The radial artery in coronary re-operations

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Abstract

Objectives: Vein graft (VG) failure often leads to coronary re-operation (re-do coronary artery bypass grafting (CABG)). As the internal thoracic artery (ITA(s)) and VG have often already been used and as the VG has usually failed, the radial artery (RA) is ideally suited for use in re-do CABG. We evaluated our experience where the RA was a key conduit in re-do CABG to determine the safety and efficacy and compared this to re-operations where the RA was not used. Methods: Three hundred and fifty-two consecutive patients who had re-do CABG using the RA(s) from July 1995 to March 1999 were studied: mean age 67.3 years, 209 (60%) angina Class III or IV, past acute myocardial infarction (AMI) in 201 (57%), left ventricular ejection fraction using the RA(s) from July 1995 to March 1999 were studied: mean age 67.3 years, 209 (60%) angina Class III or IV, past acute myocardial infarction (AMI) in 201 (57%), left ventricular ejection fraction <50% in 109 (31%). Five hundred and thirty-two RAs were used (bilateral in 180 (51%) patients). Additionally, 232 new left ITAs (66% of patients) and 71 new right ITAs (20% of patients) were placed. A total of 1022 arterial grafts used (2.6 vs. 1.2, P < 0.005) favouring the RA group. Three-year actuarial survival was 89.2% in the RA group and 88.5% in the non-RA group (P < 0.01), in deep sternal infection (0.6% vs. 2.6%, P = 0.01) and donor site infection (0.3% vs. 2.7%, P = 0.005) favouring the RA group. Three-year actuarial survival was 89.2% in the RA group and 88.5% in the non-RA group (P = 1.0).

Conclusions: Use of the RA in re-do CABG is safe, effective, allows additional conduit choice, reduces donor site and sternal infections, and may avoid further late VG failure. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Coronary artery; Re-operation; Radial artery

1. Introduction

Re-operations after primary coronary artery surgery become necessary because of progressive disease, stenosis, and occlusion of previously placed coronary grafts (especially vein grafts (VG)) and because of progress of the native coronary artery disease, especially in vessels previously only minimally stenosed [1]. VGs to coronary arteries have a failure rate of greater than 50% at 10 years, and those remaining patent at that time are often diseased and occlude over time [2].

In general, and also in our own experience, at any point in time post-operatively, patency of arterial grafts is always superior to that of VG [3]. We have been concerned that in a coronary re-operation it is not logical to replace a failed VG with yet another VG – especially as the available VG conduit at the second operation would be inferior anatomically, as the best vein conduit would have been used at the primary operation. Hence, we have pursued a policy of use of arterial grafts where possible both in primary and also in coronary re-operations.

The revival of the use of the radial artery (RA) [4] as a graft has offered an attractive additional arterial conduit which is easily procured, with minimal trauma, and is facile to use. Two RAs are potentially available in each patient with generous lengths that allow distal deployment in the coronary circulation. These factors and the potential for the RA to have a better long-term patency than for VGs makes it

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The aim of this study was to evaluate our experience with the use of the RA as a key conduit in redo coronary artery bypass grafting (CABG) with particular reference to safety, efficacy, completeness of revascularization and forearm and hand morbidity.

2. Materials and methods

2.1. Patients

We began to use the RA as a coronary bypass conduit in 1995. From July 1995 to March 1999, 5021 patients underwent isolated CABG with one or more RAs as a conduit (in addition to left ITA (LITA), right ITA (RITA) and occasional other grafts). There were 4669 primary coronary operations, and 352 (7%) consecutive patients underwent coronary re-operation (redo CABG) where the RA(s) was the key conduit. These 352 patients form the study group. Patients having additional procedures such as valve replacement, or simultaneous carotid surgery, etc., or having second or third time re-operations were not included in order to obtain a uniform study group. The pre-operative patient characteristics are detailed in Table 1.

In the same period of time only 24 (6%) redo CABG operations were performed without using the RA, either because only ITAs were required (ten) or in 14 patients where the RA was not suitable (inadequate ulnar collateral circulation (failed Allen’s test) or calcified RA).

2.2. Graft procurement

The modified Allen’s test was used as the main assessment of the adequacy of ulnar collateral circulation to the hand. Reperfusion of the radial side of the hand within 10 s of the ulnar artery release (RA still occluded) was considered adequate. Details of this modified Allen’s test have been previously reported [5,6]. Occasionally, if the light was poor, or we were unsure of the adequacy of re-perfusion within 10 s, finger plethysmography (on the index finger) was used.

If the right RA or both RAs were required, they were harvested first, with the forearms closed, placed by the torso, and then the sternum was opened. If only the left RA was required, the re-sternotomy was performed first, and then the left RA was harvested simultaneously with isolation or harvesting of the LITA. The forearm wounds were ‘rolled’ at the end of the operations to evacuate any blood that had oozed into the dissected space in the forearm over the duration of the operation. The wounds were re-dressed and a crepe bandage was applied with mild pressure.

