as a control. All revascularization groups received saphenous vein grafts to bypass the remaining coronary occlusions, if needed. Although the authors found no significant overall survival advantage between any of their revascularization groups over a follow-up period of two years, there was a significant difference in survival when considering cardiac event-free survival. Patients in groups receiving two arterial grafts had significantly better cardiac event-free survival rates when compared to patients who only received a single internal mammary artery (LIMA) grafted to the LAD with saphenous vein grafts. These arterial revascularization strategies were also seen to convey significantly better cardiac event-free survival rates to elderly (> 75 years) patients as well. The study did not find any significant differences in survival based on the choice of either the RIMA or the radial artery as the second arterial conduit [11].

In the longest reported retrospective analysis of CABG procedures, ranging from 6 weeks to 32 years of follow up, Kurlansky *et al.* conducted a review of 4,584 isolated CABG procedures between 1972 and 1994. When patient differences were accounted for and comparisons made between 2,197 matched patients, survival was 16.5% for SIMA patients and 28.5% for BIMA patients after 25 years (p = 0.001). The median survival for SIMA patients was 11.8 years compared to 15.9 years for BIMA patients. There were no significant differences between the two groups in the rates of non-fatal myocardial infarction, reoperation, percutaneous coronary intervention, permanent stroke, or composite freedom from late adverse cardiac events. [12

The location of the distal anastomosis of the RIMA graft also does not appear to significantly affect clinical outcomes of patients undergoing BIMA grafting. Kurlansky *et al.* performed a propensity-matched study of 2,215 patients undergoing BIMA CABG procedures having the RIMA grafted to either the right coronary system or to the left coronary system. In both the matched and unmatched analyses, there was no significant difference in operative or late mortality between the two groups. The median survival for propensity-matched patients in both groups was 16.1 years (p = 0.671) [13]. In another study by Rankin *et al.* there were no significant differences in long-term outcomes based on grafting territory of BIMA grafts as long as they are anastomosed to the two largest coronary systems [14].

Not all studies have found significantly increased survival rates for BIMA use over SIMA use. In a study performed by Dewar *et al.*, there was not a significant difference in the 5 or 7-year survival rates for patients undergoing either unilateral or bilateral IMA grafting with supplemental vein grafts. 5-year survival rates for SIMA and BIMA revascularization for patients less than 60 years of age were 94.4% and 94.8%, respectively (p = not significant). There was also no significant difference in 5-year survival rates for patients over 60 years of age. However, the authors did note that there was a trend in lower rates of angina in the patient group receiving BIMA grafts less than 60 years of age [15].

4. Patency of RIMA versus LIMA

Patency is the most important determinant in long-term prognosis [7]. Due to the extremely low prevalence of use for the RIMA, there have been few studies evaluating its patency compared to the LIMA. However, the studies that have been performed suggest that the RIMA has similar early and even long-term patency rates as the LIMA, especially when grafted to similar coronary territories [17].

Fukui *et al.* reviewed the angiographic records of 705 patients undergoing BIMA CABG procedures. Early angiography and 1-year angiographic results for RIMA patency are good, with an overall patency of 98.8% at early angiography and 94.3% at 1-year postoperative follow-up compared to 99.1% and 97.0% for the LIMA at the same follow-up times ($p = 0.7732$ and $p = 0.1288$, respectively). In terms of grafting technique, at both early and 1-year angiographic follow up, there were no significant differences in the patencies of *in situ* versus free RIMA grafts. For free RIMA grafts, there were also no significant differences in patency rates between sites of proximal anastomoses (composite versus aorta). However, for the *in situ* RIMA, patency rates were significantly better when anastomosed to the anterior coronary territory when compared to other grafting methods ($p < 0.0001$)[16].

Tatoulis *et al.* evaluated the results of 991 consecutive RIMA postoperative CABG angiograms taking place between 1986 and 2008. The main focus was graft patency, with grafts considered non-patent if they had a greater than 80% stenosis, string sign, or total occlusion. When compared to the LIMA for identical grafting territories, there was no significant difference in RIMA and LIMA patency. For the LAD, overall LIMA patency was 96.9% while overall RIMA patency was 94.6% ($p = 0.74$). When grafted to the circumflex, LIMA patency was 90.7% versus RIMA patency of 91.9% ($p = 0.85$). Long-term patency results for the RIMA were favorable as well, with 92% of 352 RIMA grafts in place for greater than 10 years being patent. RIMA patencies were always better than radial artery or saphenous vein graft patencies. At 15 years, RIMA patency was 79% compared to 50.7% for saphenous vein grafts ($p < 0.001$). 15-year data were not available for the radial artery; 10-year patency was 78% ($p < 0.01$ when compared to RIMA 10-year patency). However, the authors noted that data for radial artery patency is limited [17].

