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The arterialised venous flap: experimental studies and a clinical case

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SUMMARY. **It is accepted that small arterialised venous flaps (AVF) can survive on a recipient bed with poor blood supply but survival of larger flaps is not always satisfactory. Possible reasons for this include the flap anatomy, particularly the pattern of the venous network, or factors at the recipient site. To investigate the possible factors in the flap design and the recipient site of an arterialised venous flap, we studied the relationship between (1) size of the artery used to arterialise the flap at the recipient site and the survival rate and (2) the number of draining veins and the survival rate, using rabbit ear skin flap models. Our results suggest that AVFs may become necrotic in the presence of a relative excess of arterial blood inflow, and that two exit veins are more effective than one.**

We also report a case where a 10 × 15 cm sized free AVF harvested from the lower extremity survived on the forearm.

Nakayama and his colleagues demonstrated experimentally that a venous flap can survive by anastomosing one end of the vein of a venous flap to an artery and allowing the arterial blood to flow through the venous system (Nakayama *et al.*, 1981). Since that report, similar flaps have been used clinically, particularly to repair small defects of the hand (Yoshimura *et al.*, 1987; Nishi *et al.*, 1989; Inoue *et al.*, 1990). Survival of larger flaps is not always satisfactory (Inoue *et al.*, 1991). Possible reasons for this include the flap anatomy, particularly the pattern of the venous network, or vascular factors at the recipient site.

The aim of this study was to investigate some of the factors in the flap design and also in the recipient site of an arterialised venous flap. The model chosen was a rabbit ear flap. Such flaps have been described before (Ji *et al.*, 1984; Mundy and Panje, 1984). We have also reported that the arterialised venous flap (AVF) can survive on bare cartilage using a rabbit ear flap model (Inada *et al.*, 1989).

Materials and methods

We used 90 ears of 45 Japanese white rabbits, weighing 3–4 kg, in this study. The rabbits were anaesthetised using general anaesthesia by inhalation of ethyl ether or oxygen, nitrous oxide and halothane. Two separate experiments were performed.

Experiment 1 studied the relationship between blood flow into the flap and the survival rates (Fig. 1).

Forty ears of 25 rabbits were used for Experiment 1. A 3.0 × 4.5 cm venous flap with a single flow-through vein was raised, including the perichondrium, on the dorsum of the auricular cartilage. The flaps were divided into three groups.

Group A (10 flaps in both ears of 5 rabbits) was a control group; all vessels running into the skin flap were coagulated by bipolar cautery and the flap resutured to the original site. In Group B (10 flaps using both ears of 10 rabbits), a 3.0 × 4.5 cm free venous flap with a single flow-through vein was raised from the right ear. This was then used as a free flap on the bare cartilage prepared in the opposite left ears and turned 180°. After suturing of the flaps with 4-0 nylon sutures, microsurgical anastomoses were performed proximally between the recipient ear central artery and one end of the flow-through vein of the flap (afferent arteriovenous anastomosis), and distally between a vein at the recipient site and the other end of the flow-through vein in the flap. In Group C (20 flaps), after a 3.0 × 4.5 cm venous flap with a single flow-through vein had been raised, the central artery was dissected distally and passed through a subcutaneous tunnel. An

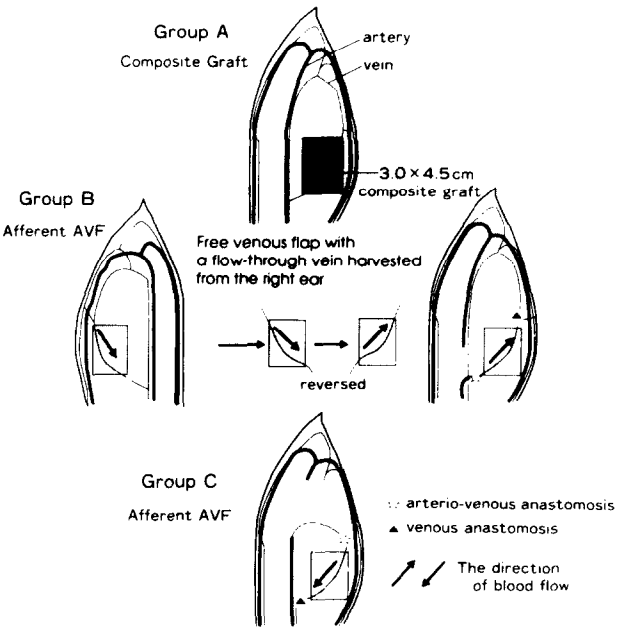


Fig. 1

Figure 1—Experiment 1; experimental groups and design.

