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Review

Enhancing Radial Artery Graft Patency: Perioperative Strategies and Clinical Insights in Coronary Artery Bypass Surgery

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Abstract

With the widespread adoption of multiple and total arterial coronary artery bypass grafting, the radial artery (RA) has regained favor among cardiac surgeons. The advent of antispasmodic medications, improvements in surgical techniques, and the selection of more suitable target conduits have led to numerous studies demonstrating significantly higher patency rates for the RA, thus broadening its application. This review discusses the historical development of arterial bypass grafts, the current use of the RA, and the effectiveness of perioperative management in maintaining the viability of the RA as a graft. It also addresses strategies to minimize perioperative factors that could impair the RA, thereby ensuring graft quality.

Keywords

coronary artery bypass grafting; radial artery; perioperative period; transradial approach

Introduction

Coronary Artery Bypass Grafting (CABG) is a critical treatment for patients with coronary heart disease (CHD), and the choice of conduit significantly affects both the early postoperative outcomes and long-term prognosis for CHD patients [1]. As a secondary choice for CABG, the radial artery (RA) has demonstrated substantial improvements in both early and long-term patency rates with the use of antispasmodic medications and refined surgical techniques and appropriate target vessel territory selection. For CABG, ensuring graft patency is paramount. Recent research indicates that graft failure is closely linked to subsequent adverse clinical events. Improved graft patency is associated with better clinical outcomes post-CABG [2]. Several studies have also shown that graft failure of arterial conduits generally occurs within the first three months following surgery [3,4]. This may indicate that graft failure could relate to surgical technique and/or the presence of competitive flow. By analyzing the physiological characteristics of RA and risk factors impacting long-term patency rates and implementing standardized perioperative management, including preoperative assessments of the RA, refinements in surgical techniques, and meticulous perioperative management, the aim is to enhance graft patency rates through improved perioperative management protocols. This article aims to detail the development history and current application of the RA, the damage caused by the transradial approach (TRA), and the enhancement of its patency rate through standardized management during the perioperative period.

History and Current Application of the RA

Initially, the RA was employed as a conduit in CABG by research teams in 1973 [5]. However, it fell out of favor due to suboptimal short-term outcomes, which were attributed to the development of vasospasm and intimal hyperplasia. Nonetheless, with the recognition that RA spasm could be mitigated through pharmacological interventions and advanced surgical techniques, it has become favored again among cardiac surgeons and is now extensively utilized. According to the latest 2021 ACC/AHA/SCAI Guideline for Coronary Artery Revascularization, using the RA as a surgical revascularization conduit is preferred over the saphenous vein to bypass the second most critical target vessel with significant stenosis following the left anterior descending coronary artery (1, B-R), to enhance long-term cardiac outcomes [6]. In terms of physiological properties, compared to the internal mammary artery (IMA), the RA features a wider internal diameter and a thicker arterial wall with superior elasticity, which facilitates both proximal and distal anastomosis, enabling it to reach any coronary target. A recent study has shown that the long-term patency rate of the RA is statistically on par with that of the IMA [7], a total of 983 patients and 3064 grafts were included in the study, and data from the study showed that the difference in patency between the RA compared to the IMA was not statistically significant (86.9% vs. 93.9%, $p = 0.189$). Also, the difference in perfect patency between the RA compared to the IMA was also not statistically significant (86.4% vs. 93.5%, $p = 0.578$). It is suggested that the RA shares similar physiological characteristics with the IMA and exhibits anti-atherosclerotic properties. For patients at increased risk of sternum or pulmonary complications, the RA is a preferable option over the IMA [8].

Clinical Strategy for Enhancing RA Patency Rates

Preoperative Assessment of the RA

General Assessment

Contraindications to using the RA as a conduit include severe arm trauma or major surgery, autoimmune diseases (such as vasculitis, Raynaud syndrome, scleroderma, and rheumatoid arthritis), end-stage chronic renal failure, use of the RA for dialysis, and inadequate compensation by the ulnar artery.