The RA was harvested using a no-touch technique in combination with low energy cautery, sharp dissection, metal clips for branches, and care to avoid adjacent nerves. This technique has been previously described in detail [5–7].

Anti-spasm prophylaxis was given with 1 mg/ml papaverine in heparinized arterial blood intra-luminally and topically, and the RA was stored in an identical solution at room temperature until used. Additionally, intravenous nitro-glycerine infusion (30–100 μg/min) was used intra-operatively, and for the first 24 h. This was followed by the oral calcium channel blocker amlodipine (5 mg) daily for 6 months [5,6].

2.3. Surgical procedure

After repeat sternotomy adhesions were divided by sharp dissection and cautery to free and provide access to the right atrium and ascending thoracic aorta for later cannulation. Old VGs were not dissected (except for identifying their proximal location on the ascending aorta). The rest of the heart was not mobilized at this time. The next step was to locate and mobilize the LITA pedicle if previously anastomosed to a coronary (for control during aortic cross-clamping) or to harvest an unused ITA de novo.

Cardiopulmonary bypass was usually established by ascending aorta and right atrial cannulation. The patient was cooled to 32°C and flows of 2.5 l/min per m² and a mean pressure of at least 80 mmHg were maintained. Occasionally, femoral artery cannulation was used if insufficient aorta was available, and right atrial and inferior vena cava cannulation was achieved by a long femoral venous cannula when it was necessary to avoid patent but severely diseased right coronary system VGs that coursed over the lateral wall of the right atrium. A retrograde coronary sinus cardioplegia cannula was always placed via a right atrial purse-string at the acute margin.

Myocardial protection was achieved with a combination of antegrade and retrograde blood, with aspartate-enriched cardioplegia maintaining the myocardium at 25°C. The initial dose was 700 ml antegrade followed by 300 ml retrograde, and then 300 ml was retrograderly given after the completion of each anastomosis. A ‘hot shot’ of 1000 ml was given retrogradely after the last anastomosis and prior

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**Table 1**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. of patients (n = 352)</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>67.3 ± 10.2</td>
</tr>
<tr>
<td>Male/female</td>
<td>288/64 (82/18)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>66 (19)</td>
</tr>
<tr>
<td>Angina Class III or IV</td>
<td>207 (59)</td>
</tr>
<tr>
<td>Unstable angina</td>
<td>32 (9)</td>
</tr>
<tr>
<td>Left main stenosis &gt;50%</td>
<td>81 (23)</td>
</tr>
<tr>
<td>Prior Q wave myocardial infarction</td>
<td>201 (57)</td>
</tr>
<tr>
<td>Left ventricular ejection fraction &lt;0.05</td>
<td>109 (31)</td>
</tr>
</tbody>
</table>

*Where applicable data are shown as the mean ± standard deviation and numbers in parentheses are percentages. The definitions of the Society of Thoracic Surgeons were used and the Canadian Cardiovascular Society Classification was used for angina.*
to the release of the cross-clamp. All distal and proximal anastomoses were constructed during the one period of cross-clamping. An aortic root vent was used. If there was any aortic regurgitation a left ventricular vent was placed via the right superior pulmonary vein prior to release of the aortic cross-clamp. The ITA pedicles were released simultaneously with removal of the cross-clamp. Intra-operative transoesophageal echocardiography was used routinely.

Where a pedicled ITA was previously placed and patent, this was carefully mobilized (especially the LITA) to allow access to the infero-lateral aspect of the heart. Additionally, a functioning ITA pedicle wasocluded with soft-jawed bulldog clamps for the duration of the aortic cross-clamping. New ITA grafts were managed pharmacologically in a similar fashion to the RA. Anti-fibrinolytics were not used because of reports of acute spontaneous graft occlusions in re-do surgery [8,9].

With the heart arrested the inferior, lateral and then posterior adhesions were divided with sharp dissection with great care to avoid handling and/or compressing old VGs. A dose of retrograde cardioplegia was usually given after completion of the cardiac mobilization and prior to grafting.

The old grafts were left in situ and the new bypasses were constructed around them. The distal anastomoses were usually performed distal to the old graft – coronary anastomosis. If the distal coronary vessel was diseased and unattractive for grafting, then the distal anastomosis was constructed either on the hood of the old VG at the site of the distal anastomosis (if the VG wall was relatively normal), or else the old graft was excised off the anastomosis leaving a 1–2 mm cuff to which the new graft was anastomosed. Distal anastomoses were constructed using continuous 7/0 polypropylene. Proximal anastomoses were constructed using continuous 6/0 polypropylene. The proximal anastomoses were most commonly constructed onto the old VG hoods which were almost always free of disease, or directly onto the normal aortic wall. Occasionally, the RA inflow was from a new or an established LITA graft (LITA-RA ‘Y’) or an RA-RA ‘Y’ graft configuration.

