Radial Artery Bypass Graft Is a Feasible and Durable Conduit for Challenging Infrainguinal Revascularization: 17 Years of Melbourne Experience

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WHAT THIS PAPER ADDS
This study demonstrates favorable long-term patency and limb salvage rates of radial artery infrainguinal bypass grafts. Therefore, in patients in need of challenging revascularization and without suitable autogenous conduit, a radial artery bypass can be performed safely as a more durable alternative to a prosthetic bypass.

Objectives: The superiority of autogenous venous conduits in infrainguinal bypass surgery is well established. In the absence of suitable leg or arm veins the radial artery can be utilized as an alternative autogenous conduit. In contrast to cardiac surgery, experience with the radial artery as a conduit for infrainguinal bypass surgery is limited. The purpose of this study was to review the outcomes of our radial artery bypasses over the last 17 years.

Methods: All radial artery bypasses performed between 1995 and 2012 were identified from a prospective database. Patency, limb salvage, and survival were calculated using the Kaplan-Meier survival estimate method.

Results: Twenty-nine radial artery bypasses were performed in 28 patients. Median follow-up was 55 months (range 1–170). Twelve-month primary, assisted primary, and secondary patency rates were 49%, 62%, and 73% respectively; Both 3-year and 5-year primary, assisted primary, and secondary patency rates were 49%, 56% and 67% respectively. Limb salvage rate was 75% at 1- and 5-year follow-up. Patient survival at 1, 3, and 5 years was 96%, 88%, and 76%.

Conclusions: For patients with need of challenging infrainguinal revascularization without suitable autogenous venous conduit, a radial artery bypass can be performed safely with favorable long-term patency and limb salvage rates.

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INTRODUCTION
Despite advances in endovascular techniques, infrainguinal bypass surgery continues to play an important role in revascularization for peripheral arterial occlusive disease (PAOD). The superiority of great saphenous vein (GSV) grafts in infrainguinal bypass surgery is well established. However, it is not uncommon for patients presenting with PAOD to have a history of prior varicose vein surgery or cardiac and/or lower extremity revascularization using one or both great saphenous veins. In case of absent great saphenous veins, alternative conduit options are arm vein, cryopreserved vein, prosthetic, or radial artery (RA). The use of an arm vein as conduit is an accepted technique with superior patency rates than prosthetic grafts, while the patency results of cryopreserved veins have been disappointing. The radial artery (RA) has proven to be a durable conduit in cardiac surgery, with (long-term) equal or superior patency rates over GSV grafts. However, due to its short length, unconventional harvesting procedure, and lack of familiarity among vascular surgeons, the use of the RA for peripheral revascularization is rare. Reports in the literature of isolated infrainguinal RA grafts are limited to case reports of up to three patients. Limb salvage surgery using a radial forearm flap or radial artery flow-through graft as a composite distal bypass graft with an overlying skin flap for wound or ulcer coverage has also been described, but in relatively small series of up to 10 patients. In this paper, we report our experience with RA bypass grafts for infrainguinal revascularization over a period of 17 years.

METHODS
From 1995 to 2012 we prospectively collected a consecutive series of patients undergoing infrainguinal reconstruction for peripheral arterial occlusive disease with RA conduits under a protocol approved by the local ethics committees. A retrospective review of patient notes was then undertaken to capture clinical data, including presenting symptoms, investigation findings, operation details, and follow-
The indication for radial artery conduit use in infralumbar bypass surgery was an absent or unsuitable vein, but with increasing experience it was also used as the primary conduit of choice in a small number of suitable patients.

**Radial artery harvest**

Prior to harvest of the RA an Allen’s test was routinely performed. If the hand did not re-perfuse within 5 seconds upon release of the ulnar artery, the test was considered positive and the radial artery was not harvested.

