

The Arterial Grafts for Coronary Artery Bypass Grafting: Review of Current Knowledge in Regard of the Radial Artery and the Right Gastroepiploic Artery

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Abstract:

The benefits of using arterial grafts in coronary artery bypass grafting (CABG) have been elucidated in previous investigations. Alternative arterial grafts such as radial artery (RA) and right gastroepiploic artery (RGEA) have been used widely for CABG with increasing importance. Med-Line (1986-2010) was searched using the subsequent keyword arterial graft, CABG, RA and GEA. Overall, a total of 82 observational and comparison studies were considered relevant to this review and were summarized. This review provides a summary of the outcomes of RA and/or GEA arterial grafts regarding morbidity, mortality, patency rates, technical features and certain characteristics of the considered arterial conduits. This review article further supports the utility of the RA when used as either a composite or aortocoronary graft which results in improved results. Although some investigations showed acceptable results justify its use in clinical settings, there is still much concern about using the GEA in CABG. Right GEA, as an arterial graft, can be used as an in situ graft or a free graft.

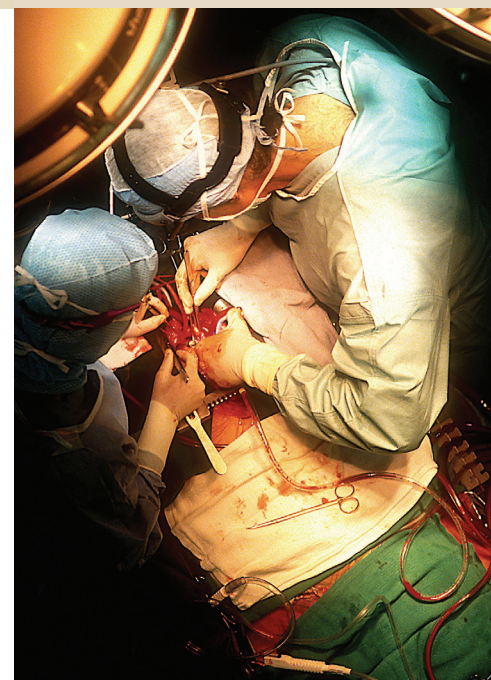
Introduction:

Coronary artery bypass graft (CABG) with arterial graft is increasingly used for myocardial revascularization (1-4). At the present time several favorable outcomes of CABG with various types of arterial grafts has been shown (10-12); however, different investigations in recent years revealed controversies in this regard (13-17). It should be pointed out that several studies revealed that the postoperative results of CABG with various types of arterial grafts resulted in improved outcomes than saphenous vein grafts (SVGs) regarding mortality, patency rate, and relief of symptoms (18-24). In view of the foregoing circumstances we decided to summarize the current investigations concerning the different aspects of arterial grafts, using

radial artery (RA). Advantages and disadvantages of using gastroepiploic artery (GEA) graft for CABG was also reviewed in this article.

Methods:

Med-Line (1986-2010) was searched using the subsequent keyword arterial graft, CABG, RA and GEA. Searches were not restricted by language or study format. A total of 122 studies were identified. Reference lists of the identified papers were also screened to recognize additional relevant publications. Overall, a total of 82 observational and comparison studies were considered relevant to this review and were summarized. Outcomes of RA and GEA grafts in CABG were focused in this review.



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RA graft in CABG:

The RA graft has been introduced since 1989 (5) as an arterial conduit for myocardial revascularization. Recently, the RA became a rational option to the SVG with the trend toward complete arterial revascularization and more frequent off-pump CABG (OPCAB) to avoid aortic manipulation (25). The RA is preferably well-matched for utilize in sequential configuration and, consequently, it facilitates maximizing the number of constructed arterial grafts.

The advantages of RA usage in CABG presented with good technical advantages (5-10). The increased wall thickness, greater luminal diameter, and longer conduit length compared with other arterial conduits make the sequential coronary anastomoses possible (26).

It should be mentioned that sequential RA grafting has been illustrated in reports focusing on all arterial coronary revascularization with generally acceptable results (27-30). Calafiore et al (1995) reported the 98% graft patency of RA at three months post operative follow-up (5). Rocha-e-Silva et al (2007) proved that RA can be used in both elective and non-elective patients with excellent results (31).