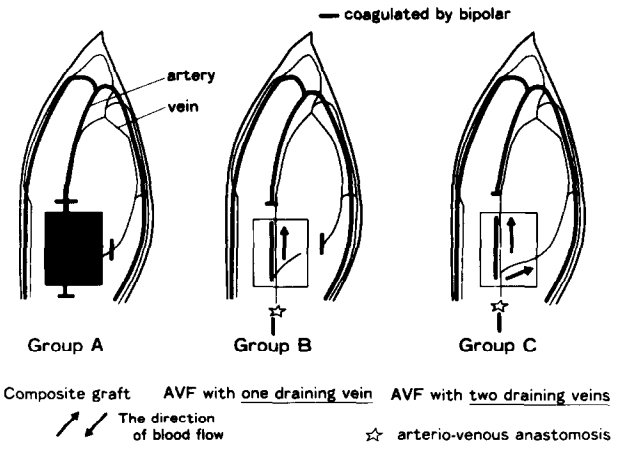


Fig. 2

Figure 2—Experiment 2; experimental groups and design.

afferent arteriovenous anastomosis was done at the distal end of the flap and the flow-through vein was cut proximally, reanastomosed microsurgically, and used as a draining vein at the proximal end of the flap. In both groups B and C, the arterialised venous flaps (AVFs) were afferent (*i.e.* the direction of flow in the vein was not reversed). In group B, the diameter of the main central artery at the site of anastomosis to the flap averaged 1.2 mm. In group C, the diameter of the distal part of the central artery averaged 0.7 mm at the site of anastomosis to the flap vein. The diameter of both the proximal and distal ends of the flow-through veins were almost the same (1.0 mm).

Experiment 2 studied the relationship between the number of draining veins and the survival rates of AVFs (Fig. 2).

In this study, 40 ears of 20 rabbits were used. A 3.0×4.5 cm venous flap with a central vein and a side-branch of the central vein was raised, including perichondrium on the dorsum of the auricular cartilage in the centre of the ear. The flaps were divided into three groups. Group A (10 flaps in both ears of 5 rabbits) was a control group; all vessels running into the skin flap were coagulated by bipolar cautery and the flaps resutured to the original sites. In Group B (10 flaps in both ears of 5 rabbits), efferent (*i.e.* blood flow in the vein was reversed) AVFs with one draining vein were made by an arteriovenous anastomosis between the central artery and vein at the proximal end of the flap. The central vein was used as the draining vein at the distal side of the flap and the side-branching vein was divided. In Group C (20 flaps in both ears of 10 rabbits), efferent AVFs with two draining veins were made – the arteriovenous anastomosis was done as in Group B at the proximal end of the flap, but two veins were preserved both at the distal and lateral sides of the flap. All flaps were sutured back to their original sites.

Immediately after surgery, 1% lidocaine and antibiotics were injected under the flaps. The rabbits were then housed in an air-controlled cage and fed with dry feed, water being available at all times.

The flaps were observed for up to 2 weeks after the operation. Viability was assessed by three methods: (1) Macroscopic inspection: assessment of survival or necrosis was made on the 14th day after surgery. (2) Microangiography: to confirm the patency of the arteriovenous anastomosis at the time the rabbit was killed, 20% Micropaque with 5% gelatine was injected through the ascending aorta under physiologic arterial pressure of 100 mmHg. Then the ears were placed in a refrigerator for 15–30 min to harden the gelatin, after which they were photographed using soft X-rays (Softex CSM). (3) Histology: the flaps were fixed with 10% neutral buffered formalin, and three specimens were taken from the distal, middle and proximal parts of the flap. After haematoxylin and eosin staining, the test samples were histologically examined.