The patient is positioned in the standard fashion for infralumbar bypass surgery with the arm at 90 degrees placed on an arm board. The skin of the entire forearm and arm is prepared with alcoholic iodine solution and the hand wrapped in a sterile drape. A linear incision is made in the supine forearm 2 cm below the midpoint of the elbow crease to approximately 2 cm above the wrist crease, where the radial pulse is felt (Fig. 1). The radial pedicle lies in a groove between brachioradialis muscle laterally and the flexor carpi radialis medially (Fig. 1). The RA with its venae comitantes is then mobilized using the “no-touch technique”, to minimize spasm. Side branches are divided between metal clips (Fig. 2A). The distal RA is doubly clipped at the wrist and divided 2 cm proximal from the wrist joint to preserve collateral circulation (Fig. 2B). The arterial pedicle is kept moist by spraying a solution of papaverine in ringer lactate (30 mg in 20 mL — 3.2 mmol/L — mixed with an equal volume of heparinized blood to buffer the acidity of the papaverine). Part of the solution is injected retrogradely into the RA (Fig. 2C) and the distal end of the artery is clipped. The RA pedicle is then mobilized proximally all the way to within 1 cm of the bifurcation of the brachial artery and doubly clipped and divided (Fig. 2D). The ulnar artery at its origin is left undisturbed. The interosseal artery usually originates from the ulnar artery, and is therefore preserved. If it is encountered coming off the proximal radial artery, it is preserved by clipping the radial artery distally to it. The radial pedicle is then stored in the papaverine solution until ready for use. The wound is closed in two layers with or without a drain as required. To prevent RA spasm, patients were prescribed 10 mg of amlodipine twice daily for 3 months postoperatively, unless contraindicated. Furthermore, patients were routinely prescribed a single anti-platelet agent.

Follow-up was performed postoperatively at 1, 3, 6, and 12 months and annually thereafter. Patency was routinely assessed by clinical examination, ankle—brachial indices,
and duplex ultrasound with selective use of computed to-
mography (CT) angiography and digital subtraction angiog-
raphy, according to the same protocol as for our vein grafts.
Follow-up data were obtained from the surgeon’s database,
hospital records, and outpatient notes. All definitions and
categories were from the Ad Hoc Committee on Reporting
Standards appointed by the Society of Vascular Surgery, and
the North American chapter of the International Society of
Cardiovascular Surgery. The protocol was approved by the
ethics committee of Austin Health.

Graft patency (primary, assisted primary and secondary),
limb salvage, and survival were calculated using the Kaplan—
Meier survival estimate method. Comparison between sur-
vival curves was performed using the log-rank test for sig-
nificance. All calculations and plots were carried out using
the GraphPad Prism statistical program (GraphPad Software,
California, USA). A p value <.05 was considered significant.

RESULTS

Over a 17-year period we performed 29 infrainguinal re-
constructions with radial artery grafts in 28 patients at four
Melbourne hospitals (The Austin, The Western, The North-
ern, and Epworth Hospitals). Mean age of the study pop-
ulation was 73 years (range 48—90 years). Patient
demographic data are presented in Table 1. The indication
for revascularization was critical limb ischemia (CLI; 59%),
threatened bypass graft (10%), acute limb ischemia (ALI;
3%), or disabling claudication (28%, Table 2). RA grafts were
selected due to the absence of suitable leg or arm vein
(86%) or as the primary conduit of choice (14%). Causes for
unavailability of the GSV were previous infrainguinal bypass
(48%), previous coronary artery bypass graft (CABG) (14%),

Table 1. Patient demographics.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number (%)</th>
</tr>
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<tbody>
<tr>
<td>Male</td>
<td>10 (36)</td>
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<tr>
<td>Hypertension</td>
<td>15 (56)</td>
</tr>
<tr>
<td>Hypercholesterolemia</td>
<td>13 (48)</td>
</tr>
<tr>
<td>COPD</td>
<td>5 (19)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>8 (30)</td>
</tr>
<tr>
<td>Hemodialysis</td>
<td>2 (8)</td>
</tr>
<tr>
<td>Cardiac failure</td>
<td>5 (19)</td>
</tr>
<tr>
<td>Ischemic heart disease</td>
<td>14 (52)</td>
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<tr>
<td>Current/ex-smoker</td>
<td>20 (71)</td>
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</table>

COPD = chronic obstructive pulmonary disease.