The RA was used in combination with the LITA, RITA, or both (depending on their use at the prior coronary surgery), and supplemented as required by additional other grafts (inferior epigastric, gastroepiploic, saphenous vein). A total of 835 new arterial conduits were used. Conduit data are detailed in Table 2. A total of 1022 distal anastomoses were constructed (mean of 2.9 per patient). A total of 909 (89%) of all anastomoses were performed using arterial conduits.

Intra-operatively on cardiopulmonary bypass the mean BP was maintained at 80 mmHg. Similarly, post-operatively the mean BP was maintained at 80 ± 10 mmHg and the cardiac index was maintained at ≈2.5 l/min per m² by appropriate use of nitro-glycerine, dopamine and noradrenaline. (Low systemic vascular resistance together with a high cardiac output state was the most common post-operative scenario.) The intra-operative details are shown in Table 3.

### Table 2

<table>
<thead>
<tr>
<th>Conduit</th>
<th>Number a</th>
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<tbody>
<tr>
<td>Single RA</td>
<td>172</td>
</tr>
<tr>
<td>Bilateral RA (180 patients)</td>
<td>360</td>
</tr>
<tr>
<td>Total RA conduits</td>
<td>532</td>
</tr>
<tr>
<td>New LITA</td>
<td>232 (66)</td>
</tr>
<tr>
<td>New RITA</td>
<td>71 (20)</td>
</tr>
<tr>
<td>Total new arterial conduits</td>
<td>835 (2.4 per patient)</td>
</tr>
<tr>
<td>Total arterial distal anastomoses (including sequentials)</td>
<td>909 (2.6 per patient)</td>
</tr>
</tbody>
</table>

* Numbers in parentheses are percentages unless otherwise indicated.

Each patient was reviewed and data were collected and entered daily until the time of hospital discharge. Key data points related to mortality and significant morbidity. This data was later analyzed.

### 2.4. Follow-up, data collection and statistical analysis

All surviving patients were reviewed 30 days or more after surgery by direct office, cardiologist or outpatient visit. Thereafter, follow-up was at 3 months and yearly (routine review). A shorter interval was used if symptoms occurred. Information from the last known follow-up was used. Data for all patients relating to the hospital stay and the 1-month follow-up were 100% complete. The long-term follow-up was 97% complete.

All data were collected and entered prospectively into a computer database programme. The definitions of the Society for Thoracic Surgeons were used for all data. Values are reported as the mean ± standard deviation, or standard error as appropriate. Statistical analysis was with the Statistical Package for Social Sciences (SPSS-PC+). The χ²-test was used to determine the significance for discrete variables, and the Mann–Whitney test was used for comparison of continuous variables. A P value of less than 0.05 was considered significant. The Kaplan–Meier method of survival was used, and the log-rank test was used for comparison of survival.

### 2.5. Comparison with an earlier era of re-do CABG

The results obtained from this cohort of 352 patients were compared with the results of re-do CABG from the previous

### Table 3

<table>
<thead>
<tr>
<th>Variable</th>
<th>Number a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distal anastomoses per patient</td>
<td>2.9 ± 0.6</td>
</tr>
<tr>
<td>Aortic cross-clamp time (min)</td>
<td>71 ± 14</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time (min)</td>
<td>98 ± 25</td>
</tr>
<tr>
<td>Total anastomoses</td>
<td>1022</td>
</tr>
<tr>
<td>Arterial anastomoses</td>
<td>909 (89)</td>
</tr>
</tbody>
</table>

a Where applicable data are shown as the mean ± standard deviation and numbers in parentheses are percentages.
5.5 years (January 1990 to June 1995; a total of 730 consecutive patients). The RA had not been used in any of these 730 patients, but in all other technical respects the surgery had been identical (myocardial protection, single cross-clamping, ITA use, haemodynamic management, etc.).

3. Results

3.1. Operative mortality

Fourteen patients died in hospital or within the first 30 days after re-do CABG with the RA, or of associated complications. The operative mortality rate thus was 3.9%. Ten of the deaths were cardiac, or from multi-organ failure associated with low cardiac output. Specifically, in four of the 14 deaths there was intra-operative bradycardia, heart block, ECG and haemodynamic changes at the time of preparation for right atrial cannulation due to inadvertent manipulation of a patent but diseased right coronary graft and consequent atheroma embolism into the distal right coronary distribution.

