Chapter 2

The Choice of Graft Conduits in Coronary Artery Bypass Grafting

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Additional information is available at the end of the chapter

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Abstract

The use of the left internal mammary artery (IMA) has been shown to improve long-term survival and has been a gold standard in coronary artery bypass grafting (CABG). However, the choice of second or third graft conduit is still controversial. Multiple studies demonstrated the benefit of using multiple arterial grafts such as right IMA and radial artery in addition to left IMA in terms of long-term survival and graft patency. However, most of the centers still perform CABG with one IMA and vein grafts in a real world. The challenges for bilateral IMA utilization include longer operative time and concerns for higher rates of perioperative morbidity and mortality associated with increased sternal wound infection. Several studies reported that skeletonization technique can reduce the risk of sternal wound infection. Radial artery is another arterial conduit, which does not increase the risk of sternal wound infection and is easy to harvest. The superiority between radial artery and right IMA has been controversial. In the meantime, multiple trials have been made to improve the patency of vein grafts. The choice of graft conduits in CABG should be well considered preoperatively based on each patient's backgrounds.

Keywords: graft, conduit, coronary artery bypass grafting, internal mammary artery, greater saphenous vein, radial artery

1. Introduction

Coronary artery bypass grafting (CABG) is one of the most common operations performed in the United States [1], and it has been established as an effective treatment for severe coronary artery disease [2]. In fact, despite the increasing use of percutaneous coronary intervention (PCI) for coronary artery disease during the past decade [3], CABG remains the gold standard for multivessel coronary artery disease or left main disease [4, 5]. A number of major trials such as SYNTAX [6], ASCERT [7], and FREEDOM [8] reported superior long-term survival rates of CABG compared to PCI.

The main factor of the superiority of CABG over PCI is the use of internal mammary artery (IMA) to left anterior descending (LAD) artery [9, 10]. The excellent long-term patency of left IMA (LIMA) to LAD graft has been established [11–14] and the use of an IMA graft seems to improve long-term survival [15].

On the other hand, the long-term outcomes of other conduits such as saphenous vein graft, radial artery, and right gastroepiploic artery have been reported to be poorer than those of IMA. The patency rates of saphenous vein grafts were 71–87% at 1 year after surgery in previous studies [16–18] and up to 50% at 10 years [16–21].

Patients often require more than one bypass graft at the time of CABG. Unfortunately, there has been a lack of evidence for selecting bypass conduits beyond great confidence in the superiority of LIMA to LAD grafting. Therefore, the second best conduit for CABG is still unknown.

2. CABG with bilateral internal mammary arteries (BIMA)

2.1. Rationale for BIMA use

The advantages of arterial grafts over vein grafts include the inherent characteristics of the arterial endothelium of the left IMA graft [22–24]. The excellent long-term outcomes of single IMA graft have stimulated the use of a bilateral IMA approach [25]. A number of previous studies have reported the superiority of BIMA use over single IMA use (**Table 1**) [41–43].

Despite these evidences, BIMA use still appears to remain underutilized in the modern era. The challenges for BIMA utilization include longer operative time and concerns for higher rates of perioperative morbidity and mortality associated with increased sternal wound infection. LaPar and colleagues reviewed a total of 43,823 primary, isolated CABG patients in a Society of Thoracic Surgeons Database [44]. They found that the overall BIMA use was 3%, and even in low-risk patients, BIMA was used only in 6%. Importantly, BIMA use was not associated with increased postoperative mortality, morbidity, or hospital length of stay. However, hospital readmission rate was greater in BIMA patients compared with that in single IMA patients.

The configuration of BIMA grafts has also been controversial. Glineur et al. performed a prospective randomized trial that showed that the graft patency of BIMA grafts was similar between in-situ and Y-grafting configuration, whereas the use of BIMA in a Y-grafting configuration was associated in lower rates of major adverse cardiovascular and cerebrovascular events [45].

2.2. A randomized trial of BIMA use

A randomized trial of BIMA use for CABG, the arterial revascularization trial (ART) has been ongoing [46]. The patients were randomly scheduled for CABG to undergo single IMA or BIMA grafting in 28 cardiac surgical centers in 7 countries. A total of more than 3000 patients were enrolled in this study. Their results demonstrated no difference between single IMA use