There are a variety of grafting techniques for BIMA, such as *in situ* grafting versus Y/T-grafts that may have an impact on patency rates. In a study by Glineur *et al*., 304 patients receiving BIMA grafts were randomized to receive either an *in situ* RIMA graft or a Y-graft with the RIMA anastomosed proximally to the *in situ* LIMA as an end-to-side graft. Follow-up angiography was performed at 6 months and the RIMA patency rate in both groups was 97% ($p = 0.99$) [18]. In a similar but slightly larger study, Calafiore *et al.* also found no significant differences in patency rates between *in situ* and Y-graft RIMA grafts at both early (13 days) and long-term (17 months) angiographic follow up [19]. A longer study by Hwang *et al.* studied 5-year angiographic patency results of BIMA grafting configurations. At 1 year of follow-up, *in situ* RIMA patency rates were not significantly different than Y-graft RIMA patency rates (92.5% versus 95.7%, respectively, $p = 0.138$). Similarly at 5 years of follow up, there were also no significant differences in patency rates (92.5% *in situ* versus 92.4% Y-graft, $p = 0.978$) [20].

5. Myocardial infarction, cerebrovascular accidents, freedom from reoperation, and quality of life

Stevens *et al.* report that patients undergoing BIMA CABG operations had significantly better long-term freedom from myocardial infarction (MI) and from coronary reoperation. After 10 post-operative years, 85% of BIMA patients were free of myocardial infarction compared to 82% of patients receiving LIMA grafts ($p = 0.001$). 99% of BIMA patients also were free from coronary reoperation compared to 98% of LIMA patients ($p = 0.01$) [4].

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While Burfeind *et al.* found no significant difference in 15-year mortality rates for patients receiving single IMA grafts or multiple (bilateral) IMA grafts, they did find significant differences in the rates of MI and CABG reoperation. However, these rates differ based on the definition of what constitutes a patient receiving multiple IMA grafts. In their study 1,067 patients that had undergone isolated CABG procedures were analyzed by three different methods. In the first analysis (analysis I), patients were analyzed based on the initial surgical strategy for revascularization – SIMA or BIMA grafts. However, not all patients who were designated to receive BIMA grafts were able to be revascularized with multiple IMAs, and likewise some patients designated to receive SIMA grafts ultimately received BIMA grafts. Analyses II and III were therefore performed based on the surgery the patient ultimately received and not the initial surgical strategy. Analysis II defined "multiple IMA grafts" based on the number of distal anastomoses performed. Therefore, in analysis II, multiple coronary systems anastomosed with multiple IMA grafts were considered "multiple IMA grafts" as well as a single coronary system sequentially anastomosed with a single IMA graft. In analysis III only multiple coronary systems anastomosed with multiple IMA grafts were considered to be "multiple IMA grafts." In both analyses II and III, Burfeind *et al.* found that there were significantly reduced rates of CABG reoperation in patients receiving multiple IMA grafts when compared to patients only receiving a single IMA graft (analysis II: 9.7% reop SIMA, 4.5% BIMA $p = 0.0095$; analysis III: 9.7% reop SIMA, 3.4% BIMA, $p = 0.0026$). However, in analysis III there was also a significantly reduced rate of MI in BIMA patients when compared with SIMA patients (17.4% versus 11.6% for SIMA and BIMA patients, respectively, $p = 0.0181$) [6].

In their original retrospective study on BIMA versus SIMA grafting in elective CABG patients, Lytle *et al.* also found that patients receiving BIMA grafts had significantly greater reoperation-free survival rates after 12 post-operative years than patients receiving only SIMA grafts with or without any additional vein grafts. BIMA patients had a reoperation-free survival of 76.8% compared to the 62.4% reoperation-free survival rate of SIMA patients [9].

