Radial artery as a conduit for coronary artery bypass graft

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Since its resurgence in the 1990s, some 30 years after its abandonment as an alternative conduit, the radial artery has rapidly gained popularity. This article describes the application of this conduit in coronary grafting and details the controversies surrounding its use. A historical account as well as technical aspects such as operative technique are also discussed.

William Harvey first described the circulation of blood in his epoch-making treatise 'Exercitatio Anatomica de Motu Cordis et Sanguis in Animalibus' published in 1628. He also described the important distinction between arteries and veins (Harvey, 1910).

The radial artery and ulnar artery form the two divisions of the brachial artery at the cubital fossa, at the level of the neck of the radius and about 1 cm below the elbow joint. The radial artery then passes distally under the brachioradialis lying on the flexor muscles. As it courses distally, it is accompanied by the superficial branch of the radial nerve. It becomes superficial at the wrist where it may be palpated against the distal anterior radius. The artery then winds along the lateral aspect of the radius, traverses the 'anatomical snuffbox' and enters the palm to form the deep palmar arch.

Histologically the radial artery has a tunica media that is entirely muscular (Van Son et al, 1990) which explains its sensitivity to spasm with poor surgical handling or with vasoconstrictors (Garcia-Rinaldi et al, 1999). The vasa vasorum of the radial artery, unlike most other arteries, are exclusively located in the adventitia and do not contribute to the blood supply of the radial artery wall (Acar et al, 1991).

EMBRYOLOGICAL ORIGINS

The arterial supply to the upper limb is derived from the seventh segmental artery arising from the primitive dorsal aorta. These segmental arteries form the entire left subclavian and the greater part of the right subclavian systems. As this forearm bud develops it is joined by several other segmental arteries to form a free capillary anastomosis. The subclavian artery itself lengthens into the upper limb up to the level of the brachial artery. The direct continuation of this in the forearm is the volar interosseous artery. As the fetus develops, this artery recedes while its branch, the median artery, accompanying the median nerve increases in size. The radial and ulnar arteries later develop from the terminal brachial artery. As these divisions grow in size, the median artery retreats and in most instances diminishes completely. Occasionally it may be seen persisting into the palm of the hand accompanying the median nerve.

CLINICAL USE OF THE RADIAL ARTERY (NON-CARDIAC)

One of the earlier routine uses of the radial artery was the construction of an autogenous arteriovenous fistula for haemodialysis. This radiocephalic fistula, described by Brescia and colleagues in 1966, remains the first choice for vascular access with good early and long-term functional patency (Suominen et al, 2003).

The radial artery has established its efficacy in other surgical and non-surgical specialities. Selective radial artery cannulation is a valuable and preferred method for invasive blood pressure assessment during high risk procedures. In the postoperative period it allows rapid and easy access for blood gas analysis. In cases of severe peripheral vascular disease affecting the femoral vessels, procedures such as cardiac catheterization with angioplasty and stenting may also be performed using the radial artery. The use of the radial artery as a conduit is not only restricted to cardiac surgery – the artery has been used as a free graft for lower limb arterial occlusions and complications with good results (Teodorescu et al, 2003).

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CLINICAL USE OF THE RADIAL ARTERY IN CARDIAC SURGERY

Use of the radial artery as a conduit for coronary bypass grafting has developed largely as a consequence of the inexorable development of intimal hyperplasia and atherothrombotic disease in aortosaphenous vein grafts. In contrast, arterial grafts have superior patency rates as first demonstrated by Loop et al in 1996. The group showed that placing the left internal mammary artery (LIMA) onto the left anterior descending artery (LAD) increases survival and reduces late cardiac events when compared to conventional saphenous vein grafts (SVG). The accomplishment of this arterial–arterial anastomosis, currently universally accepted as the gold standard, subsequently led to the use of alternative arterial conduits. Some, such as the use of bilateral internal mammary arteries, have shown lower risks of death and re-intervention (Lytle et al, 1999).

However, results for radial artery anastomosis were initially dismal. First used by Carpentier et al (1973), the use of the conduit was rapidly abandoned within a year or two when a high failure rate was described (Fisk et al, 1976), largely as a result of its hyperspastic tendency. Ironically, the accidental revival of the conduit took place in the same city as its inception – Paris – some 15–18 years later when Dr Carpentier's patients from the 1970s required coronary angiography. The investigations showed widely patent and fully functioning radial artery grafts. The same group then proceeded to describe their experience of radial artery grafts with patency rates of greater than 90% at up to 13 months following surgery (Acar et al, 1992).