3.2. Peri-operative morbidity – general

The morbidity in re-do CABG with the RA was low. Ten (2.8%) patients had a peri-operative myocardial infarction by ECG (new Q waves) and cardiac isoenzyme criteria. The mean ± SD peak level of creatine kinase cardiac isoenzyme (CK-MB) was 17.4 ± 18.7 IU/l. (Our laboratory normal values are 0–25 IU/l.) Nine (2.6%) patients required use of the intra-aortic balloon pump (IABP) for cardiac support. In three patients it was placed pre-operatively for unstable symptoms. In the other six patients it was placed intra-operatively for cardiac support to facilitate weaning from cardiopulmonary bypass.

Intra-operative spasm of the RA was noted in four (1.1%) patients. This most commonly occurred just distal to the proximal anastomosis on the aorta. Management was with topical warm papaverine and further support on cardiopulmonary bypass at high flows and pressures (mean ≥80 mmHg). In each of these instances the spasm resolved. Supplementary vein bypasses were not used. Apart from patients that developed established peri-operative myocardial infarction, sudden dramatic haemodynamic changes associated with ECG changes that may be attributed to RA spasm were not seen.

Six (1.7%) patients developed a stroke, defined as any clinically detectable neurologic abnormality producing a motor, speech or sensory deficit. One patient died. In the others the deficit tended towards resolution, but only one patient was back to normal physical neurologic examination by the time of discharge from hospital. The neurologic deficits tended to occur in older patients, but this was only a trend.

Two (0.6%) patients developed a deep sternal wound infection, defined as any sternal infection that required intravenous antibiotics and a further operation on the sternum. There were nine superficial wound infections treated with local measures (dressings) plus oral antibiotics.

Seven (2%) patients required re-operation for excessive bleeding post-operatively. There was no instance of bleeding from a RA branch. In each instance bleeding was from the raw surface areas in the mediastinum or the posterior sternal periosteum.

The mean time to extubation was 9.2 ± 5.5 h. The mean post-operative hospital stay was 6.6 ± 2.3 days.

3.3. Hand and forearm complications

There were surprisingly few hand and forearm complications. One (0.3%) patient developed a forearm donor site infection (staphylococcus aureus) requiring intravenous and then oral antibiotics. Two (0.6%) patients developed significant forearm haematomas that required surgical drainage. There were no ischaemic forearm, hand nor finger complications.

3.4. Follow-up

The mean follow-up was relatively short as the RA was first introduced into re-do CABG in July 1995. Of the survivors, 327 (97%) were available for follow-up beyond 1 month. The mean follow-up was 20 ± 12 months (range 1–50 months). The survival of patients at 3 years was 89.2 ± 8.6%. No patient who had a re-do CABG with the RA re-presented for further re-operation in the follow-up period.

3.5. Comparison to re-do CABG without the RA

The results of the current study group were compared to a cohort of 730 consecutive patients having re-do CABG without the RA in the immediately preceding time frame (January 1990 to June 1995) prior to the introduction of the RA (January 1990 to June 1995). The results and the comparisons are detailed in Table 4.

In general there were trends towards lower mortality and morbidity in the re-do RA group. However, marked differences were noted in relation to infection. The RA group had significantly lower rates of both deep sternal and donor site infections.

4. Discussion

The poor long-term performance of VGs in coronary surgery is well established [2]. Conversely, patency rates of the ITA are excellent at 10 years [2,10]. The RA has only been used in a routine fashion for the last 5 years with excellent patency results reported at 1 year [5–7,11,12] and more recently at 5 years [13]. The RA has many potential advantages as a conduit, i.e. ease of procurement, excellent length, appropriate diameter, robust structure, facile handling, and relatively resistant to kinking. It
Table 4
Comparison of results where the radial artery was used and not used in coronary re-operations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Re-do RA</th>
<th>Re-do No RA</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>352</td>
<td>730</td>
<td></td>
</tr>
<tr>
<td>Arterial grafts (mean number per patient)</td>
<td>2.6 ± 0.9</td>
<td>1.2 ± 0.6</td>
<td>0.01</td>
</tr>
<tr>
<td>Operative mortality</td>
<td>14 (3.9)</td>
<td>35 (4.8)</td>
<td>NS</td>
</tr>
<tr>
<td>Peri-operative myocardial infarction</td>
<td>10 (2.8)</td>
<td>38 (4.6)</td>
<td>NS</td>
</tr>
<tr>
<td>CK-MB IU/l (peak)</td>
<td>17.4 ± 18.7</td>
<td>16.3 ± 10.5</td>
<td>NS</td>
</tr>
<tr>
<td>IABP post-operatively</td>
<td>9 (2.6)</td>
<td>21 (2.9)</td>
<td>NS</td>
</tr>
<tr>
<td>Stroke</td>
<td>6 (1.7)</td>
<td>16 (2.2)</td>
<td>NS</td>
</tr>
<tr>
<td>Sternal infection</td>
<td>2 (0.6)</td>
<td>19 (2.6)</td>
<td>0.01</td>
</tr>
<tr>
<td>Donor site infection</td>
<td>1 (0.3)</td>
<td>20 (2.7)</td>
<td>0.005</td>
</tr>
<tr>
<td>3 year survival (%)</td>
<td>89.2 ± 8.6</td>
<td>88.5 ± 1.9</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*Where applicable data are shown as the mean ± standard deviation and numbers in parentheses are percentages. P values of significance are shown.