As previously mentioned, Nasso *et al.* found that patients receiving two arterial grafts had significantly better long-term, cardiac-event free survival outcomes than patients who just received a single arterial graft with or without additional saphenous vein grafts. As expected, adverse cardiac events occurred significantly less frequently in the groups receiving two arterial grafts versus the group receiving just one. There was no significant difference in the occurrence of adverse cardiac events between the three groups receiving two arterial grafts. Cerebrovascular complications occurred more frequently in the SIMA group, however this difference was not significant. The authors note that this increased incidence of cerebrovascular complications may be due to the more extensive manipulation of the ascending aorta needed in the SIMA group due to the greater number of proximal anastomoses [11].

Damgaard *et al.* performed a study to assess the health-related quality of life improvements in patients undergoing traditional CABG procedures versus patients undergoing TAR CABG procedures. 331 patients were randomized between the two revascularization techniques and over 90% of patients responded to the questionnaire at the specified time points. Preoperatively, patient scores in all areas of the questionnaire were significantly lower than that of the results of the standardized Danish population. Post-operatively, both revascularization groups showed significant improvement in all areas at 3 months and 11 months, with the TAR group showing improvement in the 'social functioning' category that was significantly higher than the conventional revascularization group. There was no significant difference in post-operative improvement in the categories 'physical component summary,' 'bodily pain,' and 'vitality' between the two revascularization groups [21].

6. Incidence of sternal wound infection, subset of patients benefiting from BIMA, IMA harvesting techniques, and operative time in BIMA CABG

One of the main concerns amongst surgeons regarding the use of BIMA in CABG procedures is the occurrence of sternal wound infections (SWI). When both internal mammary arteries are harvested, blood supply to the sternum may be more severely compromised than in single IMA procedures, thus increasing the risk for developing SWI. Various pre-operative and intra-operative techniques have been used to prevent the incidence of SWI, such as the use of prophylactic antibiotics, double gloving, and skeletonized IMA harvesting [7]. Skeletonized IMA harvesting is thought to preserve the collateral blood supply to the sternum and reduce the risk of infection [22].

Patients who are insulin-dependent diabetics, morbidly obese, or who have severe COPD are at a higher risk of developing SWI (DSWI = deep sternal wound infection, definition varies) and, in general, bilateral harvesting of the IMAs is avoided in these patients [7, 8].

In a study performed by Pevni *et al.*, 1,515 consecutive patients underwent CABG procedures with skeletonized BIMA grafting. In earlier studies, the authors state that, in their past experience, patients with chronic lung disease, diabetic females, and obese diabetics represented absolute contraindications to BIMA grafting for CABG procedures because of the risk of SWI. However in this study, the authors found that there was no evidence of a relationship between diabetes mellitus and DSWI in patients receiving skeletonized BIMA grafts, even with a prevalence of diabetes mellitus of 34% in their patient population [23].

In a meta-analysis of 13 studies regarding BIMA CABG procedures and the harvesting technique for the IMAs, Saso *et al.* found that skeletonizing the IMA as opposed to harvesting it in a pedicled manner lowered the incidence of SWI by 60%. An even greater benefit of skeletonized harvesting was noted in groups at an increased risk for SWI, such as in diabetic patients. The authors also found that these decreased rates of SWI applied to the entire spectrum of sternal infections, including mediastinitis [22].

Kurlansky *et al.* found a slightly higher incidence of SWI amongst diabetic patients receiving BIMA grafting compared to diabetic patients receiving LIMA grafting, but the difference was not significant. However, amongst patients receiving BIMA grafts, the presence of diabetes did affect the occurrence of SWI. This suggests that, while the presence of diabetes mellitus

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could still be considered a risk factor for SWI, the risk is not increased by receiving BIMA grafting [12].

One of the probable factors contributing to the low prevalence of BIMA use is the perceived increased operative time required to harvest both IMAs [7]. However, few studies have actually included operative time in their statistical analyses, most simply report aortic cross-clamp and cardiopulmonary bypass times. Gansera *et al.* do report total operative time and found that operative time was significantly increased for patients receiving BIMA grafting compared to patients receiving SIMA grafting (189 minutes versus 164 minutes, respectively, p = 0.00). However, the number of anastomoses in the BIMA group was significantly higher than in the SIMA group (3.8 versus 3.1, respectively, p = 0.00), which could in part explain the increased operative time observed [8].