Results (Table 1)

Experiment 1

Macroscopic observation (Fig. 3). In Group A there was less than 20% flap area survival at the periphery of the flaps (in this case composite grafts). In Group B, all flaps became markedly congested and necrotic 3 days after surgery. In Group C, 18 out of 20 flaps survived with superficial necrosis (less than 5% in area) at the flap margins. Two flaps showed severe irregular partial necrosis because of obstruction of the arteriovenous anastomoses and were excluded from further study.

Microangiograms. In Group A in the partially surviving specimens, neovascularisation from the peripheral blood vessels was observed in the viable areas. Other regions showed non-vascularity. In Group B, all flaps had separated from their recipient sites within 14 days after surgery so that microangiography could not be done. In Group C, 18 of the surviving flaps showed patency of the arteriovenous anastomoses (Fig. 4) and both flaps which became irregularly necrotic showed obstruction of the arteriovenous anastomoses.

Histological findings. In Groups A and B, all flaps showed necrotic tissue. In Group C, all surviving flaps showed normal dermal tissue without fibrosis, and patency of the veins.

Experiment 2

Macroscopic findings (Fig. 5). In Group A, all flaps showed complete necrosis. In Group B, 9 flaps became

Table 1 Summary of results

	Complete necrosis	*Partial necrosis*		*Survival with superficial necrosis*
		30% <	> 30%	
Experiment 1				
Group A	—	—	10/10	—
Group B	10/10			
Group C	—	—	2/20	18/20
Experiment 2				
Group A	—	—	10/10	—
Group B	9/10	—	1/10	—
Group C	—	—	3/20	17/20

Fig. 3

Figure 3—Macroscopic findings of Experiment 1. Group A showed more than 80% partial necrosis. Group B showed complete necrosis. Group C survived with less than 5% superficial necrosis.

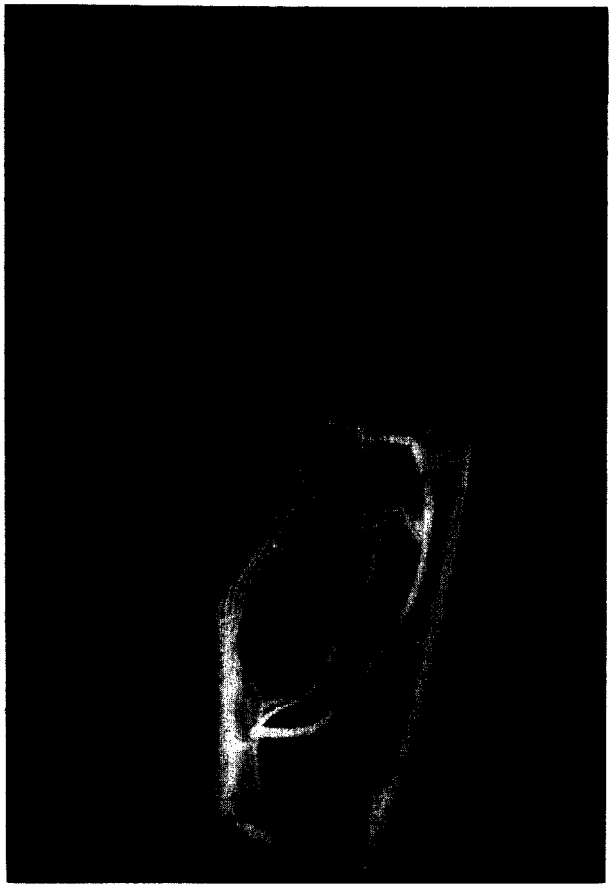


Fig. 4

Figure 4 Microangiogram of Group C at 2 weeks after surgery. Arrow shows patency of the arteriovenous anastomosis.

congested just after surgery, and then became completely necrotic by the 7th day after surgery. Only one flap showed partial survival (more than 30%). In Group C, 17 out of 20 flaps survived with superficial necrosis (less than 30% area of the flaps) at the proximal sides of the flaps. Three flaps showed severe irregular partial necrosis due to obstruction of the arteriovenous anastomoses.