Study	Year	Number of pts	Follow-up (years)	Key outcomes
Endo et al. [26]	2001	BIMA 443, SIMA 688	6.15	Graft patency was 97.3% in the BIMA group and 94.3% in the SIMA group ($p < 0.0001$).
Endo et al. [27]	2003	BIMA 190, SIMA 27	8.1	10-year survival rate was significantly better in BIMA group than in SIMA group (87.8 ± 3.5 vs 75.2 ± 3.4%, $p = 0.04$), and 10-year all death–free or repeat CABG or recurrent MI–free rate was significantly better in BIMA group than in SIMA group (86.6 ± 3.6 vs 69.0 ± 3.7%, $p = 0.0086$).
Lytle et al. [28]	2004	BIMA 2001, SIMA 8123	16.5	Survival of BIMA and SIMA groups at 7, 10, 15, and 20 years was 89 vs 87%, 81 vs 78%, 67 vs 58%, and 50 vs 37%, respectively ($p < 0.0001$).
Calafiore et al. [29]	2004	BIMA 1026, SIMA 576	7.3 ± 4.8	BIMA group had better freedom from cardiac death at 10 years (96.5 ± 0.8 vs 91.3 ± 1.4, $p = 0.0288$), late MI (98.0 ± 0.6 vs 94.3 ± 1.2, $p = 0.0180$), late MI in a grafted area (98.4 ± 0.6 vs 94.7 ± 1.1, $p = 0.0057$), and late cardiac events (93.9 ± 1.1 vs 86.3 ± 1.8, $p = 0.0388$).
Stevens et al. [30]	2005	BIMA 214, SIMA 419	11 ± 3	BIMA grafting decreased the risk of death (Hazard Ratio = 0.72 [0.57–0.91, 95% CI]) and coronary reoperation (HR = 0.38 [0.19–0.77]) in both diabetic and nondiabetic patients.
Di Mauro et al. [31]	2005	Matched; BIMA 476, SIMA 476	8.8 ± 4.0	BIMA group showed a better 10-year freedom from all-cause death (92.4 ± 2.1 vs 87.5 ± 3.5%, $p = 0.0216$), cardiac death (97.4 ± 0.9 vs 91.9 ± 1.4%, $p = 0.0042$), MI (98.7 ± 0.5 vs 94.2 ± 1.2%, $p = 0.0034$), MI in a grafted area (98.9 ± 0.5 vs 94.7 ± 1.3%, $p = 0.0017$), cardiac events (95.4 ± 1.2 vs 86.8 ± 1.8%, $p = 0.0026$), and any events (88.8 ± 2.2 vs 80.7 ± 2.1%, $p = 0.0124$).
Rankin et al. [32]	2007	BIMA 377, SIMA 490	up to 20 years	The composite of mortality, MI, PCI, and redo CABG was lower in BIMA group than in SIMA group ($p = 0.013$).
Mohammadi et al. [33]	2008	BIMA 1338, SIMA 9566	5.7 ± 3.7	Survival rates at 5, 7, and 10 years were 98.4, 97.8, and 96.5%, respectively, for patients with BIMA use, which were significantly higher ($p < 0.0001$) compared to the patients with SIMA use (96.6, 94.3, and 88.9%, respectively).
Kurlansky et al. [34]	2010	BIMA 2215, SIMA 2369	11.1–12.7	At 15 years, survival for SIMA and BIMA patients was 37.5 ± 1.1% and 53.5 ± 1.2%, respectively; at 25 years, it was 15.7 ± 2.0% for SIMA patients and 28.6 ± 2.2% for BIMA patients ($p < 0.001$).
Kieser et al. [35]	2011	BIMA 1038, SIMA 4029	7.1	Patients undergoing BIMA grafting had the lowest 1-year mortality (2.4 vs 4.3% SIMA grafting and 8.2% vein-only grafting; $p < 0.0001$).
Grau et al. [36]	2012	Matched; BIMA 928 and SIMA 928	9.0 ± 5	10-year survival for BIMA was 89% and for LIMA was 79% ($p < 0.001$).

Study	Year	Number of pts	Follow-up (years)	Key outcomes
Galbut et al. [37]	2012	Matched; BIMA 87 and SIMA 87 in EF < 30% group, BIMA 448 and SIMA 448 in EF 30–50% group, BIMA 1137 and SIMA 1137 in EF > 50% group	7.0–13	10- and 20-year survival, SIMA vs BIMA, in EF 30–50% group was 57.7 ± 0.3 and 19 ± 2.5 vs 62.0 ± 2.3 and 33.1 ± 3.4%, respectively, $p = 0.016$; and in EF > 50% group, it was 67.1 ± 1.4 and 35.8 ± 1.7 vs 74.6 ± 1.3 and 38.1 ± 2.1%, respectively, $p = 0.012$.
Locker et al. [38]	2012	BIMA/SVG 589, BIMA only 271, BIMA-RA 147, LIMA/SVG 7435	7.6 ± 4.6	BIMA/SVG and BIMA only had improved survival (86 and 76%; 82 and 75% at 10 and 15 years [$p < 0.001$]), and patients with BIMA/RA and LIMA/RA had greater 10-year survival (84 and 78%; $p < 0.001$) vs LIMA/SVG.
Kinoshita et al. [39]	2012	BIMA 244, SIMA 247	4.3 ± 1.6	The 5-year estimated freedom rate from overall death and cardiac event was higher in the BIMA group than in the SIMA group: 86.4 ± 3.2 vs 73.5 ± 3.9% ($p = 0.01$) and 93.2 ± 2.7 vs 87.5 ± 3.0% ($p = 0.01$), respectively.
Puskas et al. [40]	2012	BIMA 812, SIMA 2715	n.a.	BIMA was associated with a significant overall survival advantage at 8 years of follow-up of 89.3% compared with 68.3% with use of SIMA ($p < 0.001$).