Table 2. Bypass characteristics per patient.

<table>
<thead>
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<th>Indication</th>
<th>Previous revascularization</th>
<th>Conduit</th>
<th>Inflow</th>
<th>Outflow</th>
<th>Duration of patency (months)</th>
<th>Patent</th>
<th>Limb salvage</th>
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<td>Yes</td>
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<tr>
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<td>R RA</td>
<td>GSV graft</td>
<td>BK pop</td>
<td>33</td>
<td>Yes</td>
<td>Yes</td>
</tr>
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<td>74F</td>
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<td>R RA</td>
<td>PFA</td>
<td>AK pop</td>
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</tr>
<tr>
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<td>No</td>
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<td>PFA</td>
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<td>GSV graft</td>
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<td>AK pop</td>
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<tr>
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<td>SFA</td>
<td>AK pop</td>
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<td>L RA, bilat basilic vein</td>
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<td>GSV graft</td>
<td>PA</td>
<td>98</td>
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<td>SFA to TPT bypass with GSV</td>
<td>L RA</td>
<td>GSV graft</td>
<td>RA bypass graft</td>
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<td>GSV graft</td>
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<td>GSV graft</td>
<td>PA</td>
<td>26</td>
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FPBG = femoropopliteal bypass graft; GSV = greater saphenous vein; RA = radial artery.
small diameter/varicosity (14%), or varicose vein surgery (10%). Thirteen (45%) infrainguinal RA bypasses were “primary” (first infrainguinal bypass for that limb) and 16 bypasses (55%) were “redo” operations (Table 2).

**Graft characteristics**

The average length of harvested RA grafts was 20 cm and the average diameter was 3.1 mm. The conduit was a single length of RA in 69% and RA–vein composite graft in 31% of patients (Table 2). Inflow vessel for the RA graft was the superficial femoral artery (31%), profunda femoris artery (24%), previous vein graft (31%), popliteal artery (7%), or a tibial artery (7%). Outflow artery was the above-knee popliteal artery (28%), the below-knee popliteal artery (20%), a tibial artery (45%), or a pedal artery (7%, Table 2). Mean follow-up until death or end of study was 55 months (range 1–170 months).

**Mortality and complications**

There were no deaths within 30 days. There was one complication from the RA harvest (hematoma; 3%). Wound infections at the bypass site occurred in three patients (10%). Other complications included acute myocardial infarction in one patient (3%), arrhythmia in two patients (7%), and pneumonia in three patients (10%). There were two cases of peroneal nerve neuropaxia (7%).

**Patency**

Patency data are presented in Tables 2 and 3 and Fig. 3. There were five early graft occlusions (<30 days), with two grafts successfully thrombectomized and revised. These grafts remained patent throughout complete follow-up without any re-interventions. In the first year post-operatively there were three additional graft occlusions, which were left untreated. All grafts that maintained primary patency at 12 months remained patent without reinterventions during the complete study follow-up with the longest running graft free from reintervention at 14 years’ follow-up (Fig. 4). There was a trend to improved graft patency in claudication, primary operations, popliteal bypasses, two or more outflow vessels, and single RA conduits, but none of these reached statistical significance (data shown in Online Data Supplement).

**Limb salvage and survival**

Six patients (21%) had a major amputation (one above knee, five below knee). Four early graft failures resulted in limb loss. Two patients underwent amputation for sepsis in the setting of a patent graft at 2 and 8 months post-operatively. Limb salvage data are presented in Tables 2 and 3. Patient survival at 1, 3, and 5 years was 96%, 88% and 76% respectively. Median survival was 55 months.

**Reintervention**

There were 12 reinterventions in 10 grafts. Five thrombectomies were performed for acute graft occlusion. Two balloon angioplasties were performed for radial artery spasm within the same admission, of which one was complicated by a hematoma needing evacuation (Fig. 5). Four graft stenoses (3 vein graft stenoses in a composite graft and 1 radial artery graft stenosis) were detected on surveillance and treated with a balloon angioplasty, patch angioplasty or interposition grafting (2 patients).

