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Review

How to Use a Right Internal Thoracic Artery Graft in On- and Off-Pump Coronary Artery Bypass Grafting

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Abstract

In coronary artery bypass grafting, internal thoracic artery grafts and other arterial grafts have shown superior results compared with saphenous vein grafts. The right internal thoracic artery (RITA) has been reported as one of these various arterial graft options. However, there are some limitations and concerns associated with using the RITA. This review presents the current topics and scientific evidence on the use of RITA grafts in coronary artery bypass grafting. The reviewed papers mainly focus on the operative results of using the RITA, graft configurations and target vessels, and the comparison between on- or off-pump coronary artery bypass procedure. The results of these studies suggest the followings. The method of using the RITA (either *in situ* or as a free graft) should be selected based on the need to reach crucial targets and the number of required target vessels. A free RITA graft anastomosed to the aorta with modified proximal anastomosis allows for the revascularization of multiple vessels with acceptable flow characteristics. For revascularization of the right coronary artery system with low-grade proximal stenosis, the RITA should not be used. The decision to use cardiopulmonary bypass depends on the patient's condition, target vessels, as well as the experience of institution. Skeletonized harvesting is more effective in preventing sternal wound infections in coronary artery bypass grafting using bilateral internal thoracic arteries compared with using a single internal thoracic artery.

Keywords

coronary artery bypass grafting; right internal thoracic artery; off-pump; grafting techniques; sternal wound infection

Introduction

In coronary artery bypass grafting (CABG), internal thoracic artery (ITA) grafts have been reported to produce superior results compared with saphenous vein grafts (SVGs) [1,2]. This fact has led to the wide use of arterial grafts in CABG. Therefore, various types of arterial grafts have been used as alternatives to SVGs. Among these arterial grafts, the use of bilateral internal thoracic arteries (BITA) has shown favorable results in several reports [2–4]. Furthermore, in recent years, BITA is often used in minimally invasive CABG. However, there are still some unclarified issues concerning the use of the right internal thoracic artery (RITA) in CABG. When using the RITA in CABG, the number of reconstructed coronary arteries and target vessels are limited when it is used *in situ*. Even when it is used as a free graft, there are various proximal anastomotic sites and techniques (directly anastomosis to the aorta and composite grafting with other grafts). And the long-term graft patency and surgical outcomes for each method of using the RITA remain unclear. Discussion on the impact of cardiopulmonary bypass on surgical outcomes is also warranted. Furthermore, sternal wound complications are a major concern when using BITAs. This review discusses the use of the RITA in both on- and off- pump CABG and provides insight into the related issues.

In Situ or a Free Graft

Coronary bypass using BITA has been reported to have a better long-term event-free rate compared with using the left ITA (LITA) and SVG or single ITA (SITA) [2–6]. However, there are two main limitations when using RITA grafts. First, the RITA graft is a shorter than other grafts when used in an *in situ* fashion, typically only reaching the proximal site of each coronary artery system and usually used for only one target vessel. Bonacchi *et al*. [7] reported that an *in situ* skeletonized RITA, placed via the transverse sinus and retrocaval, can reach most branches of the circumflex system. However, multiple sequential grafting is difficult, even when using this technique. Second, there is a potential concern regarding proximal anastomosis to the aorta when the RITA is used as a free graft. Despite this concern, the patency rates of *in situ* and free RITA grafts have been reported to be similar in early and 1-year angiography studies [8]. A free RITA can reach almost all sites of the left coronary artery system [9–14], and can be used for sequential grafting [13]. As a further technique for multi-