MI, myocardial infarction; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; EF, ejection fraction; SVG, saphenous vein graft; RA, radial artery.

Table 1. Previous studies that reported the superiority of bilateral internal mammary artery (BIMA) use over single internal mammary artery (SIMA) use.

and BIMA use in terms of mortality or the rates of cardiovascular events at 5 years of follow-up [47]. Rates of major bleeding events and the need for repeat revascularization, angina status, and quality-of-life measures did not differ between the two groups, either. On the other hand, there were more sternal wound complications with BIMA use than with single IMA use. The ten-year outcomes are pending.

2.3. Sternal wound infection

One of the reasons of reluctant use of BIMA is a concern for potential sternal wound infection. There are basically two techniques for harvesting IMA: pedicled and skeletonized. Harvesting an ITA with a pedicled fashion can potentially lead to sternal devascularisation; however, Kamiya et al. reported that the damage can be minimized with skeletonization by preserving sternal and intercostal branches of IMA [48]. Boodhwani et al. reported that skeletonization resulted in reduced postoperative pain and increased sternal perfusion [49]. However, skeletonization is more technically demanding and time-consuming, and there is a concern of increased risk of injury of IMA during harvesting. Therefore, there is still a controversy regarding superiority between the two techniques.

Several previous studies reported that the skeletonization technique has a benefit over pedicled technique in terms of the incidence of sternal wound complication. Benedetto et al. reported that the risk of sternal wound infection was similar between skeletonized BIMA and pedicled single IMA [50]. Kai et al. reported that off-pump CABG with skeletonized BMA use resulted in a low incidence of sternal wound infection (0.6%) even in insulin-dependent diabetes patients [51].

3. CABG using radial artery graft

Due to the complexity of BIMA use, radial artery (RA) has been a preferred arterial graft over right IMA. RA is easier to harvest than IMA and not associated with sternal wound infection. Multiple previous studies reported improved long-term survival and patency rates for patients receiving RA as a second arterial graft compared with patients receiving vein grafts only [52–55].

However, RA is muscular and vulnerable to spasm and competitive flow. A previous study reported that the lower capacity of nitric oxide release may contribute to the susceptibility of RA to the vasospasm and may have an impact on the long-term patency [56].

There is a big controversy about which is the second best arterial graft between RA and right IMA [57] (**Table 2**). Tranbaugh et al. conducted a propensity matched study comparing RA and right IMA grafts to bypass the left circumflex coronary artery [58]. They concluded RA had fewer major adverse events, a similar patency to right IMA, and improved survival in older and chronic obstructive pulmonary disease patients. Caputo et al. reported that RA provided better early and mid-term outcomes compared to right IMA [59].

Study	Year	Number of pts	Survival	Graft patency	Conclusions
Tranbaugh et al. [58]	2014	Matched 528	10 year: 85% for RA and 80% for RIMA ($p = 0.060$)	83.9% for RA and 87.4% for RIMA at 5.1 ± 3.8 years ($p = 0.155$)	RA > RIMA
Caputo et al. [59]	2003	325 for RA, 336 for RIMA	18 months: 99.7% for RA and 98.4% for RIMA ($p = 0.07$)	n.a.	RA > RIMA
Hayward et al. [60]	2007	198 for RA, 196 for RIMA	Mean of 6.0 years follow-up: 13 deaths in RA and 18 deaths in RIMA ($p = 0.36$)	n.a.	RA = RIMA
Hayward et al. [61]	2010	198 for RA, 196 for RIMA	n.a.	5-years; 89.8% for RA, 83.2% for RIMA ($p = 0.06$)	RA = RIMA
Ruttman et al. [62]	2011	724 for RA, 277 for RIMA	5 years: 93.0% for RA and 98.9% for RIMA ($p = 0.022$)	RA occlusion was found in 37.9%; IMA occlusion was found in 10.2% ($p < 0.001$)	RA < RIMA
Raja et al. [63]	2015	Matched; 779 for RA and 747 for RIMA	10 years: 87.8% for RA and 93.4% for RIMA ($p = -0.008$)	n.a.	RA < RIMA

Table 2. Previous studies that compared right internal mammary artery (RIMA) and radial artery (RA).

