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# Internal Arteriovenous Fistula Within a Radial Forearm Flap - A Novel Technique to Increase Femorodistal Bypass Graft Flow to the Diabetic Foot and Flap Covering Ischaemic Tissue Loss",1,2,0,0,0mm,0mm,0mm,0mm>Internal Arteriovenous Fistula Within a Radial Forearm Flap – A Novel Technique to Increase Femorodistal Bypass Graft Flow to the Diabetic Foot and Flap Covering Ischaemic Tissue Loss

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***Background***. *The fascio-cutaneous radial forearm flap is especially suitable to rebuild the contour of the foot, but because of low natural low flow this flap lacks the beneficial effect of large muscle flaps on bypass graft flow. The aim of this study was to introduce a novel technique of flap coverage combined to vascular bypass: an internal av-fistula was created within a radial forearm flap.*
***Methods***. *Nine critically ischaemic limbs were treated with a modified radial forearm flap in the Department of Plastic and Vascular Surgery, Helsinki University Central Hospital 1998–2003. All the patients were candidates for a major amputation unless this combined operation was attempted. A two-team approach was used: the vascular surgeon performed the distal bypass and the radial forearm flap was raised by the plastic surgeon. In eight cases a femorodistal bypass was performed and in the ninth the vein graft supplied the flap directly. The internal fistula within the flap was created between the distal end of the radial artery and either the cephalic vein or the concomitant vein of the radial artery. Flow was measured during surgery.*
***Results***. *Vein graft flow increased significantly after the radial forearm flap anastomosis (76 vs 44 ml/min, p = 0.016). The flow of both the bypass graft and the flap artery were higher with the av-fistula patent (p = 0.016 and p = 0.004). Graft patency was 89% at 2 years. Infection was a major cause of amputation, 1- and 2-year limb salvages being 67 and 53%.*
***Conclusion***. *In a group of diabetic patients increased flow in a vascular bypass graft was achieved by an internal av-fistula within a radial forearm flap. This method is useful in selected cases with poor run off and large ischaemic lesions.*

*Keywords: Critical leg ischaemia; Foot ulcer; Radial forearm flap; Av-fistula; Flap coverage; Tissue loss.*

## Introduction

Diabetic vascular disease is characterized predominantly by the arteriosclerotic involvement of the infrapopliteal arterial tree. The combination of ischaemia, neuropathy and infection in various forms often leads to the development of major tissue defects. In patients with compromised circulation, radical wound excisions and skin grafting seldom are sufficient and lead to ulcer healing. Vascularised free flap transfer may be indicated to cover the defect in combination with infrainguinal reconstruction to prevent major amputation.

Free tissue transfer, as a solution to cover large tissue defects, was introduced in the late 1980s.[1–5] First small series of combined free flap transfer and vascular reconstruction with proper life table data were published only recently.[6–8]

When the free flap transfer is made in combination with a vascular bypass, large tissue lesions can be covered and the distal perfusion is improved simultaneously.[9] A vascular bypass can be made to a distal native artery as usually done, or if there is no option for a distal anastomosis in the foot, the free flap is

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anastomosed end to end to the vein graft. Combined procedures have been performed in active European centres since early 1990s. Our initial experience in Helsinki, with 81 treated patients, is from October 1989.[10]

Different types of free flaps have been introduced. There is still some controversy about the best type of flap to be used in foot lesions. The flaps in the lower extremity have special requirements, because they are often placed in weight bearing areas and are subject to pressure after the patient becomes ambulatory.[11]

Muscle flaps can be used in limb lesions. The advantage of the muscle flap is its good blood flow and its ability to fill cavities and to eliminate dead space. However, the muscle flap may be too bulky and it may not always provide good contour.