...can reach distally in the coronary circulation beyond all coronary stenoses, and is well suited to sequential grafting as well. The excellent length of the RA is particularly important and advantageous in re-operations as the distal anastomoses need to be constructed beyond the old ones.

Patients presenting for re-do CABG are usually older and more likely to have peripheral vascular disease and diabetes, and also limited conduit. Hence, the free availability of the RA as a conduit is a major advantage.

We have been concerned regarding replacement of a failed VG with another VG, and the goal of this study was to examine the risk and the operative results obtained by departing from the conventional operation and using the RA as a key conduit in addition to those ITA grafts that were required. Additionally, in a re-do setting, the optimum VGs had already been used, making a further case for use of an alternate graft. The presence of and use of arterial grafts (ITA grafts) has been shown to improve the operative mortality and clinical results in both primary and re-do coronary operations [14]. It appears logical to further this philosophy with the use of RA grafts. The LITA has been in routine use in our practice since 1985 and now many patients presenting for re-operation have an LITA functioning in situ already. No LITA has been damaged at re-sternotomy thus far. Although it is a theoretical risk, with careful planning this is avoided. It is important to fully mobilize the LITA pedicle to gain access to the lateral and infero-lateral regions of the heart, and also to be able to place soft bulldog clamps on the LITA pedicle during the time of cross-clamping to eliminate warm ischaemia and to allow the full effect of retrograde cardioplegia.

Although we often construct a LITA-RA 'Y' graft in both primary and re-do CABG where the LITA is used the first time, in general we have not used a functioning LITA to the left anterior descending graft for the inflow of an RA graft because we did not wish to disturb a perfectly functioning graft. Additionally, the LITA pedicle is usually found to be quite tough and difficult to handle with regard to placing an inflow anastomosis.

We have found the Allen’s test to be satisfactory as a measure of adequacy of ulnar collateral circulation. In most patients the thenar eminence and thumb and index finger were perfused within 5 s of release of the ulnar artery (while the RA is still compressed) and 97% will re-perfuse within 10 s which is the cut-off time. Using these criteria, we have not had any significant hand or finger ischaemia problems (except for two early in our experience) in several thousand RA harvests [5–7].

Older and diabetic patients are more likely to have distal calcification in the RA which may exclude the use or shorten the amount of useful conduit that is available. The shorter proximal end may still be used to construct a ‘Y’, or extend another graft. A special problem is that in every instance one of the RAs would have been cannulated at the first operation for intra- and post-operative arterial monitoring. Despite this, generally the RA is perfectly normal; however, one must always be aware of the possibility that the distal RA may be partly fibrosed or have multiple channels due to prior cannulation trauma. If this is the case, the distal fibrotic portion can be left in situ and the proximal RA can be used.

Prophylaxis against RA spasm is essential as it is a muscular artery and prone to spasm. The use of intra-luminal and topical papaverine in heparinized arterial blood is essential to dilate the RA and prevent spasm. Additionally, endothelial function is preserved [15]. Intra-operative nitroglycerine and post-operative calcium channel antagonists are important [16] as post-operative spasm may occur in both the ITA and RA grafts [4]. Avoidance of cold saline or ice slush in the pericardium is important in safeguarding against spasm. We do not use any such solutions and maintain the myocardial temperature at 25°C with blood cardioplegia.

We found the most dangerous technical scenario in re-operation to be that of the patent but severely diseased VG coursing over the lateral wall of the right atrium to the distal right coronary artery or posterior descending artery. Manipulation of these diseased grafts during right atrial cannulation may lead to embolization, sudden heart block, severe inferior left ventricular dysfunction and a non-recoverable situation. Four of our operative mortalities occurred from this situation. We now avoid this scenario by cannulation of the right atrium and inferior vena cava via a long venous cannula introduced via the right femoral vein, if required.

Myocardial protection during re-do CABG is a crucial issue. After the initial dose of antegrade and retrograde cardioplegia, we prefer to use retrograde blood cardioplegia after each anastomosis. This ensures cardioplegia delivery to areas of myocardium previously supplied by occluded or diseased grafts, and also allows flushing out of any atheromatous embolic material. The patency of the distal anastomosis is also confirmed by retrograde flow out of the proximal ends of the RA graft(s).
In general, alignment of the RA grafts from the distal anastomosis back to the aorta is usually straightforward. The proximal end of the RA is usually 3–3.5 mm in diameter and handles much like a VG and the proximal anastomosis can be readily made either into the hood of a previously placed VG, or to a new site on the ascending aortic wall. An old VG hood is preferred as this is usually free of atheroma [17]. Alternate sites of RA inflow may be from another RA graft, or from a new ITA pedicle (where length of conduit, or restricted access to the ascending aorta for proximal anastomosis are issues).