**DISCUSSION**

RA conduits are commonly used in CABG surgery and have patency rates that are equal or superior to GSV grafts. Intrainguinal revascularization with RA conduit has rarely been described and the literature is limited to case reports or small series. Widespread use of RA conduits in infrainguinal bypass surgery has been limited by the relative short length of the RA and its propensity to spasm, lack of familiarity with RA harvest, and lack of awareness among vascular surgeons. In this report we describe our experience and results of 29 RA bypass grafts for lower extremity revascularization.

In our patient cohort the percentage of male patients (36%) and patients with diabetes (29%) appears lower than in comparable series on non-GSV infrainguinal bypass surgery. A possible explanation for this could be a combination of the small total number of patients in this cohort (28), the inclusion of patients with claudication in contrast to other series, the observation that all previous varicose vein surgery was in women, and the use of RA as primary conduit (also all in women). However, percentages
of smokers, patients with ischemic heart disease, and patients with hemodialysis were comparable with other cohorts.\textsuperscript{16–18}

The long-term patency and limb salvage (5-year primary patency 49\%, primary assisted patency 56\%, secondary patency 67\%, and limb salvage 75\%) of our RA bypass grafts were comparable with or superior to previously reported patency rates of arm vein bypass grafts.\textsuperscript{2–4,16,17} However, the upper extremity veins in patients with extensive peripheral arterial occlusive disease may also have been used for previous bypass surgery or often damaged from years of multiple punctures or cannulations, rendering them useless for bypass grafting. The results of our RA bypass series suggest that the RA can be used as a durable alternative for arm vein. In comparison with prosthetic grafts, the patency and limb salvage rates of the RA grafts in our series appear superior. Three-year primary and secondary patency and limb salvage rates of RA grafts in this series were comparable but mostly superior to pooled 2-year patency and limb salvage rates of prosthetic grafts with or without vein cuff reported in recent Cochrane systematic reviews.\textsuperscript{2,19} Five-year patency and limb salvage rates of RA grafts were

\textbf{Figure 4.} Primary patency of profunda-popliteal radial artery bypass. Recent computed tomography angiography of left profunda-popliteal bypass with left radial artery graft, which was performed in 1998 for critical limb ischemia. Currently, patient is still asymptomatic with running graft without any reinterventions during 14 years of follow up.
superior to patency and limb salvage rates of prosthetic below- and above-knee femoropopliteal bypasses in recent meta-analyses. While the subgroup analyses of patency and limb salvage in our study (data shown in Online Data Supplement) did not reach statistical significance due to the small numbers they seemed to indicate that, similar to venous bypass surgery, the indication for revascularization, previous bypass, target artery, run off, and graft splicing affect patency. In our series 28% of RA grafts were performed for the indication of intermittent claudication. The subgroup analysis of patency and limb salvage suggested better patency in patients with claudication. The primary and secondary patency rates at 5 years of follow-up in both our claudication as CLI groups are comparable or slightly superior to patency rates of prosthetic grafts but inferior to GSV grafts of a recent meta-analysis. One claudicant suffered limb loss almost 5 years after the RA graft blocked in the postoperative period (and was left untreated). The number of claudicants was small (n = 8), but these results may lead to a discussion whether a RA bypass should be used for revascularization of patients with intermittent claudication. The same is true for the results of RA bypass used as a “primary” conduit. We have performed four RA grafts as the primary conduit. The first graft was an anterior tibial to dorsalis pedis bypass, which was still (primary) patent at last follow-up. Three grafts were profunda to above-knee popliteal bypasses; one of these grafts occluded and another had an angioplasty for spasm. Two were still patent at last follow-up. The occluded graft was left untreated and this patient lost the limb almost 5 years later. In this small group of “primary” RA conduits the primary patency rate (60%) at 5-year follow-up was inferior than primary patency rates of GSV in a recent meta-analysis, but secondary patency rates were comparable. However, our limb salvage rate of 50% at 5 years of follow-up and the small number of patients make it difficult to recommend use of RA as a primary conduit.