The fasciocutaneous radial forearm flap was first popularized as a free flap in the western literature by Song *et al.*[12] The radial forearm flap provides superior contour in contrast to the large bulk of muscle flaps for relatively small tissue lesions. It is raised in the forearm with a long pedicle consisting of the radial artery and its concomitant veins. The blood flow in the traditional forearm flap is low,[13] which may be a problem, since high flow often is needed to keep a vascular graft open.

The diabetic vascular disease affects also the small arteries of the foot and as a result the distal run off in these patients may be poor. It is known that poor run off results in a poor prognosis for a bypass and therefore methods to improve run off have been investigated. In vascular surgery different types of adjuvant arteriovenous (av) fistulae have been used to improve run off and graft flow.[14,15] Recent results of an av-fistula combined to prosthetic bypass did not improve bypass graft patency.[16,17] However, data for adjuvant av-fistulae with a venous bypass are very sparse.

End stage diabetic vascular disease may occur as a combination of a large infected ulcer or tissue loss and a diabetic vascular bed with minimal run off. Both coverage of the tissue defect and adequate flow to the foot are required to keep the vascular graft patent and for the foot lesion to heel.

The aim of this study was to introduce and test a novel technique of flap coverage, which also would improve distal run off and consequently graft patency: an internal av-fistula was created within a fasciocutaneous radial forearm flap. This modified free flap was combined with a femorodistal bypass in a patient group with poor run off and large distal tissue defects.

## Patients and Methods

Nine patients were treated with a modified radial forearm flap having an internal av-fistula as coverage for the tissue defect in the Department of Plastic and Vascular Surgery, Helsinki University Central Hospital between August 1998 and April 2003. All patients were diabetic and had large non-healing distal ulcers. All patients were treated by a team of a plastic and a vascular surgeon. During the same period altogether 40 patients underwent surgery for combined distal bypass and free flap transfer and a total of 790 patients were operated for critical leg ischaemia by infrapopliteal bypass.

Of the nine patients two were female and seven male. The average age of the patients was 56 years, range 37–78 years. All patients had diabetes, six had type I and three type II diabetes. Two patients had been diagnosed as having coronary artery disease and one patient had a functioning renal transplant.

The median ankle-brachial index of the patients (excluding sclerotic values with ABI$>$1.5) was 0.57 and median toe pressure was 19 mmHg. The extent of the vascular disease was assessed by digital subtraction angiography and images were scored by the method proposed by the Ad Hoc Committee.[18] The run off score varied between 4 and 10, median 8. As the radial artery is removed when raising the flap, the adequacy of the ulnar artery as the sole blood supply of the hand was tested by Allen's test and by doppler ultrasonography as required.

The indication for surgery was critical leg ischaemia with a large non-healing ulcer. All patients were candidates for a major amputation and combined hybrid operation of a femorodistal bypass and free flap reconstruction was considered to be the only option for limb salvage.

One patient had a calcaneum ulcer, one a plantar ulcer, one an ulcer in the Achilles tendon region and six patients an ulcer in the forefoot region. The ulcers were classified according to the Armstrong classification system.[19] One patient had been previously undergone femorodistal bypass, that had thrombosed immediately, and another had had a previous femorodistal bypass with a latissimus dorsi flap, which failed.

In eight cases a femorodistal bypass was feasible and in one case, due to poor distal run off, the vein graft supplied the flap directly. In four cases the bypass was anastomosed to a pedal artery and in four cases to a distal crural artery. A saphenous vein graft was used in all cases except for the one redo-case where a femoropopliteal PTFE graft with an arm vein jump graft to the posterior tibial artery was used (Table 1).