The intact and functioning VG remains a controversial issue [14,17,18]. If a previously placed VG is perfect (no wall disease), we leave it alone and do not place a further graft in that distribution – believing in the concept of a biologically privileged graft [18]. If a perfectly intact VG is left in situ, and a new additional arterial graft (particularly a RA or a free RITA graft) is placed to the same coronary artery, competitive flow is an issue, as a number of studies have shown through lower patency rates where arterial grafts have been used where there is significant competitive flow, or low grade coronary stenosis [5,19]. Where a VG is patent but atheromatous, we leave it in situ, work around it and place an additional new arterial graft to the same coronary artery a little more distally. As a result of this policy we have not seen acute hypoperfusion, as has been reported where functioning but diseased VGs were excised and replaced with an ITA [14].

The incidence of re-operation for post-operative haemorrhage was low (2%). This was achieved by careful dissection and haemostasis, particularly with the use of cautery once raw surfaces and edges were defined. There was no instance of bleeding from the RA(s). The RA branches are small and well defined and can be readily clipped or diathermied. We have not observed bleeding from an RA branch requiring a return to the operating room.

Use of the RA has allowed the mean number of new anastomoses constructed on a patient to be similar to that in primary coronary surgery. Additionally, use of the RA has allowed 89% of all anastomoses at coronary re-operation to be arterial. This has not been associated with any additional mortality or morbidity. In fact in all areas (mortality, peri-operative acute myocardial infection, IABP use, etc.) the results have tended towards being more favourable than when fewer arterial anastomoses were used. There is a growing body of literature to support the notion that both the short-term and long-term results are improved with an increasing number of arterial coronary anastomoses [20,21].

Not only were the results in re-do CABG with the RA equivalent or more favourable than our non-RA re-do experience, but also the results compared favourably with those results in larger reported series of conventional CABG [22].

A limitation of the study is that of a relatively short follow-up, as the technique (re-do CABG with RA) has only been recently introduced. Although theoretically having a greater number of arterial anastomoses should confer significant benefits to patients, in terms of freedom from further cardiac events and prognosis, the relatively old age of the patients may preclude those benefits from being seen.

Apart from conduit availability, we found a number of other distinct advantages in RA use in re-do CABG. The sternal infection rate was significantly lower by comparison to where VGs were used. This may be due to the 'cleaner' donor site, by comparison to the legs and thighs. Avoidance of leg incisions is also important, as is avoidance of concurrent incisions and dissections in the leg and thigh area, in the rapid ambulation of these older patients undergoing re-do CABG. Another significant benefit is the lower rate of donor site complications, especially infection, as the forearm tissues are more vascular and supple with soft muscle and subcutaneous tissue by comparison to the peri-tibial area in the leg or fat in the thigh.

An important limitation in the comparison of the RA/re-do group with the non-RA/re-do patients is that the operations were performed in different time periods (1995–1999 compared to 1990–1995). In all measurable ways the techniques were identical – the same surgeons, single aortic clamp, myocardial protection and antibiotic prophylaxis. However, it is possible that subtle improvements in the surgical technique, particularly relating to avoidance of infection, may have occurred.

The long-term results, and especially the patency of the RA, are not addressed in this paper. However, a number of reports indicate that the patency of the RA is equal to or better than for VGs, and at present patency rates of 90% or better have been documented at 1, 3 and 5 years post-operation [5,11–13,19].

In conclusion, the RA is ideally suited for use in re-do CABG as one or both are freely available, are of excellent length, robust and facile to handle and offer arterial revascularization of the heart with few complications in the donor site. The use of the RA is safe, produces equal or superior results in the short term, and may avoid the problems of late VG failure.

References


Brian Buxton and his colleagues. I would just be interested to know how

Appendix A. Conference discussion

**Mr T. Treasure (London, UK):** The use of radial arteries in our group has gone up very dramatically in the last two or three years and we are very comfortable with them, and in fact it has been influenced very much by Brian Buxton and his colleagues. I would just be interested to know how

many people out of the audience are using radials pretty routinely these days. (Show of hands). Right. So it has become quite commonplace, so we have got an informed audience who are interested in your results.

**Dr V. Subramanian (New York, NY):** The Melbourne group continue their interest in the radial artery and a very high angiographic rate to show the patency of these grafts.

Our experience also validates their results that the radial artery is a good conduit. We do have a little bit different twist.

In the last year we have been using exclusively the endoscopic technique for radial artery harvesting, and this has been a veryatraumatic technique. Currently both radial arteries could be easily obtained by the endoscopic technique. This procedure takes roughly 15 to 20 minutes.