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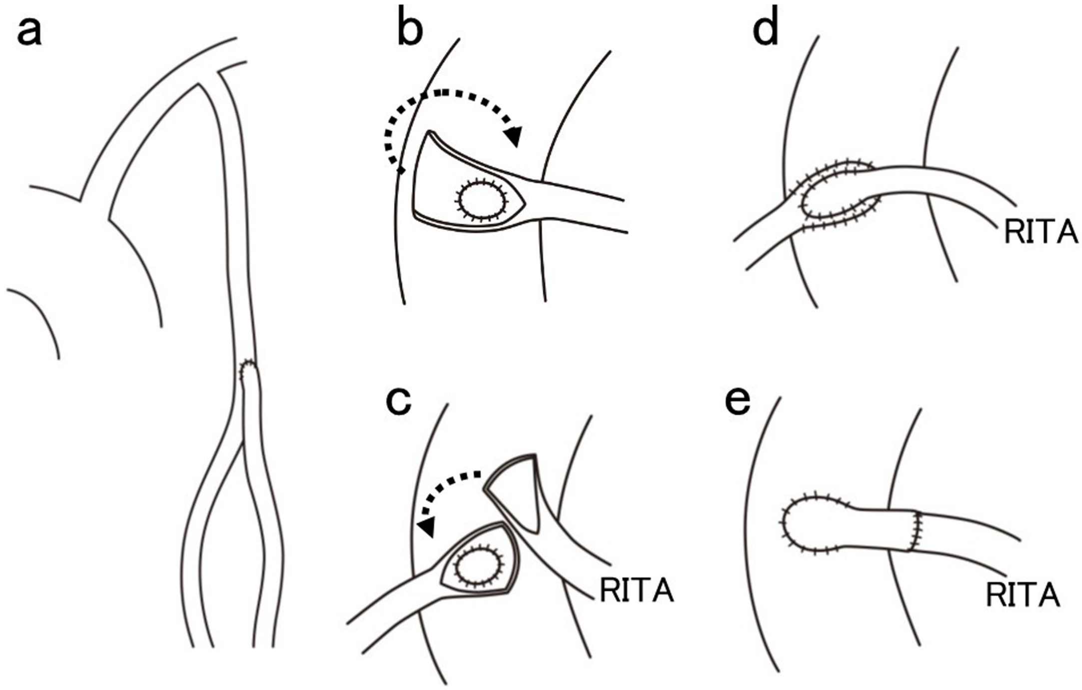

Fig. 1. Various configurations of free right internal thoracic artery (RITA) graft. (a) Y-composite, (b) foldback technique (dotted line shows the proximal graft flap of remnant tissue is folded back), (c) piggyback technique (dotted line shows the proximal end of the free RITA is sutured onto the longitudinally opened other graft), (d) V-composite, and (e) interposition of a short segment of another graft.

ple sequential grafting, the required length can be shortened by selecting the anastomotic site at the proximal region of the target coronary artery as much as possible [12]. A Y-composite graft with the LITA is one of the possible alternatives for using a free RITA graft in multi-vessel revascularization [13–15]. This configuration allows many vessels to be reconstructed with BITA grafts. Although the use of a free RITA in a Y-composite fashion is commonly adopted, it carries the potential risk of the steal phenomenon and competitive flow [16,17]. On the other hand, Loop *et al*. [18] reported a high closure rate of a free ITA directly anastomosed to the aorta in follow-up angiography performed within 18 months, although long-term patency beyond 18 months was feasible. This fact suggests technical difficulty in proximal anastomosis to the aorta. Because of the small caliber of the ITA and the thickness of the aortic wall, technical difficulty of this anastomosis may result in anastomotic stenosis. Tatoulis *et al*. [19] reported the effectiveness of CABG using a free RITA directly anastomosed to the aorta with favorable clinical results, achieving a mid-term patency rate of 94.5%, but follow-up angiography was performed in a limited number of cases (4.9%).