Schwann et al (2009) compared late survival of 532 consecutive patients receiving sequential RA grafting and reported an excellent 10-year survival rate that seems to be superior to conventional or internal thoracic artery/saphenous vein (ITA/SV) CABG results (32).

Nezic et al (2005) review proved the promising findings regarding the long term favorable outcomes of RA grafts and supported its continued use as a bypass conduit (33). Maniar et al (2003) investigated 1505 patients underwent CABG using the RA as either a composite (n = 1022) or RA-aorta graft (n = 483) and concluded that the site of the proximal anastomosis did not affect the patency (34). Berreklouw et al (2004) also confirmed that technique of proximal RA anastomosis and number of inflow grafts are not significant predictors for hospital outcome of the patients who underwent CABG with RA grafts (35). Chen et al (2009) showed that RA patency by coronary angiography was 95.83% after a mean time of 74 months of follow up in the elderly patients (36). Achouh et al (2010) revealed that the RA-to-coronary bypass conduit provided a low coronary reoperation rate with an excellent patency (83%) up to 20 years postoperatively (37).

RA vs ITA:

Several studies discovered suitable vascular biological uniqueness of the RA graft as a long lasting arterial conduit which results in almost equivalent to the ITA graft (18-21). Khot et al (2004) in a review article made the conclusion still controversial (15). Khot et al in patients mainly presenting with signs and symptoms of myocardial ischemia after CABG reported lower patency rate of RA grafts than LITA grafts and SVGs (15). Khot et al proposed selective use of the RA grafts predominantly in women (15).

Hayward et al (2010) performed a 10-year prospective, randomized, single-center trial and finally reported 6.6% higher estimated 5-year patencies of RA grafts vs. RTA grafts in group of patients less than 70 years (38).

The intrinsic worth of the RA conduit compared with the ITA graft is still a matter of debate (39, 40). Some studies reported the comparisons between conduits on the basis of clinical parameters, such as survival or freedom from ischemic events (27, 41-43). Because of the diversity of confounding factors, even complicated statistical tests on large cohorts of patients have failed to identify the type of graft as a determinant of clinical outcome (42, 43). Conflicting factors of these studies are mainly related to the method of evaluation of graft patency failure (27, 41-43). An angiographic assessment seems to be the gold standard way of evaluation at present. Therefore further prospective clinical studies with the same applied procedure of angiography are mandatory to elucidate clear findings in this regard.

However, the site of the target artery is a recognized and important parameter influencing coronary graft patency (39, 44, and 45). In several previous studies (37, 39, 44, 45) the patency of left anterior descending coronary artery (LAD) grafts was significantly higher than that of non-LAD grafts irrespective of the type of conduit.

Y composite grafts using RA and ITA:

Complete arterial myocardial revascularization using the left ITA (LITA) and the RA as composite Y-graft has been shown to be a safe method which can significantly increase blood flow in response to conditions of increased myocardial oxygen consumption (46). Several investigations revealed the good early after surgery results of arterial composite Y-grafts in CABG which seem to be a feasible technique that may keep the myocardial O₂ supply-to-demand ratio normal in stressful conditions which requires more demand

of oxygen supply (46-48). The benefits of multiple versus single arterial grafts and the role of different arterial conduits with respect to short- and medium-term outcome remain controversial. Borger et al (1998) reported that the use of 2 arterial grafts [RA and right ITA (RITA)] is safe, with a reduction in perioperative cardiac morbidity or mortality rates compared with 1 arterial graft after adjustment for other risk variables (49).

Sajja et al (2002) investigated the viability of using RITA and RA as a composite graft while protecting the distal two thirds of the RITA to leave the sternal blood supply intact in 18 patients underwent CABG (50). Sajja et al concluded that myocardial revascularization using proximal RITA and RA in situ pedicle graft was within acceptable results in patients with diabetes, obesity and chronic obstructive pulmonary disease (50).

Royse et al (2000) presented data of RAs which were anastomosed to the ITA as a Y graft in 17 patients and proved that using a composite graft supplied a 2.3-fold reserve of blood flow to the coronary vascular bed through the grafts (51). Previous researches showed that the supplementary application of an RA graft with a left ITA graft appears practicable for CABG (18, 52).