Since the resurgence of this arterial conduit, several centres have adopted the radial artery as the conduit of choice after the LIMA. Early and midterm results have been encouraging with patency rates comparable to SVG, if not better (Acar et al, 1998; Bhan et al, 1999; Tatoulis et al, 2004). In a recent study comparing angiographic findings in over 2000 arterial conduits, Tatoulis et al (2004) showed radial artery patency of 96% at 1 year, 90% at 27 months and 89% at 4 years. Although these patency rates are lower than both internal mammary arteries (98% and 96% respectively at 5 years for the LIMA and the right internal mammary artery), the group suggest another 5 years of follow up is necessary to allow a better comparison. This later assessment is especially important when comparing patency rates to SVG where a marked attrition rate is seen after the first 5 years from 95% patency at 5 years to 61% at 10 years (Tatoulis et al, 2004).

In a long-term study evaluating angiographic results at 105±9 months in 90 consecutive patients in whom the radial artery was used as an aortocoronary graft, Possati et al (2003) showed excellent patency and perfect patency rates of 91.6% and 88% respectively. These encouraging results may be explained by the observation made by Hagiwara et al (2004) who found that the conduit did not undergo structural changes after bypass grafting even several years following surgery.

Some debate has focused on the influence of coronary territory on patency rates. While there is little doubt that the best results for the LIMA anastomosis are when it is grafted to the LAD artery, patency of the radial artery does not appear to follow any specific trends. Some groups have shown a lower patency rate when the radial artery is anastomosed to the posterolateral or posterior descending branch (Maniar et al, 2002). However, more recent publications have failed to demonstrate any significance (Possati et al, 2003; Tatoulis et al, 2004).

What does appear to influence patency is the degree of stenosis in the native coronary vessel. Generally, superior radial artery patency rates are achieved with higher grade stenosis and even complete occlusion where minimal competitive flow occurs (Acar et al, 1998; Maniar et al, 2002; Tatoulis et al, 2004). In a study comprising 177 aortocoronary radial artery grafts, Tatoulis et al (2004) showed that the conduit was more sensitive than the LIMA. While the LIMA demonstrated significant patency rates when the native vessel stenosis was less than 60%, a similar radial artery patency was observed with a stenosis of less than 80% in the native coronary artery.

The radial artery may be harvested pedicled or skeletonized. A study with 244 radial artery grafts has suggested that skeletonization leads to better angiographic results at 3 months, perhaps because it causes less vasospasm (Amano et al, 2002). However, skeletonization using the ultrasonic harmonic scalpel is more frequently associated with severe endothelial damage (Rukosujew et al, 2004) when compared to conventional sharp dissection with scissors and clipping.

The dismal failure of radial artery grafts in the early 1990s was the result of the vasospastic tendency of the muscular artery (Acar et al, 1992). Subsequently, there have been many fears about its potential for spasm with subsequent ischaemia during high inotropic support such that many centres have been discouraged from using the conduit in patients with severe left ventricular dysfunction. However, data have suggested that although severe left ventricular dysfunction remains a strong independent predictor of death and cardiac events postoperatively, the risk is no more significant if the radial artery is used (Fazel et al, 2003).

TECHNICAL ASPECTS OF RADIAL ARTERY USAGE

Perioperative assessment

The radial artery is usually harvested from the non-dominant forearm in case of any postoperative complications, unless assessment of circulation dictates otherwise. The left radial artery also allows simultaneous harvesting of the LIMA. Before harvesting the conduit, an accurate clinical assessment must be made of the limb. A number of tests have been described to assess the adequacy of ulnar collateral circulation. The principal aim is to evaluate the viability of the forearm once the radial artery has been removed.

The most common clinical examination is the Allen test. Both the ulnar and radial arteries are occluded at the wrist and the patient asked to open and close his/her hand as a fist for about 30 seconds. The ulnar artery is then released at the same time ensuring that the patient does not hyperextend his/her wrist. If the hand demonstrates rapid refilling as judged by a capillary refill time of less than 5 seconds, the radial artery is suitable for harvesting. The test is equivocal if reperfusion takes between 6 and 10 seconds. The authors harvest the artery in such circumstances with no adverse consequences. Reperfusion taking greater than 10 seconds constitutes a contraindication for conduit harvesting.