Considering potential impacts on hand sensation and motor function, the RA from the non-dominant side is usually harvested. Non-invasive methods are typically employed preoperatively to assess the palmar arch circulation and the RA blood flow, with the Allen's test and the 'reverse' Allen's test being commonly utilized. However, studies have shown that both tests have limitations and are subjective in assessing the patency of the palmar arch and the RA [9]. Previous research has suggested a quantitative approach to the 'reverse' Allen test [10], which yields a more objective and reliable outcome by monitoring changes in thumb oxygen saturation (SpO2), rather than using palm color change as the criterion. Additionally, Doppler ultrasound a crucial diagnostic tool as it not only measures the RA blood flow patency accurately but also detects thrombosis and aortic dissection. Although no definitive research has proven Doppler ultrasound superior to the Allen test, the latter is generally recommended for initial evaluation due to its practicality and lower cost, and Doppler ultrasound is advised in exceptional cases.

Evaluation of Previously Cannulated RA

In recent years, TRA has increasingly been adopted as the preferred method for coronary angiography (CAG) and percutaneous coronary intervention (PCI). The primary reasons for this preference are its lower complication rates, such as those related to vascular issues and bleeding, compared to the femoral artery approach, as well as a reduction in mortality among high-risk patients, such as those suffering from acute coronary syndrome [11]. Additionally, TRA offers increased patient comfort and a reduction in the average hospital stay [12]. Despite TRA's clear advantages, it presents certain drawbacks, including pain and vascular-related issues such as RA damage and even RA occlusion. Although clinical manifestations are infrequent due to the dual blood supply to the hand, symptoms of RA occlusion occur in only a few patients. However, RA damage or occlusion may preclude the use of the RA as a conduit for CABG in patients with CHD [13].

Several studies have demonstrated that TRA can cause irreversible damage to the morphology and function of the RA [12]. Damage to the RA primarily occurs as: injury to the wall structure, impairment of vasomotor reactivity, and alterations in the diameter.

Damage to the RA wall can be categorized as acute or chronic. Acute damage typically includes intimal tears and the formation of vascular dissections, while chronic damage is characterized by diffuse intimal thickening, often affecting the distal portion of the RA, though it may also occur proximally. This suggests that angiography can lead to diffuse damage to the RA, primarily affecting the distal segments [13]. The impact of catheterization on RA vasomotor function is currently debated. In research, flow-mediated dilation (FMD) and nitroglycerin-mediated dilatation (NMD) are commonly employed non-invasive methods to assess endothelial function and smooth muscle vasomotor function of the RA [12]. Studies have shown that after catheterization, the FMD and NMD of the RA may not return to pre-catheterization levels [14], with some reporting a complete loss of FMD response [15]. Conversely, other studies suggest that the impairments in FMD and NMD observed immediately post-catheterization can almost fully recover to baseline levels within 3 months [16], with some indicating complete restoration of endothelial function within 2 months [17]. The impact on RA diameter, similar to changes in RA vasomotor function, does not have a definitive consensus on whether the diameter of the RA recovers over time after catheterization. However, all studies to date indicate that the diameter of the RA does not revert to pre-procedure levels after TRA [12]. It is critical to note that the diameter of the RA is a vital parameter, as a reduction in diameter may heighten sensitivity to competitive flow phenomena when the RA is used as a conduit for CABG [12].

Overall, it is evident that functional damage to the RA caused by TRA does not resolve quickly and requires at least 2 to 3 months for recovery. To date, limited research has specifically examined the impact of prior TRA on the function of RA used as conduits in CABG. While early studies have indicated that using the catheterized RA does not affect early clinical outcomes, their patency rates are significantly reduced (77% vs. 98%, $p = 0.017$) [18], a result that was confirmed by later studies (59% vs. 78%, $p = 0.035$) [19]. In a recent study, Worku Berhane *et al.*

[20] compared the early patency rates of the catheterized RA when bilateral RAs were used. Their results showed no significant difference in patency rates between non-catheterized and catheterized RAs at 239 days (89% vs. 84%, p = 0.72). Despite this, with only 17 days between TRA and CABG, the current consensus recommends that the catheterized RA should ideally be used for CABG only after a minimum of 3 months to allow adequate recovery time [18,21]. Given the limited number of studies and small sample sizes, more research is necessary to determine the impact of catheterized RA on long-term graft patency.