Kobayashi et al (2002) in 257 patients underwent OPCAB grafting showed that OPCAB grafting with ITAs and composite RAs resulted in excellent early and intermediate clinical results and graft patency (53).

The technique of Y composite graft construction between an in-situ ITA and free RA is regularly considered and reduces manipulation of the ascending aorta. This approach will be specifically functional for OPCAB. Nakamura et al (2003) reported that OPCAB using only the LITA with a composite RA can be effectively and securely carried out in patients with multivessel disease (54).

Takahashi et al (1998) reported a patient with severely diseased ascending aorta and small ITA, who underwent OPCAB to the LAD and right coronary artery (RCA) using composite arterial grafts consisting of the pedicled proximal ITA and interposed RA (55). The interposed RA graft resulted in straightforward coronary anastomosis on the beating heart and increasing the flow capacity of the ITA (55). Kano et al (2002) in two patients showed that the minimally invasive direct coronary artery bypass grafting (MIDCAB) procedure using the LITA-RA composite graft is safe and

helpful to adjust the bypass graft length and avoid the widely harvest of LITA in redo surgeries (56).

RITA can be elongated with RA for sequential grafting in redo total arterial revascularization procedure. Zhang et al (2009) reported a case which full length RA was anastomosed with the distal stump of pedicled RITA graft in an end-to-end pattern, thus creating a long composite arterial graft for sequential anastomosis with successful result in redo total arterial revascularization procedure. (57).

RA grafts vs SVGs:

Patency rate, lower consequent adverse effects and higher survey of the patients have been reported as the advantages RA grafts versus SVGs (18-21).

Donor site injury also seems to be an essential factor for selection of RA or SVG.

The RA harvest has been shown to be moderately safe with only a small group of patients experiencing problems (e.g., donor site hematoma, finger tip ischemia, dysesthesia, and scar hypersensitivity) related to its harvest (58-60). The SV harvest may be associated with similar adverse effects such as pain and poor wound recovery (61).

Hata et al (2002) found that RA harvest outperformed SV harvest in terms of patient concern (5.2% versus 7.4%) and discomfort (5.2% versus 11.9%) (62).

Randomized controlled trials did not show obvious long-term results of graft patency and cardiac-event-free survival compared with SVG, most likely because the incidence of flow competition and the definition of graft patency varied (901). Santarpino et al (2010) proved that RA-CABG demonstrated better transit-time flow meter and graft flow reserve results compared to SV-CABG (25).

Hadinata et al (2009) in an investigation of 621 patients reported that RA patency is at least comparable to that of the SV when grafted to the RCA or its branches during an 8-year period after primary CABG (63).

Hortmann et al (2010) results also should be noted which RA presented worse results when compared to SV as a second graft in a CABG, especially in women who were anastomosed in the RCA (64).

Zacharias et al (2010) investigated whether use of RA versus SVG during CABG reoperations is associated with a significant long-term survival benefit (65). Zacharias et al conclude that the use of RA as opposed to SV grafting for reoperative CABG, either with or without concomitant ITA

grafts, is associated with a substantial improvement in late survival (65). RA as opposed to SV grafting at reoperation is not an effective factor on hospital outcomes but is associated with a considerable risk-adjusted late survival benefit when the RA was used as a second arterial conduit (41, 66). In a related analysis, Tatoulis et al (2004) (67) evaluated the outcomes of redo CABG with RA grafting with those of a historical control group undergoing redo CABG with SVGs, with both groups including patients with or without additional ITA grafts at reoperation. RA use is correlated with outstanding early results that are identical or superior to those seen with SV grafting. Although significant difference in 3-year unadjusted survival was shown, investigators were able to attain total arterial revascularization in 92% of the RA cohort (67) with probable long-term survival benefits (27).

Vasospasm of RA during harvesting:

It is apparent that RA is a muscular artery that is sensitive to vasospasm during harvesting and sometimes after CABG. It is recognized that application of muscular arteries as vascular conduits (versus elastic arteries like ITA) may result in occasional vasospasm which is known as one of the negative disadvantages of muscular arteries.