Some centres also advocate the use of preoperative duplex scanning to evaluate artery calibre and flow either on its own or as an adjunct to the Allen test (Starnes et al, 1999; Jarvis et al, 2000; Abu Omar et al, 2004). The conduit is not removed if calcification or low flow is seen in the ulnar artery. The conduit may also be cannulated and the arterial pressure trace studied before harvesting. The use of pulse oximetry has also been described although it has been reported to have a high falsely normal rate with potentially dangerous consequences for the patient when compared to other methods of assessment (Levinsohn et al, 1991).

Harvesting technique

The selected arm for radial artery harvesting is prepared from mid-upper arm to the hand and draped on an arm board. In the authors' practice, the hand is enclosed in a sterile clear plastic bag with a drawstring, which is then rotated externally and clipped to the arm board to maintain adequate exposure of the operative field. The tendon of the biceps is then palpated in the cubital fossa.

The skin incision is started one finger breadth distal to this extending to the proximal wrist crease. The incision is of a lazy S-shape overlying the radial artery (*Figure 1*). It skirts the medial border of the belly of the brachioradialis muscle, taking care to avoid the lateral antebrachial cutaneous nerve coursing just laterally. During deeper dissection the superficial branch of the radial nerve, which runs alongside the radial artery about midway in the forearm, must be avoided. The nerve supplies the skin of the dorsum of the hand over the first metacarpal and proximal phalanx.

The authors previously used a combination of sharp dissection with scissors and clipping but have recently moved to the harmonic scalpel (Ethicon Endo-Surgery, Cincinnati, OH) to mobilize the artery on its pedicle and including its two venae comitantes. The radial artery is mobilized from the recurrent branch proximally to the superficial palmar branch distally using a 'no-touch' technique (*Figure 2*). It is then gently dilated with hydrostatic pressure using heparinized blood to test for any leaks and stored in a verapamil solu-

Figure 1. The 'lazy S' incision used for radial artery harvesting. The incision skirts the medial border of the brachioradialis muscle.

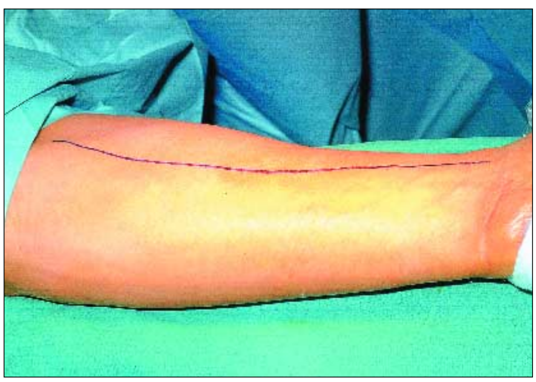
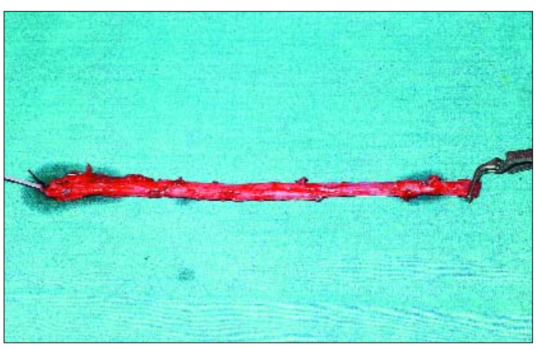


Figure 2. The harvested pedicled radial artery with its venae comitantes intact.



tion (2.5 mg/ml verapamil in 100 ml Hartmann's solution containing 2000 U heparin in 10 ml blood at room temperature) until use.

Closure of the wound is obtained in layers over a small vacuum suction drain using absorbable subcutaneous and subcuticular sutures. The drain is left in situ for 48 hours and the patient commenced on diltiazem 60 mg three times daily for 6 weeks from the first postoperative day.

Endoscopic radial artery harvesting has been described with improved and reproducible results and better patient satisfaction (Newman and Lammle, 2003). However, generally the incidence of complications following radial artery harvesting using the conventional approach is low. In an analysis of the functional status of almost 4000 cases, Meharwal and Trehan (2001) report a zero incidence of acute ischaemic injury with numbness and paraesthesia in 6.5% and 3% of patients respectively at 3 months.

Vasoreactive pharmacology

A major concern with radial artery use remains its propensity for graft spasm with subsequent myocardial ischaemia. Poor surgical handling of the conduit usually leads to instantaneous spasm so care must be taken to use a no-touch technique during harvesting with the excision of excessive fascia. Several topical agents have been advocated to prevent the potentially fatal complication of vasospasm with varying success. In addition, systemic vasodilators such as calcium antagonists are used by some groups.