One other benefit of the endoscopic technique if we find those radial arteries which are not suitable in a very small percentage, as you show, that there is some calcium in the radial artery or previous scarring, we can abandon the operation very early.

One other observation we have is currently we do not know which radial artery is going to biologically behave in the long term. Do you have any way of predicting which radial artery in which group of patients are going to work well? We have some fundamental basic pharmacological and histopathological observations in a group of patients showing that people who are diabetic, who have smoked within the past one week, who are taking a heavy dose of aspirin have a major problem in the prostacycline synthesis in this radial artery. And perhaps you can share some observation in what radial artery is going to work well in which group of patients.

**Dr Tatoulis:** We have not used endoscopic harvest to this point, but we certainly are very interested in it.

With regard to abandoning the radial artery, if it is calcified, early in the dissection before you make such a big incision, we usually start the incision near the wrist and ensure that the radial artery, at least in that area, is normal before we extend the incision further proximally.

With regard to the prediction of which ones will do best, I don’t know. We have a prospective, ethics-approved study in which we are performing angiograms on patients at 3 months, 12 months, three years and five years, some in the same patients but some different, and thus far we have over 300 radial artery angiograms, a mean of just over 14 months post-operatively. The main correlations we have with poor patency are when the radial artery is used in a native coronary artery that is less than 60% stenosed, and there is competitive flow, and also when it is used as a Y graft. The segment between the last obtuse marginal and the posterior descending, around the back of the heart has a lower patency of about 70%. So those are the two things that we have found so far.

In terms of biologic behaviour, although we are doing some bench studies on the pharmacology of the radial artery, we do not have yet a correlation between the structural wall and pharmacologic properties of the artery and its long term patency.

**Dr D. Grandmougin (Lille, France):** We have a good experience in the radial artery, and I totally agree with you in the fact that usually saphenous is not a problem, but I am also quite convinced that the way to harvest remains very important to prevent this spasm. Could you tell us more about your way to harvest, if you use intraluminal dilatation or, for instance, if you use calcium blockers to prevent spasm?

**Dr Tatoulis:** We harvest the artery by exposing it with a no-touch technique. We use papaverine, 1 mg/ml, in heparinized arterial blood at 37 degrees C temperature, and we place that intraluminally, with no pressure. We clip the distal end of the radial artery and we just let it pulsate until we secure the proximal end, and then we store it in a similar solution for about 20 or 30 minutes until we are ready to use it. Also importantly, we have the myocardium at 25°c and we do not use any intrapericardial cold slush. I think that is a key issue. Topical cold in the pericardium may well cause secondary radial artery spasm. We do not have intravenous diltiazem available in Australia, so we use intravenous nitroglycerin, quite liberal doses for 24 hours, and my colleague, Brian Buxton, sometimes uses milrinone as a vasodilator.

**Dr B. Aberg (Karlskrona, Sweden):** Many reports, and also ourselves, use calcium blockers for six months after surgery. There is maybe no rationale for that. Maybe it is good, but maybe we should give it for a...
shorter time or maybe oral nitroglycerin might even be better? Do you have any ideas about this?

**Dr Tatoulis**: We use amlodipine, which is a once daily calcium channel blocker, for six months. We also use nitroglycerin peri-operatively. Both are very powerful vasodilators, and we believe, particularly with some work that we have done, but also from the Mayo Clinic, that amlodipine is probably a better calcium channel blocker for the radial artery as opposed to diltiazem.

Why do we use it for six months? I think there is some rationale. Both in our own study of over 300 angiograms but also in some published reports, we do see localized radial artery spasm weeks or months after surgery when we are doing angiography, and intragraft nitroglycerin at the time of angiography relieves the spasm. The spasm is usually several centimeters away from the proximal anastomosis, and it is usually smooth and dissipates with intragraft nitroglycerine at the time of cath. I think that has been documented by other workers as well. So I think it is a real phenomenon, and on that basis we continue to use a calcium channel blocker for at least six months.

**Dr D. Saksena** (Bombay, India): Do you think it makes any difference where you put your proximal anastomosis, whether it is in the aorta or the mammary or any other graft? Does that make any difference in your long term patency of the radial artery?

**Dr Tatoulis**: This is a controversial topic, and there have been many advocates of placing the inflow of the radial artery on the LITA, particularly Dr Calafiore. We do not know what the answer is. At this point in time I can say that, again, from the angiograms which we have done, in over 300 radial arteries, that there appears to be no difference in patency whether the proximal anastomosis is directly from the aorta, or it is from the LITA. The only two findings that we have noticed so far are lower distal patencies when the anastomosis is to native coronary arteries with stenoses of low grade or around the back of the heart to the posterior descending artery as part of a Y graft.