To improve the quality of the RA conduit, harvesting technique and topical and systemic antispasmodic medication are imperative (25). Acar et al (1992) and Reyes et al (1995) implicated medications in regard of prevention of vasospasm that might be an important step for improving the patency of RA graft (5, 8). Ueyama et al (2004) from an animal study concluded to use vasodilator nitroglycerin or milrinone in postoperative period to avoid probable hazardous decreases in graft flow of muscular arteries (68). Na et al (2006) in an investigation of 32 patients who underwent isolated CABG implicated a Y-graft was with an in situ LITA and free RA graft attached to the proximal side of the LITA (69). Na et al proved that milrinone significantly reduced RA and LITA resistances and increased the total Y-graft flow (69).

The summarized information of selected articles regarding RA grafts in CABG could be seen in Table 1.

GEA arterial graft:

The right GEA (RGEA) has been used as a conduit in CABG. The RGEA has been used since 1984 mostly as

pedicled graft to the posterior arteries of the heart (11). Composite graft with proximal anastomoses to the LITA was first used by Sauvage in 1986 (12). The RGEA is usually harvested as a conduit alongside with harvest of the LITA and/or RITA for multiple bypass surgery. The most often targeted area is the RCA (proximal, atrioventricular branch, posterior descending branch) where the RGEA is used as an in situ graft.

Although some investigations presenting satisfactory outcomes justify its use in clinical settings, there is still much concern about using the RGEA in CABG. RGEA, as an arterial graft, can be used as an in situ graft or a free graft (16). The RGEA is principally used to graft to RCA because of its anatomical position, and its patency is not worse than SVG (16).

Isomura et al (1993) used RGEA as an arterial graft for CABG between 1988 and 1991 (70). Isomura et al reported that the patency rate of the RGEA for 36 patients was 94.4%, relief of angina was 95.5% and exercise tolerance test performed within 2 months after operation showed improved capacity (70). Sueda et al (1994) showed that postoperative angiography results of the patients with RGEA graft was superior graft than SVG (96% vs. 86%) (71).

Redo operations and dilated veins grafts also justify the search for alternatives arterial grafts, and of them, RA and RGEA have been used frequently.

Santos et al (2002) compared the results of composite Y-grafts RA and the RGEA proximally anastomosed to the LITA for CABG through angiography in a prospective randomized study (72). Santos et al concluded that RA had improved early outcomes than RGEA and suggested that use of the RGEA as composite graft should not be encouraged (72).

Kamata et al (1999) proved the successful results of RGEA graft in emergency and subemergency CABG (73). Formica et al (2006) investigated the results of CABG of 271 patients with the use of RGEA (74) and finally showed that the RGEA can be considered as a an applicable arterial conduit, comparatively simple to harvest, safe to use with low perioperative risks, and acceptable mid- and long-term results (74). The low early and late rate mortality and the satisfactory clinical results are good reasons for using routinely this conduit in selected patients .

RGEA anastomosis to RCA:

Conduits considered acceptable to revascularize the RCA system include the RGEA (75), the RITA in situ or used in a Y graft configuration (49), RA implanted into the aorta or into the LITA (5), and the SVG (11).

Malvindi et al (2007) in a review article concluded that the RGEA has been found to have a fine short- and long-term patency when anastomosed to the RCA (76). Long-term patency of RGEA has been reported 80-90% at 5 years and around 62% at 10 years in this review (76).

According to the indication of RGEA graft usage in CABG, the most encouraging target is the distal of RCA, the posterior descending artery, and posterolateral branch with tight proximal stenosis (888). Anastomoses of the GEA to the LAD artery carried out with much more unsuccessfully results and should be avoided if possible (76).

With sufficient length of RGEA or by making a composite graft with other grafts the coverage of lateral walls is anticipated (16). In reoperative CABG in which the ITA has already been used, the RGEA is a noteworthy graft material. For minimally invasive surgery, the RGEA is also important which can also be used to graft selected areas like the distal LAD or RCA without conventional median sternotomy.