7. Radial artery grafts as a second arterial conduit

The success of the LIMA in CABG procedures has lead surgeons to search for other arterial conduits. The radial artery has become a popular choice as an additional arterial conduit in attempts to achieve total arterial revascularization of the myocardium. There are numerous advantages to using the radial artery, including its long length, exposure to systemic blood pressures, and the fact that it is seldomly affected by atherosclerosis. However, the radial artery has a thicker tunica media, which is thought to contribute to its greater vasoconstrictor response than the IMA and could possibly lead to vessel occlusion. Thus, care must be taken during operative harvesting and the use of calcium-channel blockers may ameliorate a vasospastic response [24].

Like the LIMA, the radial artery has been shown to have significantly better short and long-term patency results and outcomes than vein grafts. In the radial artery patency study (RAPS), Desai *et al*. randomized 561 patients to receive a radial artery graft to either the inferior (right) coronary territory or to the lateral (circumflex) coronary territory, with a saphenous vein graft anastomosed to the opposite territory in each group as a control. All patients also received a LIMA graft to the LAD, with the main endpoint of the study being 1-year angiographic complete occlusion of the radial artery versus saphenous vein. In this definition of occlusion, grafts displaying the string-sign would be considered patent. At the mean follow-up of 10.9 months, 13.6% of saphenous vein grafts were completely occluded and 8.6% of radial artery grafts were completely occluded (p = 0.009). The authors also found that the patency of radial artery grafts depends on the severity of the native vessel stenosis, with better patency results corresponding with higher grades of stenosis. Thus, the authors recommend using the radial artery for the most highly occluded coronary vessel after the LAD [25].

In a follow-up to the original RAPS study, Deb *et al.* extended the mean angiographic follow-up time to 7.7 years, with 269 patients of the original 561 undergoing late angiography. The primary endpoint was functional graft occlusion; vessels displaying narrowing or reduced flow were considered occluded as well as vessels that were completely occluded. 12.0% of radial artery grafts were determined to be functionally occluded compared with 19.7% of saphenous vein grafts (p = 0.03). For the secondary endpoint of complete occlusion, 8.9% of radial artery grafts were completely occluded compared with 18.6% of saphenous vein grafts (p = 0.002) [26].

Zacharias *et al.* compared 6-year outcomes in propensity matched CABG patients receiving LIMA to LAD grafts who also received either radial artery grafts or vein grafts only. The authors found that mortality rates were 67% and 98% greater in vein patients than in radial artery patients after 1 and 6 years, respectively. While LIMA patencies were always significantly greater than both radial and vein patencies, 6-year radial graft patencies were systematically greater than that of vein grafts, although the results failed to reach statistical significance. Overall, the use of the radial artery as a second arterial conduit in LIMA to LAD CABG patients is associated with improved long-term survival [27].

Collins *et al.* compared 142 patients receiving either radial artery or saphenous vein grafted to the left circumflex coronary artery, with the end point being 5-year angiographic patency. 98.3% of radial artery grafts and 86.4% of saphenous vein grafts were found to be patent after the 5-year angiographic study of 103 patients (p = 0.04). The rate of graft narrowing was also significantly less in radial artery grafts compared to vein grafts, with narrowing occurring in 10% of patent radial artery grafts and 23% of patent saphenous vein grafts (p = 0.01) [28].

A smaller study by Cameron *et al.* also examined the 5-year angiographic patency results of radial artery grafts. Grafts that displayed a string sign were considered not patent. With a radial artery graft patency rate of 89%, the authors found that the radial artery had a patency rate similar to that of other grafts, although the study was too small to determine whether or not this result was statistically significant [29]. Acar *et al.* report similar results for radial artery graft patencies when compared to the LIMA [30].

Not all studies of radial artery use have been favorable. In a review of 310 patients receiving radial artery grafts between 1996 and 2001, Khot *et al.* found significantly lower patency rates for radial artery grafts when compared to IMA grafts, and similar patency rates when compared to saphenous vein grafts after a mean follow up of 565 ± 511 days. Patency rates of radial artery grafts, LIMA grafts, and saphenous vein grafts were 51.3%, 90.3%, and 64.0%, respectively. While patency rates were similar between radial artery and saphenous vein grafts, there was a significantly higher incidence of severe disease in radial artery grafts (p = 0.0003). Women were also found to have significantly lower radial artery patency rates than men [31]. However, Desai *et al.* specifically note that this study did not use randomized controls, standardized surgical methods, concurrent pharmacology, or routine angiographic follow-up that could lead to potential bias [25].