Microangiograms. In Groups A and B, all specimens showed lack of vascularity. In Group C, all of the 17 surviving flaps showed patency of the arteriovenous anastomoses (Fig. 6) and all of the three flaps which became irregularly necrotic showed obstruction of the arteriovenous anastomoses. In the proximal regions where there was superficial necrosis, vascular networks were not as developed as in the distal regions of the flaps.

Histological findings. In Groups A and B, all flaps became necrotic. In Group C, all surviving flaps showed normal dermal tissue without fibrosis and patency of the veins. In the regions with superficial necrosis at the proximal ends of the flaps, the venous network and neovascularisation were poor, while in completely surviving regions, many vessels were recognised in the subcutaneous layer.

Case report

A 40-year-old man trapped his left upper extremity between cement blocks. A wide skin and muscle defect, open fracture of the left ulna and dislocation of the proximal end of the radius occurred (Fig. 7).

On the day of injury, after open reduction and external fixation of the left ulna and radius, the extensor side of the forearm was explored and the dorsal interosseous artery and radial nerve could be seen to be damaged within the wound. The radial and ulnar arteries were intact. To cover this wound, a venous flap with a subcutaneous venous network involving a short saphenous vein (Fig. 8) was raised on the right lower extremity. The venous flap was 10×15 cm, with four vessels available at the periphery. A free split-thickness skin graft was used to cover the defect of the donor site. The flap was used as an afferent AVF. It was reversed, and one end (distal) of a vein in the venous flap anastomosed microsurgically to the posterior interosseous artery proximal to the injured part. After confirming arterial outflow from

Fig. 5

Figure 5—Macroscopic findings of Experiment 2. Group A and Group B showed complete necrosis, but Group C survived with less than 30% superficial necrosis at the proximal side of the flap.

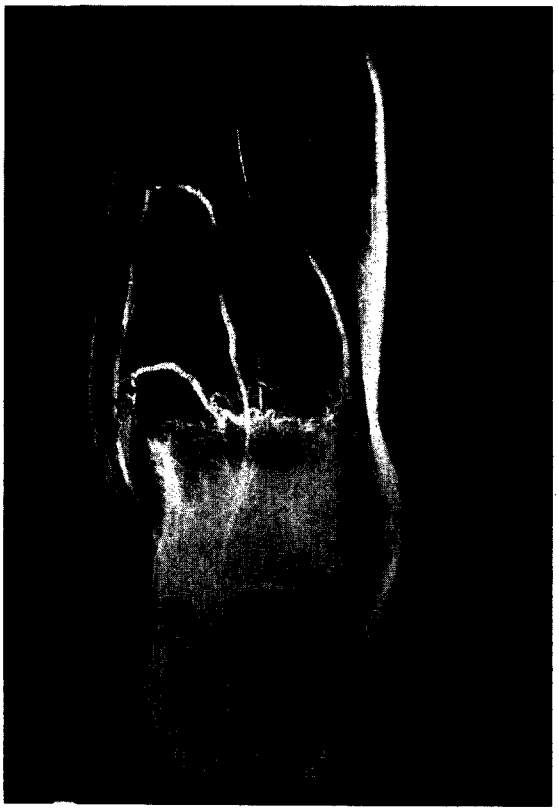


Fig. 6

Figure 6—Microangiogram of Group C at 2 weeks after surgery. Large arrow shows patency of the arteriovenous anastomosis. Small arrows show the two draining veins.

the other three ends of the veins, these were anastomosed to subcutaneous veins in the forearm (Figs 9, 10). The flap survived despite partial superficial necrosis. A free bone graft and rigid internal fixation to the ununited ulna 3 months later, and a tendon transfer for the treatment of radial palsy 8 months later, were carried out. He has returned to work. The range of motion of the left elbow is lacking 20 degrees of extension but has 130 degrees of flexion despite the previous severe damage (Figs 11, 12). The transplanted arterialised venous flap shrank slightly due to the partial superficial necrosis (Fig. 13). There are no abnormal findings in postoperative ECGs 2 years and 10 months after surgery.