Hayward et al. conducted a randomized study and concluded that, when patients receive a left IMA graft to the LAD, the next target may be grafted with a RA or a free right IMA to achieve similar clinical outcomes based on a mean of 6-year follow-up [60]. To the contrary, Ruttman et al. reported a superiority of right IMA graft compared to RA in terms of both survival and cardiac-related morbidity [62]. Raja et al. also reported the superiority of RIMA over RA [63].

4. CABG using saphenous vein grafts

Despite the potential benefits of multiple arterial grafts [41], saphenous vein graft (SVG) is still the most frequently used conduit in CABG. However, the long-term patency of SVG is reported to be poor [16–21]. The late-term SVG failure is mainly due to atherosclerotic obstruction occurring on a foundation of neointimal hyperplasia [64]. Attempts to mitigate intimal hyperplasia and SVG failure have been made; however, only persistent use of statin therapy and beta-blockers have been shown to reduce intimal hyperplasia in vein grafts [65]. Edifoligide [16] and aspirin plus clopidogrel have failed to reduce the process of SVG intimal hyperplasia [66].

Mechanical external stenting with polyester has shown potential benefits in preclinical testing with reduction of both neointima formation and early atherosclerosis, both of which are key aspects of SVG disease [67, 68]. The outcomes of initial trials of external stents for SVG were poor. Murphy et al. reported 100% occlusion of external stented SVG at 6 months [69]. Schoettler et al. reported that the patency rate of mesh-supported SVG was 27.8% at 9 months, whereas conventional SVG showed 85.7% patency [70]. Rescigno et al. reported 66.9% occlusion at 12 months of SVG supported with nitinol mesh [71]. Taggart et al. performed a randomized study comparing the one-year patency rate of stented SVG vs nonstented SVG [72]. They reported that the overall SVG failure rates did not differ between the stented SVG and nonstented SVG (30 vs 28.2%); however, stented SVG had less intimal hyperplasia and better lumen uniformity.

On the other hand, a previous study showed that the "nontouch technique," in which SVG is harvested with a pedicle of surrounding tissue, was associated with a decreased vascular smooth muscle cell activation, which affects long-term patency of SVG [73]. Souza et al. conducted a randomized study comparing graft patency of SVGs using nontouch technique and those using conventional technique [74]. They concluded that harvesting SVG with surrounding tissue provided excellent short- and long-term patency, which was comparable to the IMA [75].

5. CABG using right gastroepiploic artery

The successful use of right gastroepiploic artery (GEA) in CABG was reported in 1980s [76–78]. Histologically, GEA contains many smooth muscle cells in the media, whereas IMA has rich elastic fibers in the media [79]. Therefore, GEA is considered as a muscular artery, whereas IMA is an elastic artery. This difference becomes important when harvesting a graft, because GEA is more vulnerable to spasm than IMA.

GEA is most suitable for grafting to the distal right coronary artery and the posterior descending artery because this site is the nearest for the in-situ GEA graft and the most distant from the in-situ right IMA graft. In addition, in-situ GEA grafting can avoid manipulation of the aorta and can result in less neurological complications [80, 81].

Suma et al. reported that the cumulative patency rate of GEA graft was 92.3% at 1 year, 85.5% at 5 years, and 66.5% at 10 years after surgery, and skeletonization technique can improve the graft patency [82]. Suzuki et al. reported that skeletonized GEA grafting to the right coronary artery provided better survival and lower adverse cardiac events than SVG grafting [83].

In a real world, although multiple studies also demonstrated excellent surgical outcomes of CABG using GEA graft [84–87], GEA is rarely used in the United States mainly due to technical complexity.

6. Conclusions

CABG has been a gold standard for severe multivessel coronary artery disease. There is a conclusive evidence of a benefit of using IMA in CABG surgery. Therefore, arterial grafts are thought to provide better outcomes than vein grafts. In a real world, however, multiple arterial revascularization is still underutilized. There are multiple studies that showed a survival benefit of using right IMA or radial artery as a second arterial graft compared to using vein grafts. The superiority of right IMA vs radial artery is still controversial. Some studies suggested skeletonization technique can minimize the risk of sternal wound infection, which is the main concern for using bilateral IMAs. In the meantime, multiple trials or techniques have been tried to improve the long-term patency of vein grafts.

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