8. RIMA versus radial artery as a second choice arterial conduit

With favorable clinical results for both RIMA and radial artery use, it is then necessary to decide which is the better choice as a second arterial conduit when attempting to achieve multiple arterial revascularization.

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Ruttman *et al.* studied 1,001 patients undergoing CABG procedures either receiving RIMA grafts or radial artery grafts as second conduits after LIMA grafts with or without concomitant saphenous vein grafts added when necessary. Propensity-score matched analysis was performed on the two patient groups to examine the short and long-term outcomes of BIMA grafting versus LIMA plus radial artery grafting. Overall, the evidence provides strong support for the use of the RIMA over the radial artery as a second choice arterial conduit. Radial artery graft occlusion and disease rates were significantly higher than both IMA and saphenous vein anastomoses, with occlusion/disease rates of 37.9%, 10.2%, and 20.9%, respectively. Survival rates for BIMA grafting were 98.9% at 1, 3, and 5 years post-operatively, compared with rates for the radial artery group of 96.8%, 96.3%, and 93.0% at the same post-operative years. The BIMA group also had significantly higher rates of major cardiac and cerebrovascular events-free survival than the radial artery group at the same yearly intervals post-operatively [32].

In a 10-year prospective, randomized trial, Hayward *et al.* examined angiographic outcomes of patients receiving either a radial artery, RIMA, or saphenous vein graft to the second largest coronary target after the LAD, which was grafted with the LIMA. Patients were randomized to two groups: those less than 70 years of age received either a radial artery or RIMA as the second arterial conduit, and those greater than 70 years of age received either a radial artery or saphenous vein. At a mean follow up of 5.5 years, a total of 350 patients between the two groups had angiography performed. In the first group, Kaplan-Meier estimates of graft patency were 89.8% for the radial artery and 83.2% for the RIMA ($p = 0.06$). In the second group, patency estimates were 90.0% for the radial artery and 87.0% for the saphenous vein ($p = 0.29$). With no significant difference in the patency rates between the conduits in each of the two groups, the results show that the choice of conduit for the second largest coronary target does not significantly affect patency, giving surgeons flexibility in their revascularization plans [33].

9. Total Arterial Revascularization (TAR)

The clinical benefits of RIMA and radial artery use have been established, and many studies have indirectly examined the results of TAR in patients receiving BIMA or radial artery grafts without the need of concomitant saphenous vein grafts. However, few studies have specifically compared the clinical outcomes of TAR to conventional CABG procedures.

In a prospective study by Muneretto *et al.*, 200 patients over 70 years of age were randomized into two groups either receiving TAR or conventional CABG (LIMA to LAD with additional saphenous vein grafts if needed). Even though 31% of patients in the TAR group received BIMA grafts, the incidence of perioperative sternal wound complications was found to be 1% in both groups. At the mean follow up of 15 months, the incidence of cardiac-related events (MI, angina, coronary angioplasty, and graft occlusion) was significantly higher in the conventional CABG group compared to patients receiving

TAR. The presence of diabetes and hyperlipidemia had a negative impact on clinical outcome, especially in patients receiving saphenous vein grafts in the conventional CABG group. Conventional CABG surgery was also found to be significantly associated with coronary graft occlusion. Overall, at follow-up, TAR resulted in improved clinical outcomes in patients undergoing CABG procedures when compared to conventional CABG [34].

In a more recent, long-term study with a mean follow-up of 6 years, Chung *et al.* examined 503 patients undergoing isolated CABG procedures for three-vessel coronary disease. Patients in the study either received TAR (117 patients) or conventional revascularization (386 patients). In both the crude analysis and propensity-score matched analysis, there was no significant difference in the rates of death, reintervention, MI, or stroke between the patients receiving TAR or conventional CABG. However, the study did not examine graft patency. The authors conclude that, since the outcomes were similar between the two groups, "the selection of conduit should be more liberal" [35].