To address the concern of proximal anastomosis to the aorta when using a free RITA, various types of proximal anastomosis methods and procedures have been reported [20–24] (Fig. 1). Nishigawa *et al*. [20] described a V-composite graft in which the proximal anastomosis of the free RITA is performed onto an SVG (used for other target vessels) at the proximal anastomotic site. As a modification of the proximal anastomosis between free RITA and SVG, Hayashi *et al*. [22] introduced the piggyback technique. In this technique, the SVG is first anastomosed to the aorta in a side-to-side fashion, leaving remnant tissue at the proximal end. The reverse side of the SVG graft is then opened longitudinally, and the graft flap at the proximal end of the free RITA is sutured onto this site. When using the RITA as a Y-composite graft, as described above, there are concerns about graft flow, including the possible risk of the steal phenomenon, competitive flow, and an insufficient response to the flow demand of the entire left coronary system. However, the mean flow and conductance of a free RITA graft directly anastomosed to the aorta are significantly higher than those of a Y-composite graft [25]. Furthermore, Hosono *et al*. [12] demonstrated that the grafts did not affect each other's flow when the proximal anastomosis of a free RITA to the hood of an SVG is performed as close as possible to the ascending aorta and in a parallel configuration. As a direct anastomosis technique to the aorta, Ito *et al*. [21] reported the foldback technique, which involves modifying of the proximal anastomosis of a free RITA without using any other interposition materials. In this technique, the free RITA is first anastomosed to the aorta in side-to-side fashion, leaving remnant tissue at the proximal end. The reverse side of the RITA graft is opened longitudinally, and the proximal graft flap of remnant tissue is folded back and sutured onto the longitudinally opened proximal part of the graft. Another modification of the proximal end of the free RITA is the pouch technique [24], where the proximal anastomosis is performed on the aorta after creating a pouch-like end of the free RITA. Isomura *et al*. [23] adopted a composite graft using a short segment of an SVG and a free RITA. In this technique, the proximal end of the free RITA is anastomosed to the short segment of the SVG, which is proximally anastomosed to the aorta.

As mentioned above, various techniques for using a free RITA have been reported. The early results of the modifications in proximal anastomosis to the aorta when using a free RITA show promise, even in off-pump CABG. However, long-term results are not established yet. In V-composite grafts, 1-year patency rates were favorable [20]. The fold back and the piggy back techniques demonstrated superior 5-year patency compared with that of the *in situ* RITA (free 97.0% *vs*. *in situ* 80.3%, $p = 0.01$) [22]. These findings suggest the potential for favorable long-term results from these modifications. On the other hand, Bakaeen *et al*. [26] showed that long-term RITA patency was high and independent of its inflow configuration among patients undergoing BITA grafting. Even if the operative results and late graft patency of a free RITA are comparable to those of an *in situ* RITA, modifying the proximal anastomosis in using a free RITA enables the revascularization of a larger number of targets [27]. In patients with severe ascending aortic disease, the options are limited to an *in situ* or a Y-composite configuration in off-pump surgery. However, for most patients, the decision on how to use the RITA can be determined based on the approach to reaching the crucial coronary targets and the required number of target vessels. Utilizing a free RITA graft anastomosed to the aorta with modifications to the proximal anastomosis, allows the revascularization of multiple vessels while maintaining acceptable flow characteristics.

Recently, a minimally invasive approach has been increasingly adopted in CABG, including procedures performed through mini-left thoracotomy and robotic surgery. Because proximal anastomosis to the ascending aorta is technically challenging procedure through small left thoracotomy incision, using BITA with the aorta non-touch technique tend to be preferred [28–30]. In this minimally invasive approach as well, the RITA has been utilized in various configurations such as: *in situ* fashion, Y-composite, grafts, and composite graft with other arterial grafts [31–33]. Despite these different approaches in minimally invasive procedures, the nature of the RITA as a graft material remains unchanged. However, the long-term results and patency of these approaches have not been fully clarified, and further studies on the use of the RITA in minimally invasive procedures are anticipated.