Discussion

Since Nakayama and his colleagues first reported their experimental work on AVFs (Nakayama *et al.*, 1981), several authors have studied these in an attempt to extend their clinical applications (Inoue and Maeda, 1984; Yoshimura *et al.*, 1987; Nishi *et al.*, 1989; Inoue *et al.*, 1990, 1991; Koshima *et al.*, 1991).

In spite of success with experimental arterialised venous flaps (Nakayama *et al.*, 1981; Voukidis, 1982; Ji *et al.*, 1984; Mundy and Panje, 1984; Inada *et al.*, 1989), few of these flaps have been used clinically. Reports have shown that small AVFs were useful for small skin defects in the hand, and, in addition, to repair the larger skin defect (4.0×7.0 cm to 6.0×12.0 cm) resulting from the donor site of wrap-around flaps, Inoue and his colleagues reported that medium sized AVFs have potential indications (Inoue *et al.*, 1991). Their success rate with flaps from leg and foot donor sites (including partial survival cases) was 75% and 87.5%, respectively. Koshima and his colleagues reported an AVF using the long saphenous vein which completely survived (Koshima *et al.*, 1991).

One reason these flaps have not been used more widely clinically is the difficulty in determining the size of venous territories. In the authors' rabbit ear model (Inada *et al.*, 1992), venous flow-through flaps had a limited width (1.1 ± 0.48 cm) when based on a single vein. This suggests the need for more than one vein in larger flaps. While others have shown experimentally wider AVFs on a single flow-through vein (Voukidis, 1982; Takato *et al.*, 1991), their arterialised versions of the same flaps are wider than the venous versions. This suggests that arterialised venous flaps may have larger vascular territories than their purely venous equivalents. Clinically, most authors have recommended a rich venous distribution at the donor site, such as the dorsal aspect of the digit or the flexor aspect of the forearm.

Another reason concerns venous valves. Experimentally, all authors (Nakayama *et al.*, 1981; Ji *et al.*, 1984; Inada *et al.*, 1989) reported that they could not