Zacharias *et al.* conducted a long-term study of 4,743 patients undergoing multivessel CABG procedures receiving either TAR (612 patients) or conventional CABG (4,131 patients). Early, 30-day mortality was similar for both patient groups, with a 1.30% mortality rate in the TAR group and a 1.67% mortality rate in the conventional group. Due to significant differences in the patient cohort for the two groups, propensity-matched analyses were performed for the 12-year follow up. Late survival was found to be significantly better in total arterial patients with three-vessel disease compared to conventional CABG patients with three-vessel disease ($p < 0.001$). However, there was not a significant difference in late survival between the two groups for patients with two-vessel disease ($p = 0.89$). The authors also noted that the completeness of myocardial revascularization was "critical for maximizing the achievable long-term benefits of total arterial grafting" [36].

10. Summary

Poor long-term patencies of saphenous vein grafts coupled with the greater long term patency results of the LIMA as the gold standard conduit for CABG has prompted surgeons to seek out additional arterial conduits [1,2]. Achieving total arterial revascularization of the myocardium would then be a natural progression for the procedure.

Since it is anatomically identical to the LIMA, the RIMA would be the next logical choice in arterial conduits, yet is rarely used in CABG operations due to the perceived technical difficulty of harvest and increased operating times, a higher risk of developing SWIs, and previous lack of long-term studies of clinical outcomes [7,8]. However, several studies have demonstrated significantly increased long-term survival rates for patients receiving BIMA grafting compared to SIMA grafting [9-12]. BIMA patients also have significantly improved cardiac event-free survival than SIMA patients [4, 6, 9]. Patency rates for RI-

MA grafts have also been shown to be similar to those of the LIMA, even when considering the sites of distal anastomoses and the proximal anastomosing techniques [16, 17, 18, 19, 20]. Further studies are needed to determine if there is any significant effect on operative length in BIMA grafting versus conventional CABG.

The incidence of SWI has been a significant concern for surgeons, especially among high-risk patients such as the morbidly obese, insulin-dependent diabetics, and those with COPD. BIMA harvesting is generally avoided in these patients [7, 8], however studies have shown that BIMA harvesting in general does not significantly affect the incidence of SWIs [12, 23]. The risk of SWI can be even further reduced with the use of skeletonized BIMA harvesting rather than pedicled harvesting [22, 23].

Studies have shown that the radial artery is also a good choice for an arterial conduit after the LIMA. Studies examining clinical outcomes and patency rates of the radial artery have been mixed, with some studies showing better short-term patency rates than saphenous vein grafts [25-28], while other studies have shown that radial artery outcomes are at least similar to those for the RIMA and saphenous vein [11, 32, 33].

While not all studies have been favorable with regards to BIMA and radial artery use [11, 15, 32, 33], studies generally find patency rates and clinical outcomes of these two arterial conduits are at least as good as the currently accepted standards of care, which should give surgeons flexibility in their choice of conduits, ultimately leading to total arterial revascularization.

Studies in general have provided favorable results for TAR, with TAR at least being similar in outcomes to conventional CABG [35]. Several studies have demonstrated that TAR, and the use of arterial conduits in general, provides significantly better late survival (especially in patients with three vessel coronary disease), cardiac event-free survival, and improved health-related quality of life when compared to conventional CABG [11, 21, 36].

11. Conclusion

With favorable results for the use of arterial conduits and results that are at least as good as those seen in conventional CABG, these results should allow surgeons flexibility in their choice of conduits. Due to the significantly increased long-term survival advantages over saphenous vein grafts, BIMA use should be particularly indicated for younger patients, with special attempts to achieve TAR in patients with three vessel disease. Especially with skeletonized harvesting, BIMA may be safe to use in high-risk patients for SWI, such as insulin-dependent diabetics. BIMA use may also decrease the incidence of postoperative cerebrovascular events due to the decreased manipulation of the ascending aorta if both IMAs are used *in situ.* The radial artery is also a suitable conduit to use in conjunction with BIMA or as a second arterial conduit if either the LIMA or RIMA is not suitable for use. This ultimate flexibility provided by TAR should allow surgeons to determine their revascularization strategies not based on the availability of conduits, but by the possible co-morbidities and post-operative complications that may arise based on the patient in question.

Author details

Sean Maddock[1], Gilbert H. L. Tang[1], Wilbert S. Aronow[2] and Ramin Malekan[1]

*Address all correspondence to: TangG@wcmc.com

1 Section of Cardiothoracic Surgery, Department of Surgery, New York Medical College, Westchester Medical Center, Valhalla, NY, USA

2 Division of Cardiology, Department of Medicine, New York Medical College, Westchester Medical Center, Valhalla, NY, USA

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