Target Vessels

Favorable midterm results have been observed when employing a skeletonized free RITA as a composite graft to the left anterior descending artery in cases where an *in situ* ITA cannot be utilized [34]. Recent studies also showed feasible surgical outcomes of RITA to left anterior descending artery grafting in both *in situ* and free graft [35,36]. Although RITA grafts demonstrate optimal patency when grafted to the left anterior descending artery [36,37], it is established that the gold standard remains the LITA to left anterior descending artery. Therefore, the RITA is typically reserved for other coronary arteries. A study indicated that using an SVG may be superior to using a composite graft (*in situ* LITA and free RITA) for reconstructing the right coronary artery system in terms of early operative results and the rate of return due to angina [38]. When planning grafts and selecting target vessels, the degree of native coronary stenosis is an important factor. When using a Y-composite graft of the free RITA proximally anastomosed to the LITA, concerns regarding competitive flow, which might affect anastomotic patency, have been reported [16,39]. Robinson *et al*. [39] demonstrated that the maximal degree of native stenosis at preoperative angiography affected RITA limb patency. Their findings revealed a higher rate of RITA limb occlusion in cases with low to moderate grades ($<$95%) of stenosis compared with those with high grade stenoses. When revascularizing the right coronary artery, SVGs exhibited superior patency in patients with moderate stenosis of the right coronary artery compared with those with an *in situ* RITA in off-pump CABG [40]. Similarly in another study investigating grafting to the right coronary artery system in off-pump CABG [41], proximal stenosis ($<$90%) was predictive of graft failure in the arterial groups (RITA and right gastroepiploic artery), but not in the SVG group (hazard ratio: 3.1, $p = 0.024$). In patients who underwent BITA grafting in off-pump CABG with the RITA anastomosed to the right coronary artery system, BITA grafting did not offer advantages over SITA grafting in the 10-year cardiac-related death-free rate compared with those who underwent SITA grafting (90.0% *vs*. 90.9%, $p = 0.871$) [42]. Furthermore, Shah *et al*. [43] reported that the RITA exhibited the worst patency when used for the right coronary artery but RITA patency for the left system was identical to that of the LITA. Interestingly, in their patients' cohort, a free RITA proximally anastomosed to the aorta demonstrated superior patency compared with an *in situ* RITA in the revascularization of the right coronary artery system [43]. A study assessing the cumulative patency of the RITA over a mean follow-up of 67.0 $\pm$ 39.4 months identified several risk factors associated with graft failure. These factors included grafting to the arteries with low-grade stenosis ($<$60%), grafting to the right coronary artery system, and utilizing *in situ* rather than free ITA grafts [37].

These findings suggest that the use of the RITA for revascularization of the right coronary artery system, particularly in cases with low-grade proximal stenosis, should be avoided, and a free RITA is more favorable than *in situ*.

On-Pump or Off-Pump Surgery

Similar to on-pump surgery, the RITA is used in various configurations, including the *in situ* fashion, as a free graft directly anastomosed to the aorta, and as a Y-composite graft, in off-pump CABG [20–24,41,44]. Commercially available devices for proximal anastomosis in off-pump CABG facilitate the utilization of any configuration. However, direct anastomosis to the aorta is not feasible in patients with a severely diseased aorta. In such cases, the *in-situ* or Y-composite configuration under off-pump CABG becomes the only viable option. On the basis of these reports on CABG utilizing the RITA, early results have been promising across all configurations, even in off-pump CABG.

Regarding late patency, some reports have indicated no significant difference between on- pump and off-pump CABG [45,46]. However, other studies have reported lower graft patency in off-pump CABG compared with on-pump CABG [47,48]. A review article on comparative studies between on-pump and off-pump CABG demonstrated similar early and late survival rates [49]. As shown here, many different results on the impact of off-pump CABG have been reported. In terms of arterial graft patency, Zhang *et al*. [50] demonstrated poorer early vein graft patency in off-pump surgery than in on-pump surgery, but similar mid-term arterial graft patency, with no difference in long-term venous or arterial graft patency. In a recent meta-analysis of randomized controlled trials on graft patency after off-pump versus on-pump CABG, off-pump CABG was associated with a higher risk of occlusion in the overall graft (risk ratio: 1.31, 95% confidence interval [CI]: 1.17–1.46) and in SVG (risk ratio: 1.40, 95% CI: 1.23–1.59), but not in arterial grafts (LITA, radial artery, and RITA) [51]. Despite arterial graft patency not appearing to be affected according to these reports, concerns remain regarding lower overall graft patency and incomplete revascularization in off-pump CABG. However, a recent analysis showed no significant difference between off-pump and on-pump CABG in mid-term results [52,53]. Some reports have suggested that the number of revascularized vessels and the on-pump conversion rate are associated with the surgeon's expertise in off-pump CABG [54,55]. Furthermore, the lower graft patency rate in off-pump CABG may be influenced by the surgeon's expertise. To address these issues, Kim *et al*. [55] demonstrated that intraoperative flowmetry and revision of anastomosis of abnormal grafts improved early arterial graft patency. However, even when using this flowmetry, the on-pump conversion rate cannot be improved.