**Table 1. Ischaemic tissue lesion, type of graft, anastomoses and outcome of the patients**

| Patient | Age | Sex | ABI and toe-pressure | Run off score | Localisation of ischaemic lesion | Armstrong class | Graft material | Proximal anastomosis of the graft | Distal anastomosis of the graft | Arterial anastomosis of the flap | Venous anastomosis of the flap | Current outcome (last follow up) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 64 | Male | 1.22/18 | 4 | Forefoot | IIID | VSM | Popliteal artery end to side | ADP end to side | Radial artery end to side to graft | Cephalic vein end to end to ATP concomitant vein | Leg salvage 46 months |
| 2 | 66 | Male | 0.57/* | 10 | Forefoot | IIC | VSM | Femoral artery end to side | ADP+ATP dist. end to side | Radial artery end to side to graft | Cephalic vein end to end to ATP concomitant vein | Amputation at 1 month |
| 3 | 58 | Male | 1.20/34 | 10 | Forefoot | IIID | VSM | Popliteal artery end to side | Radial artery of the flap end to end | Radial artery end to end to graft | Radial concomitant vein end to end to ATA concomitant vein | Leg salvage 46 months |
| 4 | 78 | Male | 0.68/17 | 7 | Achilles region | IIC | VSM | Popliteal artery end to side | Plantar end to side | Radial artery end to side to graft | Radial concomitant vein end to end to ATP concomitant vein | Leg salvage 46 months |
| 5 | 49 | Female | 0.36/* | 8 | Heel | NA | PTFE+ Miller cuff and jump graft with cephalic vein | Femoral artery end to side | ATP dist. end to side | Radial artery end to side to graft | Radial concomitant vein end to end to ATP concomitant vein | Leg salvage 23 months |
| 6 | 46 | Male | 0.36/0 | 10 | Forefoot | IIIC | VSM | Femoral artery end to side | ATP dist. end to side | Radial artery end to side to graft | Cephalic vein end to end to ATP concomitant vein | Amputation at 1 month |
| 7 | 63 | Male | * | 8 | Forefoot | IIID | VSM | Femoral artery end to side | ATP dist. end to side | Radial artery end to side to graft | Radial concomitant vein end to end to ATP concomitant vein | Amputation at 2 months |
| 8 | 37 | Male | 1.64/20 | 10 | Forefoot | IIID | VSM | Femoral artery end to side | Plantar end to side | Radial artery end to side to graft | Cephalic vein end to end to ATP concomitant vein | Amputation at 13 months |
| 9 | 39 | Female | 0.63/45 | 8 | Plantar | IID | VSM | Femoral artery end to side | Peroneal artery end to side | Radial artery end to side to graft | Cephalic vein end to end to lesser saphenous vein | Leg salvage 17 months |

ATP, tibialis posterior artery; ATA, tibialis anterior artery; ADP, dorsalis pedis artery; VSM, vena saphena magna. Run off score according to the Ad Hoc 1–10, Armstrong classification: depth I–III, ischaemic non infected, C; ischaemic infected, D.

* Pressure measurements not available due to wound status.

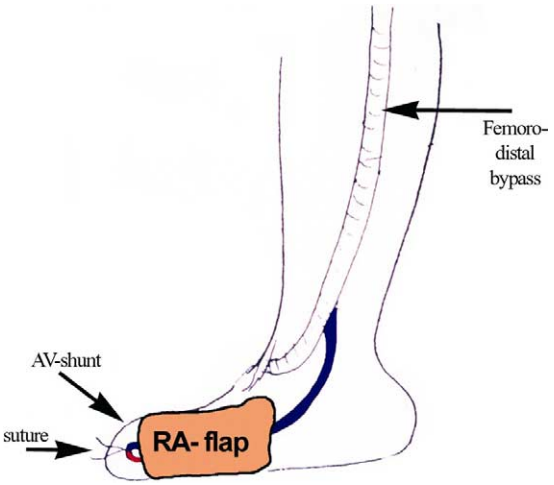


**Fig. 1.** Illustration of the modified radial forearm flap connected to the vascular bypass.

*Operative technique*

A two-team approach was used in all cases. First, a vascular and a plastic surgeon performed radical wound excision and minor amputation, if necessary. After that the final assessment of the foot viability was performed.