Therefore, when feasible, the non-catheterized RA should be prioritized. When the choice of grafts is limited and catheterized RA are considered the best option, pre-operative Doppler ultrasound should be employed to rigorously assess their patency and diameter.

Surgical Techniques

RA Harvesting

The key to harvesting the RA lies in the no-touch technique, which includes gentle and precise manipulation and the use of a low-power ultrasonic scalpel or electro-surgical knife to avoid mechanical or thermal injury to the RA. The RA can be harvested using the conventional open technique or the endoscopic non-sealed approach. For the choice of access technique, one study included 164 patients in a propensity-matched analysis, which, after 5 years of follow-up, showed that endoscopic access to the radial artery significantly reduced wound and neurological complications [22]. In addition, endoscopic techniques have resulted in smaller and more aesthetically pleasing surgical incisions. It was noted that there was no significant difference in graft-related deleterious effects between the two methods, either open incision or endoscopic access, and there was no significant difference in the time of access. In a study of graft failure, it was similarly concluded that the type of access technique used was not associated with an increased risk of graft failure. However, the investigators emphasised that the key is to reduce damage to the RA during the acquisition process rather than simply choosing an acquisition technique. The RA wall is primarily perfused by the vasa vasorum. Therefore, it should never be harvested as a 'skeletonized' vessel, but rather as a pedicle with its accompanying fat and vasculature, known as 'pedicled harvesting'. After being harvested, the RA is preserved in a specialized solution containing antispasmodic drugs, typically formulated as papaverine combined with heparinized blood or calcium antagonists (verapamil or nicardipine) combined with nitroglycerin.

Target Vessel Territory Selection for the RA

Three primaries factors are considered in selecting the target vessel territory: the degree of stenosis, the location of the target vessel, and the size of the vessel.

The RA is prone to functional occlusion, known as 'string sign', or even complete occlusion in the future, due to competitive blood flow from the coronary artery [23]. It is advised for patients with native coronary vessels with tight stenoses. According to the 2011 American College of Cardiology/American Heart Association (ACC/AHA) guidelines, the RA as a conduit for CABG should be considered only for patients with significant (≥90% diameter stenosis) right main coronary artery stenosis and (>70% diameter stenosis) left coronary artery stenosis [24]. In subsequent updates, the RA is recommended for coronary artery target vessel with severe stenosis [25].

The impact of the distribution of target vessel territory in the right and left coronary systems on RA patency is unclear. It has been suggested that from an anatomical perspective, the right coronary artery, due to its larger diameter, may maintain more residual flow at the same degree of stenosis and is more susceptible to competitive flow phenomena [26]. From the viewpoint of specific conduit grafting sites [7], grafts placed in the left anterior descending (LAD) artery region demonstrate higher patency rates (p = 0.003) and perfect patency rates ($p < 0.001$) compared to those in the circumflex or right coronary artery regions.

The optimal diameter for target vessel is not established, but reference can be made to the RAPCO study, sponsored by the Radial Artery International Database Consortium, which included patients with a minimum target vessel diameter of 1.5 mm [27].

Perioperative Management

Preoperative Management

Preoperative management of the RA aims to ensure vessel patency while minimizing the impact of TRA on its viability. TRA can lead to RA damage or even occlusion, potentially rendering the RA unsuitable as a conduit for CABG. For patients undergoing their initial PCI or CAG, clinicians must weigh the benefits of TRA against the potential risks of arterial injury, considering the patient's future surgical needs. For those with limited alternative conduit options, at higher risk of requiring CABG, or with severe renal impairment who might soon need arteriovenous fistula creation, the femoral artery approach may be more suitable. For patients who have experienced TRA, documenting the specific side of access is crucial to support future retrospective studies and vascular selection. Although surgeons often opt for the non-catheterized RA, many operators may switch to the contralateral side if the initial radial approach attempt fails [28]. Therefore, for patients for whom the RA is the best option available and conduit options are limited, a multidisciplinary team discussion should be held to determine the optimal management strategy.