The conversion rate is a crucial issue in off-pump CABG, given that intra-operative conversion from off-pump to on-pump CABG is associated with poorer postoperative outcomes. Ntinopoulos *et al*. [56] demonstrated that limited experience among anesthetists in off-pump CABG is associated with a higher conversion rate. In terms of surgical technique and hemodynamic instability, off-pump CABG is more technically demanding, particularly when grafting lateral wall targets [57]. This fact affects both graft patency and conversion rate. In terms of patient factors, an observational study utilizing the Society of Thoracic Surgery (STS) database found that off-pump CABG was associated with significantly reduced in-hospital morbidity and mortality compared with on-pump CABG in patients with a higher risk of mortality in the STS score [58]. These results suggest that the outcomes of off-pump CABG may be influenced by the patient's condition, target vessels, and the level of expertise of the institution including the surgeon and anesthetists. However, a recent review article of comparing on- and off pump CABG mentioned that the two groups were comparable in terms of acute-phase and long-term mortality rates [59]. The decision to use cardiopulmonary bypass should be individualized for each patient, considering factors such as the patient's condition, severity of aortic disease, left ventricular function, target vessels, and the experience of the institution.

Bilateral or Single ITA

The excellent clinical results and graft patency of the LITA are supported by pathological findings [60,61], thereby prompting the use of various arterial grafts in CABG. Free arterial grafts, such as radial artery and free RITA graft, tend to exhibit superior patency compared with SVGs at 5years, particularly when used for secondary targets [62]. Despite favorable results demonstrated in some reports regarding CABG using the BITA [2–6], other studies including a recent randomized trial, have shown no significant differences in overall survival between SITA and BITA use [63]. These long-term results concerning the BITA and SITA are shown in Table 1 [2,4,63–67]. Among these seven reports, two meta-analyses support the use of BITA [4,67] and one randomized trial does not [63]. The current guidelines on CABG using BITA reflect the lack of conclusive evidence, suggesting that BITA grafting should be considered in patients without a high risk of sternal wound infection [68,69]. However, the pooled data and reports favoring the using of BITA should be considered. Furthermore, the utilization methods of the RITA varied in most studies and lacked standardization. The chosen configuration and the condition of the target vessel have an impact on the results of using the RITA. From a technical perspective, using the RITA is considered to be demanding procedure [70]. Navia *et al*. [71] described the superior-

Table 1. Late operative results of CABG using SITA or BITA.

	Author	Publication	No. of patients	Follow up	SITA *vs.* BITA
Comparative study	Taggart *et al.* [63]	2019	3102	10 years	There was no significant difference in any cause mortality at 10 years. There were 20.3% of the patients in the BITA group and 21.2% in the SITA group (HR: 0.96, 95% CI: 0.82–1.12, $p = 0.62$).
	Dalén *et al.* [64]	2014	49,702	7.5 years	Using BITA was not associated with better survival compared with SITA in the matched cohort (HR: 1.04, 95% CI: 0.78–1.40).
	Benedetto *et al.* [65]	2014	4195	4.8 years	BITA use was associated with a significantly lower risk for late mortality (HR: 0.61, 95% CI: 0.38–0.97, $p = 0.03$).
	Dorman *et al.* [66]	2012	1107	9.6 years	Late survival was significantly enhanced with BITA use (median survival: SITA, 9.8 years versus BITA, 13.1 years; $p < 0.001$).
	Lytle *et al.* [2]	1999	10,124	10 years	Late survival for the BITA group was 94%, 84%, and 67%, and for the SITA group 92%, 79%, and 64% at 5, 10, and 15 years ($p < 0.001$).
Meta-analysis	Buttar *et al.* [67]	2017	89,399	8.6, 7.0 years	BITA cohort had significantly improved long-term survival compared with SITA cohort (HR 0.78; $p < 0.00001$).
	Taggart *et al.* [4]	2001	15,962	>4 years	The BITA group had significantly better survival than the SITA group (HR, 0.81; 95% CI: 0.70–0.94).