Second, the operation was continued in two separate clean fields. The vascular surgeon harvested the vein and performed the distal bypass.

The fascio-cutaneous radial forearm flap was raised by the plastic surgeon. Before ligating the radial artery, the viability of the hand was tested by clamping the radial artery. The flap was then raised with a long pedicle consisting of the radial artery and its concomitant veins. The internal fistula within the flap was created by performing an end-to-end anastomosis between the distal end of the radial artery and the cephalic vein (6) or the concomitant vein of the radial artery (3) depending on which of the veins better suited the purpose. If venous hypertension was encountered, a piece of thread was left around the av-fistula allowing it to be ligated during the post-operative period. Since it was only a precaution and turned out to be unnecessary, this method was only used in the first three patients (Fig. 1).

Finally, the flap was removed from the arm and fixed to the foot to cover the defect. An end to side anastomosis using continuous 8–0 polypropylene sutures was created in eight cases between the vein graft and the proximal end of the radial artery of the flap. In one case the flap artery was (end to end) connected directly to the vein graft as no recipient native artery was available in the foot. The concomitant vein of the radial artery or the cephalic vein was anastomosed end to end by 8–0 interrupted sutures to a deep vein of the limb to provide an outflow for the flap. The flap was sutured in place and the wound closure was completed with meshed split thickness skin graft in four cases, Fig. 2(a)–(c).


**Fig. 2.** (a) Status of the limb after thorough revision in a patient with an Achilles tendon region ulcer. (b) Completed hybrid operation: a popliteo-pedal bypass and a modified radial forearm flap transfer. (c) Final status of the limb.

*Flow measurements*

Flow was measured and recorded during surgery with a transit time flowmeter (CardioMed CM4006, Medistim A/S, Oslo Norway). The flow in the radial artery was measured while the vascular pedicle was intact, with both the fistula open and closed. Vein graft flow was recorded prior to flap transfer. After the anastomoses were completed and flow stabilized, the flow to the graft and to the flap artery were recorded with both the av-fistula open and closed.

*Medication*

Systemic heparinization was used during the surgery. All patients received a prophylactic antibiotic and the post-operative therapy was continued according to bacterial cultures taken from the ulcer prior to the surgery. LMWH (low molecular weight heparin) therapy was started the night before the surgery and extended to the immediate post-operative period. ASA (acetylsalicylic acid) was used as antiplatelet therapy permanently with the exception of the patients already on anticoagulation medication for concomitant disease.

*Post-operative surveillance*

All patients were monitored in the intensive care unit or the recovery room for the first 24 h so that the vitality of the flap could be checked, by clinical monitoring and by Doppler ultrasonography as appropriate. Patients were kept on bed rest for 7 days with the limb elevated. Ambulation was started gradually with exercises in standing position and weight bearing was allowed only after 4–6 weeks.

*Follow up*

The first follow up visit was at 1–2 months post-operatively. After that the visits were at 3, 6 and 12 months and annually depending on the healing of the foot. The follow up time varied from 14 to 51 months. At each visit the viability of the flap was recorded as well as the patency of the vascular graft, by ABI measurements or duplex ultrasonography as appropriate.

*Statistics*

The life table method and the Kaplan–Meier method were used for survival analysis. The Wilcoxon signed rank test was used for analysis of the non-parametric data. (SPSS for Windows version 11.0, SPSS, Chicago, Ill).

## Results

*Flow measurements*

The median flow through the radial forearm flap, while still in the arm, was 8 ml/min (range 4–12 ml/min). After the av-fistula had been created, the flow increased to a median of 58 ml/min (range 31–110 ml/min). The median graft flow prior to the flap transfer was 44 ml/min (range 20–60 ml/min). The vein graft flow almost doubled after the radial forearm flap anastomosis, the median flow being 76 ml/min (range 32–105 ml/min), $p=0.016$ (Fig. 3).