In recent years, numerous studies have demonstrated that compared to traditional proximal radial artery (pRA) access, using distal radial artery (dRA) access (i.e., through the snuffbox area) significantly reduces the incidence of early RA occlusion. Eid-Lidt Guering *et al*. [29] conducted a randomized controlled trial involving 282 patients to analyze the incidence of RA occlusion post-TRA. Patients were randomly assigned to either the pRA access group or the dRA access group (i.e., snuffbox area access). The results showed that at 24 hours and 30 days post-procedure, RA occlusion rates were significantly lower in the dRA access group compared to the pRA access group (8.4% vs. 0.7%, $p = 0.002$ and 5.6% vs. 0.7%, $p = 0.019$, respectively), with no increase in bleeding or other vascular-related complications.

Additionally, research has shown that postoperative hemostasis time, heparin dosage, and sheath size are key factors affecting RA damage and even occlusion. Reducing the size of sheaths and catheters is essential for minimizing RA injury [30].

Postoperative Management

Studies indicate that TRA often damages the distal portion of the RA. Therefore, it is advisable to avoid using the distal segment of the RA during procedures [12]. The RA is prone to spasm due to its well-developed smooth muscle layer. Calcium antagonists, alone or in combination with nitrates, are frequently administered intravenously during intraoperative RA acquisition and in the early postoperative period, the time of greatest risk for RA spasm. However, it is important to note that the most significant side effect of intravenous anti-spasmodic drugs is hypotension, and they should be used in conjunction with topical applications, including intraluminal and surface infiltration injections. Oral calcium antagonists are often recommended postoperatively, and a recent study [31] demonstrated that the use of postoperative Calcium Channel Blocker (CCB) analogs significantly reduced the incidence of mid-postoperative adverse events and RA occlusion, compared with patients not receiving postoperative CCB. The optimal duration of use is one year, as postoperative oral CCB analogs administered for up to one year are associated with better clinical outcomes and higher patency rates of the RA compared to shorter durations. Dihydropyridines, such as nifedipine or amlodipine, are recommended, having been shown to be more efficacious than non-dihydropyridines.

Conclusions

Many studies have demonstrated that multiarterial grafting (MAG) significantly enhances long-term survival and reduces cardiovascular complications [3,32]. Using the RA as the optimal second arterial conduit of choice is increasingly accepted among clinicians. Ensuring the quality of conduit involves preoperative assessment of RA suitability, enhancement of surgical techniques, perioperative management of RA, evaluation of the patient's potential for RA as a conduit, and reduction of factors that may harm the RA during the perioperative period. These measures are essential to determine whether the RA can serve as the secondary "gold standard" arterial conduit and to improve patient outcomes.

In recent years, the use of the RA has declined, primarily due to a perceived lack of evidence from randomized controlled trials supporting its superior patency rates. Notably, the impact of gender factors in CABG has been the subject of extensive scrutiny. Existing studies have generally shown that female patients have a higher short-term mortality rate after CABG [33,34]. Several studies have pointed out that the main reason for this phenomenon is the higher number of underlying diseases and comorbidities in female patients with CHD [33,35]. In a study on graft failure [2], analyses showed that female patients were an independent risk factor for graft failure. The investigators concluded that, in addition to baseline risk differences, female patients typically have smaller coronary arteries and CABG conduits, which require greater surgical technique and are more prone to spasm [2]. However, it has also been noted that there is no clear association between female gender and smaller vessels, more diffuse coronary atherosclerotic lesions, and longer distal anastomosis construction times [36].

Of note, it was noted that there was no significant difference in mortality between female and male patients after off-pump CABG [37]. This finding suggests that performing such procedures in female patients is not more technically challenging than in male patients, suggesting that gender per se should not be a major factor in determining the surgical approach. In a study comparing the way male and female patients underwent CABG, researchers found that female patients were less likely to undergo guideline-compliant reconstruction of anterior descending disease using the IMA for haemodilution, complete haemodilution, and multiple arterial grafting compared with male patients, after adjusting for differences in baseline risk [38].

There is a particular need to promote the development of standardised cross-gender surgical revascularisation techniques and to conduct multicentre randomised controlled studies in female patients. Research specifically focusing on CABG in female patients remains limited. At the same time, sufficient research evidence regarding the use of catheterized RA is still lacking, necessitating further exploration and validation.

Author Contributions

TY and KLH designed the review plan. MLZ and QZH did the interpretation of data for the work. QZH wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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