CABG, coronary artery bypass grafting; SITA, single internal thoracic artery; BITA, bilateral internal thoracic arteries; HR, hazard ratio; CI, confidence interval.

ity advantages of the RITA graft compared with the radial artery as a second conduit in total arterial revascularization in off-pump CABG, despite the longer and technically more demanding operation. In a study of off-pump CABG by Lamy *et al.* [72], surgeon expertise was defined as having more than 2 years of experience and having completed over 100 procedures involving the specific technique. This definition of expertise may also be applied in CABG using the RITA. In surgeon's learning curve, early postoperative angiography can provide valuable feedback for quality control and technical improvement when adopting technically demanding surgical procedures. As previously mentioned, intraoperative flowmetry and the revision of anastomosis of abnormal flow grafts can also improve early graft patency. Further studies designed with these factors in mind are needed to evaluate the long-term outcomes of CABG using the BITA.

In CABG using BITA grafts, deep sternal wound infection is a concern. Peterson *et al.* [73] reported that skeletonized harvesting of BITA grafts reduced the risk of deep sternal wound infection in patients with diabetes. In their study, the prevalence of deep sternal wound infection was significantly lower in patients used skeletonized grafts compared with those used pedicled grafts (1.3% *vs.* 11.1%). Sternal wound healing may be impaired by pedicled harvesting of ITA grafts owing to decreased sternal blood flow. Cohen *et al.* [74] suggested that skeletonized harvesting may result in a lower decrease in sternal blood flow than pedicled harvesting of ITA grafts. Skeletonized harvesting can preserve collateral sternal blood flow and the internal thoracic veins. However, according to the Arterial Revascularization Trial, the use of skeletonized harvesting of SITA grafts did not result in fewer sternal wound infections [75]. Conversely, a meta-analysis on using the BITA showed that pedicled harvesting of the RITA was associated with an increased risk of sternal wound complications (odds ratio [OR]: 3.18, 95% CI: 1.34–7.57), but not in skeletonized harvesting (OR: 1.07, 95% CI: 0.67–1.71) [76]. Another meta-analysis also reported that the overall OR of sternal wound infection showed a significant difference in favor of a skeletonized ITA (OR: 0.443, 95% CI: 0.323–0.608, $p < 0.001$) [77]. In a sensitivity analysis of this study, a difference in favor of skeletonized harvesting was also observed in subgroups, such as patients with diabetes, BITA use, and patients with both diabetes and BITA use [77]. These findings suggest that skeletonized harvesting is more effective for preventing sternal wound infection when using the BITA than the SITA in CABG.

Conclusion

A free RITA graft anastomosed to the aorta with modified proximal anastomosis allows revascularization of multiple vessels with acceptable flow characteristics, except in patients with severely diseased ascending aortas. For revascularization of the right coronary artery system with low-grade proximal stenosis, the use of the RITA should be avoided. The choice of how to use the RITA can be selected according to how to reach the important and necessary coronary targets and the number of required target vessels. The decision to use cardiopulmonary bypass depends on the patient's condition, aortic disease severity, cardiac function, target vessels, and the experience of the institution. Skeletonized harvesting is more effective for preventing sternal wound infection using the BITA than the SITA in CABG. Further studies are needed to evaluate the long-term surgical results of CABG using the BITA in various configurations. These studies may reveal the optimal use of the RITA in on- and off-pump procedures, as well as in minimally invasive approach CABG.

Author Contributions

MH was the main contributing author of context conception and writing this review article. MH contributed to editorial changes in the manuscript, approved the final version of the manuscript and agrees to be accountable for all aspects of the work.

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Conflict of Interest

The author declares no conflict of interest.

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