**Dr R. Dion** (Leiden, The Netherlands): Personally I still have doubts about the patency in the long term. I would like to submit a short practical example. The patient is 50 years old, needs reoperation, no COPD, no diabetes, no obesity. Would you use the radial artery? Personally I would use both mammary arteries.

**Dr Tatoulis**: It depends on whether the mammary arteries have been used in the first operation, so I assume from your question they have not been, and it is a reoperation. Yes, we use bilateral mammary arteries routinely. We have a big experience of bilateral internal mammary artery grafting.

I do not think that the radial artery competes with the mammary artery, and as I said in the conclusion, I think it is an excellent choice for the conduit of second choice. So for your practical example, I would use the LITA as a pedicled graft, I would use the right ITA, usually as a skeletonized pedicled graft, through the transverse sinus to the circumflex, or wherever it is going to go. Depending on the other anatomy, I might use it as a T graft, like a Tector technique. If there is a very inferior descending artery, I might then use the radial artery for that last graft. So we would have a very strong preference for the grafts of choice to be the two mammary arteries first and the radial artery as a supplementary graft.

**Dr T. Helmy** (Cairo, Egypt): After harvesting the radial artery sometimes you find two or three segments of spasm before using it. What do you do for this area? Do you apply higher pressure inside or do you probe? What do you do?

**Dr Tatoulis**: We do notice spasm when it is being harvested, and so we use intraluminal and topical papaverine and also store it in a little beaker of heparinized blood with papaverine (1 mg/ml). By the time you actually get to use it, it is very uncommon to see spasm 30 or 40 minutes later on. Again, after we have actually used the artery and placed it onto the heart, occasionally we do see spasm. The most common place is just beyond the proximal anastomosis, and we have seen that on a number of occasions – four that I know from the manuscript – and the way we treat that is by applying warm topical papaverine and maintain the patient on cardiopulmonary bypass a further 15 minutes at high pressures. Usually the spasm resolves over that period of time.

**Professor G.-W. He** (Hong Kong, China): I have two short questions. The first is, do you have any preference for the target vessel for the radial artery, and what is the first choice as to the target vessel?

The second question is, in your midterm angiographic studies, do you see any differences with regard to the patency of the radial artery graft when they are grafted to the different vessels?

**Dr Tatoulis**: The order of preference for use is the left internal mammary artery first, right internal mammary artery second, usually to the circumflex, and the preference for the radial artery in younger patients, if we use it, is to the posterior descending coronary artery. In older patients we would still use it to the same distribution, the posterior descending coronary artery or the inferior circumflex marginal territory. So that would be our preference for the radial artery graft. Very occasionally we have used it to the right coronary artery more proximally (before the crux) or even to the left anterior descending artery if there was a problem there such as a poor LITA. So we have used it in those other situations.

With regard to the patency, our patency results only go out to 15 months mean. We do have some angiograms at three years. At this point in time, the best patency is to the left anterior descending, in those few grafts that we have used there, and to the circumflex marginals, and that is over 90%. The patency to the posterior descending as the last segment from a Y graft is about 70 to 75%. So I think that that is the area that one has to be very careful about. By comparison aorto-coronary radial grafts to the posterior descending have a 92% patency. We don’t have a lot of angiograms beyond three years at this point because we only started using the graft in ’95.

**Professor He**: I hope that you will look at this on a long term for the angiographic studies.

**Dr Tatoulis**: We are planning to do another angiographic series at five years post operatively.

**Dr G. Mani** (New Delhi, India): In keeping with the tradition, are you still recommending that we should continue using pedicled grafts rather than skeletonized grafts or would you change into skeletonized radial arteries?

**Dr Tatoulis**: We’re evolving all the time with our internal mammary artery experience. We usually take the left as a very small pedicle, just the medial vein and the mammary artery, so it is partly skeletonized. The right mammary we always take as a skeletonized graft.

With regard to the radial artery, thus far we take it with the two veins on either side. We have not gone the next step like some, who have removed the veins, or the venae comitantes. To this moment we have not used the radial artery as a truly skeletonized graft. So it always has the two venous branches that run parallel to it.

**Dr Mani**: Do we have the opinion of the chairmen on this, skeletonizing radial arteries?

**Mr Treasure**: We do not skeletonize radial arteries, but we will await results, and we would make the same comments about the internal thoracic artery, we would prefer the pedicle if it were reached.

**Dr A. Penna** (Marilia, Brazil): Do you use the radial artery in any grade of coronary stenosis?

**Dr Tatoulis**: This is an important issue. We have a policy not to bypass arteries that have a stenosis of less than 50%, so we must have 50% or more stenosis. Particularly in younger patients, we are mindful of when an artery only has a 50 or 60% stenosis as to which graft we would use, and, if possible, we use a pedicled mammary artery graft to that artery. We would prefer to place a radial artery to a native artery that has a greater than 70, or 80% stenosis.