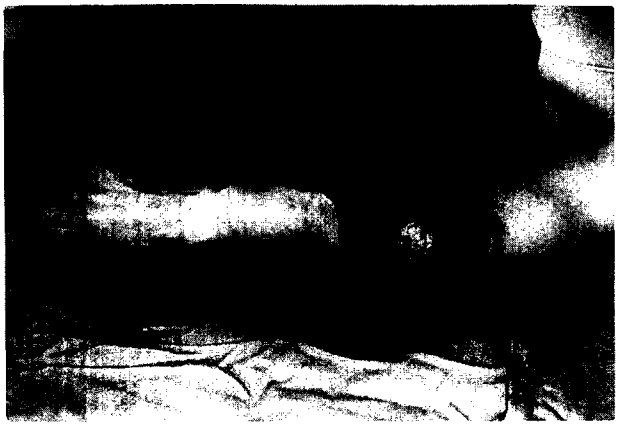


Fig. 7

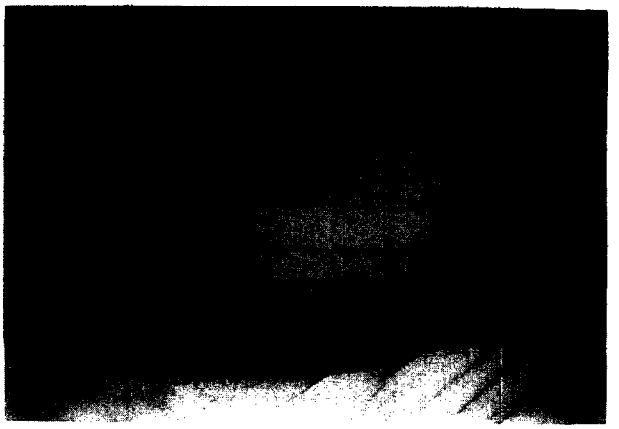
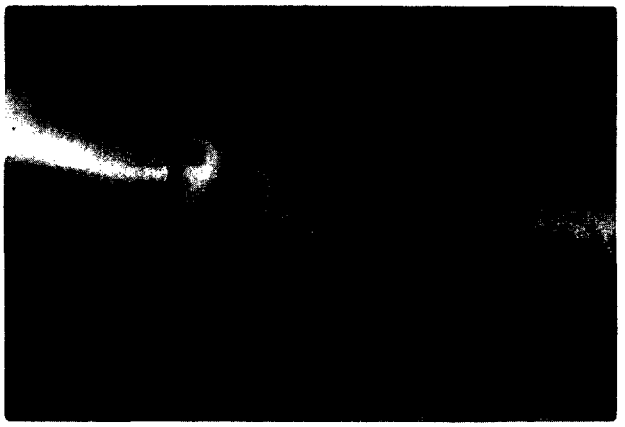


Fig. 8



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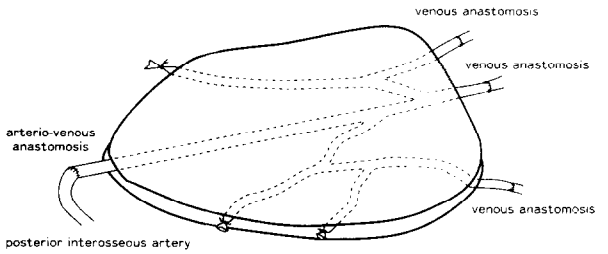

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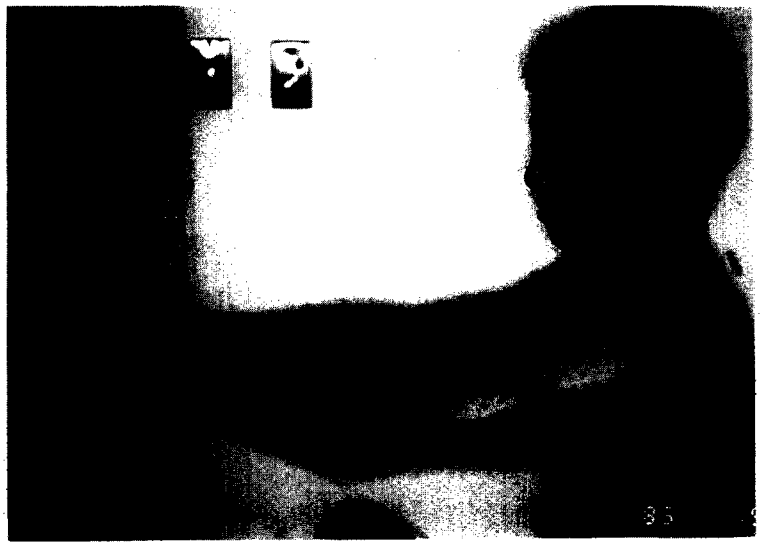

Fig. 11

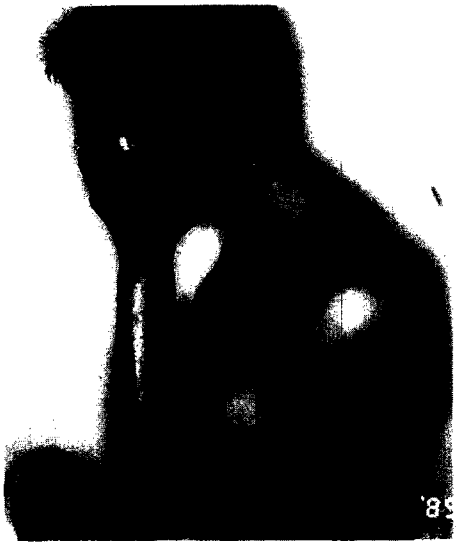

Fig. 12

Figure 7—Preoperative situation. **Figure 8**—Design of the venous flap on the flexor aspect of the right lower extremity. **Figure 9**—Just after operation. **Figure 10**—Diagram of operative technique. **Figure 11**—Extension of the left elbow 8 months after surgery. **Figure 12**—Flexion of the left elbow 8 months after surgery.

confirm the presence of venous valves under the microscope. Proof of the existence of venous valves is still unclear at present, and further investigations are needed in this area. Voukidis suggested that AVFs were possible with reversed flow-through valves and discussed reasons how this could be possible. Takato *et al.* also showed that valves were not a problem. Therefore, perhaps either type of AVF, afferent or efferent, could survive with or without the existence of venous valves experimentally.