GEA vs SVG:

Glineur et al (2008) determined the pre-operative angiography defined factors which may affect graft patency and flow pattern of SVG and RGEA grafts which regularly used to revascularize the RCA (22). Glineur et al observed a significant difference in the distribution of flow patterns between SVG and RGEA which in multivariate analysis, graft-dependent flow pattern was significantly associated with both minimal lumen diameter (MLD) and percent stenosis of the RCA in the RGEA group but with percent stenosis only in the SVG group. In the RGEA group, the proportion of patent grafts was higher when MLD was below a threshold value lying in the third MLD quartile (0.77 to 1.40 mm) (22).

Glineur et al (2008) in other investigation explored the RCA revascularization in two groups of the patients with SVG (n= 116) and with RGEA (n=122) grafts (23). All patients underwent angiographic control 6 months postoperatively (23) and it was reported that there were no significant patency or major adverse cerebrocardiovascular events rate

differences between the 2 groups; however, the number of functional grafts was significantly higher in the SVG group (23). Malvindi et al (2007) reported that the long-term patency of the GEA seems to be similar to that of the SV (76). Lev-Ran et al (2003) compared SVG with RGEA as the supplemental conduit to the RCA when left-sided bilateral ITA (BITA) grafting is implemented (77). Lew-Ran et al found that occurrence of postoperative complications, return of angina and midterm follow-up (4 to 56 months) did not differ significantly between two groups of the patients and finally suggested that in patients undergoing left-sided BITA grafting, the use of RGEA for revascularization of the right coronary system does not confer clinical benefits over SVG after midterm follow-up (77). Penvi et al (2005) evaluated the grafting technique to left-sided BITA grafting and RCA revascularization with the RGEA and SVG (78) and proved similar 6-year survival and similar return of angina in two groups (78). Fuku et al (2010) reported the one-year patency of RGEA versus SVG patency: 81.4% vs. 82.6% (79). Kim et al (2010) also reported that early patency of SVGs was significantly lower than that of RGEA grafts (80).

The summarized information of selected articles regarding GEA grafts in CABG could be seen in Table 2.

Conclusion:

Alternative arterial grafts such as RA and RGEA have been used widely for CABG with increasing importance. This review article further supports the utility of the RA when used as either a composite or aortocoronary graft which results in improved morbidity and mortality. Although the safety of the RA has been well recognized the RA may offer even more acceptable early, intermediate and long term outcomes when compared with SV. Compared with other arterial conduits, the RA could be straightforwardly and safely harvested which provides feasible length of conduit. To avoid RA graft vasospasm, which might be life threatening to patients, the use of vasodilators, such as milrinone is highly recommended early in the postoperative period. When performing multiple arterial grafting, careful attention to the selection of graft material and design is important to gain the full advantage of arterial grafts.

Although some investigations showed acceptable results justify its use in clinical settings, there is still much concern about using the RGEA in CABG. RGEA, as an arte-

rial graft, can be used as an in situ graft or a free graft. We can suggest that to decrease the probable side effects use of RGEA as composite free graft should not be encouraged and must be preferred as an in situ graft.

The RGEA is principally indicated to graft to RCA according of its anatomical position and also better graft patency

than SVG.

Long-term results of graft patency and cardiac-event-free survival of RA or GEA compared with SV graft are still controversial in randomized controlled trials, almost certainly due to both the incidence of flow competition and the definition of graft patency varied.