The flow through the flap artery when sutured to the foot was 45 ml/min (range 13–108 ml/min) with the av-fistula open, but when the av-fistula was closed temporarily it was only 9 ml/min (range 3–15 ml/min). There was no difference in the flow values of the artery of the flap whether it was in the arm or transplanted to the foot ($p=0.43$).

The flow of both the bypass graft and the artery of flap were significantly higher when the av-fistula was patent in comparison to when it was closed temporarily ($p=0.016$ and $p=0.004$, respectively). The median flow in the graft was 76 ml/min and in the flap 45 ml/min with a patent fistula but when the fistula

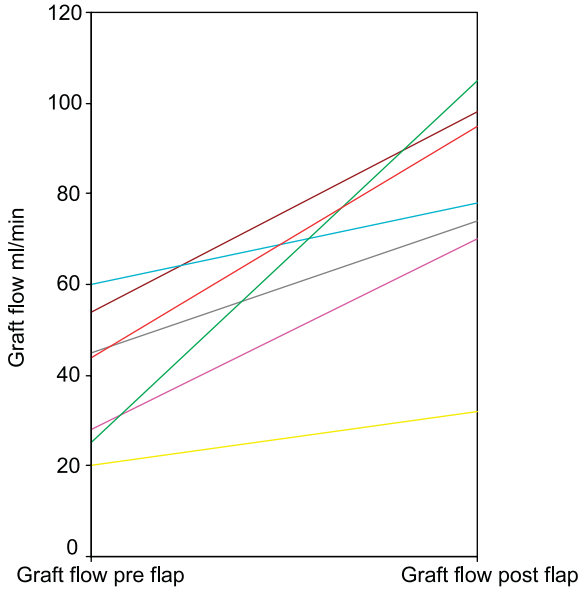


**Fig. 3.** Flow in the vein graft prior to and after the free flap transfer, $p=0.016$.

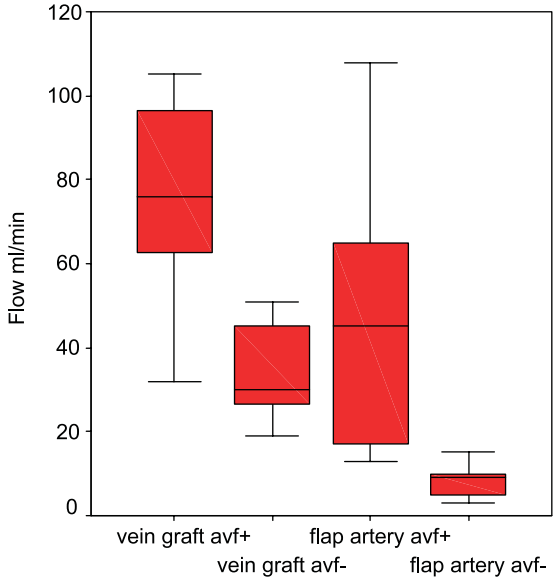


**Fig. 4.** Flow values in the vein graft and in the flap artery, both the av-fistula patent and closed. The flow levels were significally higher when the av-fistula was patent, $p=0.016$ and $p=0.004$, respectively.

was closed temporarily the flow decreased to 30 ml/min in the vein graft and 9 ml/min in the flap artery, Fig. 4.

### *Early outcomes*

The average duration of surgery was 362 min (median 369, range 311–437 min) and blood loss 1570 ml (median 1200, range 800–4200 ml). One patient had an acute myocardial infarction on the second post-operative day. One patient had ischaemic changes on ECG and stayed in an intensive care unit for cardiac problems for 5 days. The rest of the patients recovered uneventfully.

There were three immediate (<30 days) re-operations. In two cases revision and split thickness skin grafting was performed. In one case an exploration of the flap was performed on the 5th post-operative day and both the vein graft and flap artery were found to be patent.

After the immediate post-operative period one wound revision was performed.