Clinically, however, even a human digital vein has many venous valves (Moss *et al.*, 1985), so in clinical use behaviour of efferent AVFs may be different from the experimental situation.

Yet another reason for clinical caution is possible problems with arteriovenous shunts (AVS). Construction of a subcutaneous AVS (diameter 8–10 mm, Anderson *et al.*, 1976) is a well-accepted method of maintenance of vascular access for long-term haemodialysis. Although haemodynamic alterations do occur

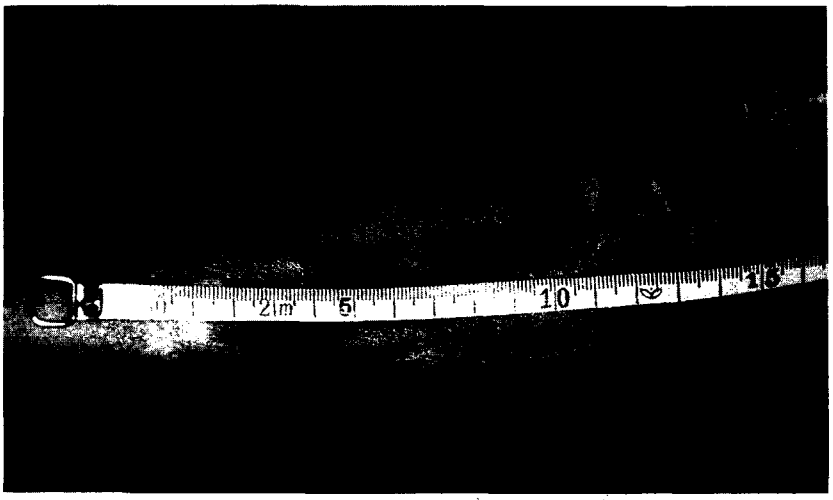

Fig. 13

Figure 13—Appearance of the AVF 8 months after surgery.

Poiseuille's equation

$$F = \frac{\Delta P \cdot \pi \cdot r^4}{8 \cdot \eta \cdot L}$$

F = flow

ΔP = pressure difference between the ends of the tube

r = radius of the tube

η = coefficient of viscosity

L = length of the system

Fig. 14

Figure 14—Poiseuille's Law.

in their presence they are usually without deleterious effects, except in a few individuals (Ahearn and Maher, 1972; Anderson and Groce, 1975; Anderson *et al.*, 1976). Even in the traumatic AVS, heart failure has not been seen when the arteries of the upper extremity were involved (Pate *et al.*, 1965). Generally, it is estimated that cardiac failure occurs only when 20–50% of the cardiac output is shunted through an AVS (Friedberg, 1966). The diameter of the AVS in AVFs which are located in extremities is little more than 1 or 2 mm. Consequently, we believe that complications secondary to shunting will not occur in a patient without severe systemic disease.

The behaviour of the Group B flaps in Experiment 1 is interesting, and suggests it may be more appropriate to select a smaller arterial branch to nourish an AVF.

Poiseuille's Law (Fig. 14) states that the blood flow into Group B flaps (Experiment 1) may be about 8.3 times that of Group C. However, the difference in survival of groups B and C in this Experiment (1) could also be due to differences in venous drainage. This led us to carry out Experiment 2, which suggests that two exit veins are more effective than one in ensuring flap survival, with a given arterial input to the venous system of the flap. A delay method (Mundy and Panje, 1984) or prefabrication (Takato *et al.*, 1991) may also lead to improved survival.