Table 1: Review on Selected articles on RA grafts in CABG

Author	Year	Sample Size	Important findings
Acar et al (5)	1992	56	Early angiographic controls (less than 2 weeks) were obtained revealed 56 of 56 patent RA grafts
Calafiore et al (6)	1995	163	The cumulative patency rate of the radial artery grafts was 93.1%
Manasse et al (7)	1996	109	two operative deaths 88.88% early graft patency
Royse et al (51)	2000	17	presented data of RAs which were anastomosed to the ITA as a Y graft and proved that using a composite graft supplied a 2.3-fold reserve of blood flow to the coronary vascular bed through the grafts
Kobayashi et al (53)	2002	257	OPCAB grafting with ITAs and composite RAs resulted in excellent early and intermediate clinical results and graft patency
Sajja et al (50)	2002	18	Myocardial revascularization using proximal RITA and RA in situ pedicle graft was safe in patients with diabetes and in obese and chronic obstructive pulmonary disease patients
Nakamura et al (54)	2003	55	OPCAB using only the LITA with a composite RA can be effectively and securely carried out in patients with multivessel disease
Lemma et al (46)	2003	27	Soon after the operation, arterial composite Y-grafts (RA and LITA) can significantly increase blood flow in response to conditions of increased MVO ₂ , keeping normal the myocardial O ₂ supply-to-demand ratio
Maniar et al (34)	2003	1505	used the RA as either a composite (n = 1022) or RA-aorta graft (n = 483) and concluded that the site of the proximal anastomosis did not affect the patency
Berrekouw et al (35)	2004	512	multivariate analysis did not show that technique of proximal RA anastomosis and number of inflow grafts are important predictors for hospital outcome
Nezic et al (33)	2005	(Review article)	long term favorable outcomes of RA grafts
Rocha-e-Silva et al (31)	2007	47	RA can be used in both elective and non-elective patients with excellent results

Table 1: Review on Selected articles on RA grafts in CABG (continued 1)

Author	Year	Sample Size	Important findings
Schwann et al (32)	2009	532	The risk-adjusted 10-year survival using a logit propensity score was substantially better for the sequential RA cohort versus the conventional CABG cohort
Chen et al (36)	2009	377	RA patency by coronary angiography was 95.83% after a mean time of 74 months of follow up in the elderly patients
Hadinata et al (63)	2009	621	RA patency is at least comparable to that of the SV when grafted to the RCA or its branches during an 8-year period after primary CABG
Achouh et al (37)	2010	202	the RA-to-coronary bypass conduit provided a low coronary reoperation rate with an excellent patency (83%) up to 20 years postoperatively
Hayward et al (38)	2010	1,181	6.6% higher estimated 5-year patencies of RA grafts vs RITA grafts in group of patients less than 70 years
Santarpino et al (81)	2010	330	RA-CABG demonstrated better transit-time flowmeter and graft flow reserve results compared to SV-CABG
Zacharias et al (65)	2010	61	use of RA versus SV grafts during CABG reoperations is associated with a significant long-term survival benefit

CABG, coronary artery bypass grafting; radial artery, RA; SVG, saphenous vein graft; LITA, left internal thoracic artery; RITA, right internal thoracic artery; OPCAB, off-pump CABG.

Table 2: Review on Selected articles on GEA grafts in CABG

Author	Year	Sample Size	Important findings
Isomura et al (70)	1993	36	the patency rate of the RGEA for 36 patients was 94.4%
Sueda et al (71)	1994	134	postoperative angiography results of the patients with RGEA graft was superior graft than SVG (96% vs 86%)
Kamata et al (73)	1999	59	successful results of RGEA graft in emergency and subemergency CABG
Santos et al (72)	2002	60	RA had improved early outcomes than RGEA and suggested that use of the RGEA as composite graft should not be encouraged
Lev-Ran et al (82)	2003	234	the use of RGEA for revascularization of the right coronary system does not confer clinical benefits over SVG after midterm follow-up

Author	Year	Sample Size	Important findings
Penvi et al (78)	2005	1000	Early and midterm results in patients undergoing left-sided BITA grafting are not affected by the conduit used for RCA grafting (RGEA)
Formica et al (74)	2006	271	RGEA can be considered as an applicable arterial conduit, comparatively simple to harvest, safe to use with low perioperative risks, and acceptable mid- and long-term results
Malvindi et al (76)	2007	Review article	Long-term patency of RGEA has been reported 80-90% at 5 years and around 62% at 10 years
Glineur et al (22)	2008	172	significant difference in the distribution of flow patterns between SVG and RGEA
Fuku et al (79)	2010	930	the one-year patency of RGEA versus SVG patency: 81.4% vs 82.6%
Kim et al (80)	2010	1345	early patency of SVGs was significantly lower than that of RGEA grafts

GEA, gastroepiploic artery; RGEA, right GEA. CABG, coronary artery bypass grafting; RA, radial artery; SVG, saphenous vein graft; LITA, left internal thoracic artery; RITA, right internal thoracic artery; OPCAB, off-pump CABG.

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