### *Vein graft and flap artery patency*

There was one immediate (<30 days) flap failure. The flap was lost due to the thrombosis of the flap artery, albeit the bypass graft remained open. In this patient the necrosis of the flap started on the 8th post-operative day. The flap was finally removed 13 days after the operation and the wound granulated and was covered with split thickness skin grafting.

Only one vein graft thrombosed. The occlusion of the vein graft took place at 2 months resulting in the occlusion of the flap artery and below knee amputation. Flap artery and graft patency were 78 and 89%, respectively, at 2 years. Open grafts at the time of amputation were considered as withdrawals rather than occlusions, Fig. 5(a).

### *Limb salvage*

Two limbs were lost due to persistent infection, with patent grafts and vital flaps in the immediate post-operative period (<30 days). Infection in these patients led to below knee amputation. There was one late loss of limb due to infection at 13 months.

Thus, altogether four limbs were lost during follow

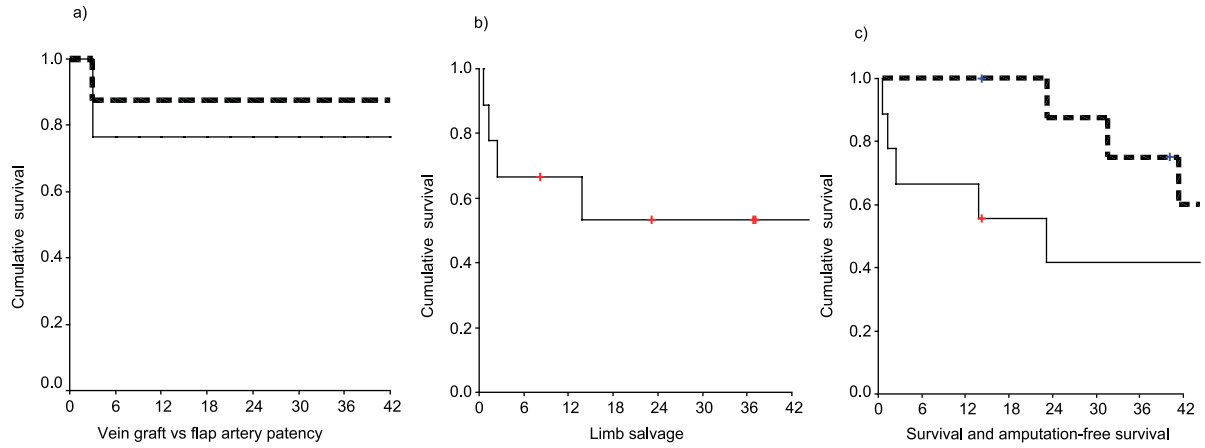


**Fig. 5.** (a) Life table of the vein graft(- - -) and flap artery patency (—). (b) Kaplan–Meier curve of the limb salvage. (c) Kaplan–Meier curve of the survival (- - -) and amputation-free survival (—).

up: three limbs were amputated due to infection, in addition to the one limb due to flap artery thrombosis. One and two year limb salvage were 67 and 53%, respectively, Fig. 5(b).

*Survival and amputation free survival*

There were no peri-operative deaths. The survival rate of these patients was 100% at 1 year and 88% at 2 years. Currently (June 2004) there are three patients (out of nine) alive with a viable limb (33%), Fig. 5(c).

## Discussion

Even in relatively young diabetic patients an acute infected ulcer, large tissue defect or graft infection may necessitate a major amputation. In selected patients these problems can be treated using free flap transfer in combination with femorodistal bypass surgery.[1–8,20]

To our knowledge this is the first series using the combination of a vascular bypass and a free flap transfer with an internal av-fistula. In the present study the patency of the vascular vein graft at 1 year was acceptable, even when compared to the data from femorodistal vein grafts.[21] To illustrate the results life table analysis was used in a series of nine patients. The validity of the analysis is, of course, open to criticism in this very small series, but there are no other measures to illustrate the results. Because persistent infection was the major cause of amputation in this patient group, graft patency cannot be used as the sole predictor of the outcome. However, the present limb salvage rates cannot be compared directly to other reports in the literature. First, our series represents a demanding patient group with very poor natural history. Second, this novel technique was used as a last attempt to salvage the limb in our patients.