An ex vivo comparative study evaluating the efficacy of several topical agents demonstrated that the broadest efficacy against radial artery spasm was achieved with a verapamil and nitroglycerin solution. However, its effect waned completely after 5 hours. Papaverine showed limited antispasmodic activity for the shortest period. The most effective agent was phenoxybenzamine, with activity against catecholamine-mediated vasospasm for at least 5 hours (Mussa et al, 2003). Other agents have also been studied. Bosentan, an endothelin receptor antagonist, has shown promise in reversing severe and protracted vasospasm in comparison to conventional agents (Verma et al, 2002).

The role of systemic vasodilators in preventing graft spasm remains unclear. However, many centres routinely use calcium channel antagonists and nitrates. An extensive literature review of all published data since 1966 has shown inconclusive results and called for systemic evaluations in the form of clinical trials (Kalus and Lober, 2001). What is clearer is that the use of calcium channel antagonists beyond the first postoperative year offers no additional benefit. In a randomized trial with 120 patients, continuation of diltiazem beyond 1 year did not affect radial artery graft patency on angiography or clinical results (Gaudino et al, 2001).

Anastomotic technique

The radial artery is an 'obligatory' free graft unlike the LIMA and therefore requires a proximal anastomosis. This anastomosis may be directly to the aorta (aortocoronary) as with conventional SVGs or form a composite T- or Y-graft with the LIMA. The distinct advantage of the composite grafting approach is that the aorta is not manipulated or any side clamps applied for the proximal anastomosis. This in turn is associated with lower atheroembolic complications and better clinical outcome as shown in a recent prospectively randomized trial in elderly patients (Muneretto et al, 2004).

The T-graft (radial end to LIMA side) or Y-graft (radial oblique to LIMA side) is constructed and tested first. In cases where cardiopulmonary bypass is used, the anastomosis is performed before bypass is instituted, leaving only the distal anastomosis under the cross-clamp. Composite grafting also allows for a greater conduit length. However, a significant risk includes the additional complexity of the proximal anastomosis with the potential of hypoperfusion in case of technical problems with the anastomosis. Graft patency rates for either the composite or aortocoronary techniques are similar as shown by Maniar et al (2003). Moreover, both techniques demonstrate equal sensitivity to target location and degree of stenosis in the native coronary vessel.

CONCLUSIONS

Since Vinberg first successfully implanted the internal mammary artery to the coronary tree in 1954, coronary bypass surgery is one of the most successful and commonly performed surgical procedures globally. Recent years have seen a re-emergence in the use of the radial artery as an alternative arterial conduit for coronary bypass surgery for advantages detailed in *Table 1*. Like many centres, the authors routinely use it as the second choice of conduit after the LIMA and in preference to saphenous veins. Clinical results for mid-term patency rates are encouraging and reproducible, with few complications reported following harvesting the artery. Moreover, despite earlier reports about its vasospastic tendency it appears to be safe in severely impaired left ventricles. There is little established data on the ease of handling of the conduit but the authors have found the radial artery to be superior to saphenous veins when constructing either the proximal or distal anastomosis. **HM**

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TABLE 1.
Advantages of radial artery use in cardiac bypass surgery

Vessel diameter slightly greater than internal mammary artery and therefore more comparable to coronary artery size
Arterial vessel more adapted to systemic pressures
Vessel wall thicker than the internal mammary artery with excellent handling and suturing characteristics
Easy harvesting of conduit owing to its superficial position in the forearm
Simultaneous harvesting of internal mammary and radial artery allows shorter procedure time
Despite earlier reports, conduit use in elderly and impaired ventricles remains safe
Compatibility with internal mammary allows composite grafting. This precludes the use of a side biting clamp for proximal anastomosis, especially in atherosclerotic aortas. Moreover, it facilitates total arterial anastomosis
Good conduit length achievable after harvesting. This allows all target vessels to be reached either as a free graft or as a composite graft

KEY POINTS

- Radial artery use in coronary artery bypass grafting is currently seeing a resurgence following initial dismal results.
- It is gaining popularity as the conduit of choice after the internal mammary artery.
- Patency rates have been shown to be superior to saphenous vain grafts.
- Despite earlier reports about its vasospastic tendency it remains a safe conduit even in patients with impaired ventricles and the elderly.
- Technically the conduit is more appealing in its handling characteristics and anastomotic capability.