In the subgroup analysis for primary or “redo” bypass surgery, there was a significant trend towards increased long-term primary patency in patients with primary surgery versus secondary bypass. This reflects the reality that a “redo” bypass can be regarded as secondary patency of the previous bypass and may already have a compromised outflow. The same trend (although not as significant) towards better patency of grafts anastomosed onto the popliteal artery versus a tibial artery and grafts with two vessel outflow versus one vessel outflow was demonstrated in the subgroup analyses of different target vessels and outflow.

Because of its relatively short length, we utilized isolated RA grafts for short infrainguinal bypasses, such as profundapopliteal to popliteal, popliteal to pedal or skip grafts from a previous bypass onto a tibial artery. When a longer length was required a composite RA with an arm or GSV graft was used. The RA graft was always used for the distal part of the composite grafts. In the subgroup analysis, patency rates of single RA grafts trended towards superiority over patency rates of RA composite grafts, which may be explained by the longer bypass length but is in concordance with previously published superior results of single arm vein grafts versus spliced arm vein grafts.

One of the challenges in RA bypass grafting is to avoid early graft spasm and failure. In our series we experienced five graft occlusions within 30 days postoperatively. Contributing factors to these early graft occlusions could have been poor outflow (4 patients had tibial bypass with single vessel run-off), type, and length of graft (2 composite grafts), technical problems and/or RA spasm. Spasm is a common early complication of RA grafts, which is well described in the cardiac literature. To decrease the risk of RA spasm, firstly, it is essential to perform a careful “no-touch” dissection. Secondly, the RA graft should be prepared intra-operatively with a buffered solution to induce vasodilation. Several pharmacological agents have been utilized intra-operatively to prevent spasm, but there is no

Figure 5. Postoperative spasm in profunda-popliteal radial artery (RA) bypass graft. Left: Angiographic images before treatment, demonstrating mid RA graft spasm. Right: Angiographic images after balloon angioplasty with good result.
consensus on which is the optimal agent. A recent review suggested that preparing the graft with a verapamil–glycerine trinitrate solution would theoretically achieve optimal results extrapolated from the biological properties of this combination of agents. In our protocol, RA grafts were prepared with a buffered papaverine solution, which is a widely used agent and is regarded by many as the gold standard. Thirdly, postoperative treatment with calcium channel blockers has been suggested to decrease RA graft spasm (after CABG); hence, we routinely prescribed amiodipine for 3 months postoperatively to our patients. If RA spasm occurs in the postoperative period despite the above measures, balloon angioplasty is an invasive treatment option, which has proven effective and durable without re-stenoses in our patient cohort (Fig. 5). The 1-year primary patency rate of 49% remained unchanged during follow-up up to 5 years, suggesting that RA grafts can be very durable, if early graft failure is avoided (Fig. 4).

A potential disadvantage of the use of the RA for infrapopliteal bypass surgery is the loss of a conduit for future possible life-saving CABG in patients without an available venous conduit. However, limb salvage in patients with CLI by revascularization using RA bypass may also be a life-saving procedure. Patients with CLI have a 1-year mortality of 25% and projected 2-year mortality of 40—50% and a 1-year major amputation rate of 30%. Moreover, in our study around half of the patients had (treated) ischemic heart disease and a subset had already undergone CABG. We also treated elderly patients who would not be candidates for coronary bypass surgery. The survival in our patient cohort at 5 years’ follow-up was 75%. Therefore, we believe that a RA graft does not have to be withheld from a patient with CLI and absent venous conduits who is in need of revascularization.

In conclusion, our series is the largest reported series of RA grafts for infrapopliteal revascularization and demonstrates that RA graft is a feasible and durable conduit in case of absent GSV or arm vein. In our opinion, this technique should therefore be in the armamentarium of a vascular surgeon.

FUNDING
None.

CONFLICT OF INTEREST
None.

APPENDIX A. SUPPLEMENTARY DATA
Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ejvs.2014.03.016.

REFERENCES
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