The run off in these patients was very poor, as shown in the pre-operative run off score and the flow values of the vein graft prior to the flap transfer. A free muscle or fascio-cutaneous flap increases the distal outflow bed and thus decreases the outflow resistance for the vein graft. Also, the flow through a free flap has been shown to increase during the post-operative period, and it is generally understood that this is caused by the denervation of the flap.[9]

The current method using a radial forearm flap is not suitable for all patients. Allen's test was performed both pre- and intra-operatively to find out whether the patient would cope without the radial artery, which is removed by raising the flap. A large muscle flap like the latissimus dorsi flap was not suitable in these patients because the tissue defects were on inappropriate anatomical areas. Large muscle flaps have high flow, which is an advantage for a vascular bypass. Compared to a muscle flap the radial forearm flap has low flow.[13] The thrombotic threshold velocity theory hypotheses a specific flow velocity rate for different graft materials, that would be needed to keep the graft patent.[22] The aim of the present novel technique was to increase the flow by using an av-fistula within the radial forearm flap as well as to improve bypass graft patency and limb salvage.

Lorenzetti *et al.*[9] have previously shown flap transfer to increase the flow of an infra-popliteal graft by about 50%. In the current study the flow values in the bypass graft increased significantly, by 100% after the transplantation of the free flap with the internal av-fistula. When the fistula was closed temporarily, the graft flow dropped close to the level it had before anastomosing the flap, which indicates that flow in the traditional forearm flap is low. Only one vein graft occluded during our study. This finding may reflect the augmentation effect of the free flap on the bypass graft patency.

No difference was shown in the flow through the radial forearm flap whether it was still in its original site or after the flap anastomosis. This implies that the inflow through the vein graft was adequate and that our measurement method was valid. The flow within the radial forearm flap increased four to10-fold after the creation of the av-fistula. In consequence, the low flow radial forearm flap was turned into a high flow flap.

Despite the increased flow the fistula did not cause steal. So far we have not observed steal phenomenon when using an adjuvant av-fistula, since adequate inflow has always been a pre-requisite for this kind of procedure. Indeed, steal is mainly caused by inflow stenosis.[23]

The non-physiological state caused by the internal av-fistula resulted in cyanosis and moderate oedema of the radial flap as well as sloughing of the skin. Since these findings subsided mostly by the second post-operative week, banding of the fistula was not necessary in any of the patients. The marked cyanosis and oedema are well documented in arterialised venous flaps.[24] These findings make it more difficult to monitor the flap viability, and for this reason Doppler ultrasonography was used when the flap artery status was in doubt.

The role of infection cannot be over-emphasised in diabetic patients. Most patients had an Armstrong IIID wound i.e. an infected ischaemic wound. The infection was treated by thorough revision and with antibiotics, the distal circulation was improved by the

bypass, and the flow in a poor run off vascular bed was increased by the internal av-fistula. Despite these attempts, three out of the four amputations were performed for persistent infection. Indeed, deep infection is a major cause of limb loss in this type of patient population.[19,25]

## Conclusion

Free flap transfer combined with a vascular bypass is a major surgical procedure with attendant risks. In a group of diabetic patients with end stage vascular disease, increased flow in a vascular bypass graft was achieved by creating an internal av-fistula within a radial forearm flap. The flow values both in the graft and within the flap were increased significantly, leading to acceptable limb salvage with no operative mortality in a patient group otherwise condemned to a major amputation. These results suggest that, in selected cases with poor run off and large ischaemic lesions, this method can be beneficial.

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