Despite the same composite graft situation in Group A of Experiments 1 and 2, the survival results were slightly different. There were some differences in the anatomy of these flaps. For example, Group A of Experiment 1 did not contain the central vessels within the composite graft whereas Group A of Experiment 2 had the central vessels, albeit coagulated, within the graft. This may explain the different survival in these 2 groups, though it may be merely fortuitous. Neovascularisation, when seen in Group A (Experiment 1) came from the peripheral tissue.

In our clinical case, three draining veins were used to drain the free venous flap. Despite the partial superficial necrosis, the 10×15 cm sized large AVF survived, and we believe this is the largest AVF reported clinically (Chia *et al.*, 1988).

At present, the best indication for an AVF is to cover a skin defect in an area of poor blood supply in an emergency, because of simplicity and lack of morbidity.

References

Ahearn, D. J. and Maher, J. F. (1972). Heart failure as a complication of hemodialysis arteriovenous fistula. *Annals of Internal Medicine*, **77**, 201.

Anderson, C. B. and Groce, M. A. (1975). Banding of arteriovenous dialysis fistulas to correct high-output cardiac failure. *Surgery*, **78**, 552.

Anderson, C. V., Codd, J. R., Graff, R. A., Groce, M. A., Harter, H. R. and Newton, W. T. (1976). Cardiac failure and upper extremity arteriovenous dialysis fistulas. Case reports and a review of the literature. *Archives of Internal Medicine*, **136**, 292.

Chia, S. L., Cheng, H. H. and Mao, L. (1988). Free transplantation of venous network pattern skin flap. *Plastic and Reconstructive Surgery*, **82**, 892.

Friedbert, C. K. (1966). *Diseases of the heart*. 3rd edn. Philadelphia, W. B. Saunders Co.

Inada, Y., Fukui, A., Tamai, S. and Masuhara, K. (1989). Experimental studies of skin flaps with subcutaneous veins. *Journal of Reconstructive Microsurgery*, **5**, 249.

Inada, Y., Hirai, T., Fukui, A., Omokawa, S., Mii, Y. and Tamai, S. (1992). Experimental study of flow-through venous flap: investigation of the survival width and area with one flow-through vein preserved. *Journal of Reconstructive Microsurgery*, **18**, 297.

Inoue, G. and Maeda, N. (1984). Arterialized venous flap coverage for skin defects of the hand or foot. *Journal of Reconstructive Microsurgery*, **5**, 151.

Inoue, G., Maeda, N. and Suzuki, K. (1990). Resurfacing of skin defects of the hand using the arterialized venous flap. *British Journal of Plastic Surgery*, **43**, 135.

Inoue, G., Maeda, N. and Suzuki, K. (1991). Closure of big toe defects after wrap-around flap transfer using the arterialized venous flap. *Journal of Reconstructive Microsurgery*, **7**, 1.

Ji, S. Y., Chia, S. L. and Cheng, H. H. (1984). Free transplantation of venous network pattern flaps: an experimental study in rabbits. *Microsurgery*, **5**, 151.

Koshima, I., Soeda, S., Nakayama, Y., Fukuda, H. and Tanaka, J. (1991). An arterialised venous flap using the long saphenous vein. *British Journal of Plastic Surgery*, **44**, 23.

Moss, S. H., Schwartz, K. S., von Drasek-Ascher, G., Ogden, L. L., Wheeler, C. S. and Lister, G. D. (1985). Digital venous anatomy. *Journal of Hand Surgery*, **10A**, 473.

Mundy, J. C. and Panje, W. R. (1984). Creation of free flaps by arterialization of the venous system. *Archives of Otolaryngology*, **110**, 221.

Nakayama, Y., Soeda, S. and Kasai, Y. (1981). Flaps nourished by arterial inflow through the venous system: an experimental investigation. *Plastic and Reconstructive Surgery*, **67**, 328.

Nishi, G., Shibata, Y., Kumabe, Y., Hattori, S. and Okuda, T. (1989). Arterialized venous skin flaps for the injured finger. *Journal of Reconstructive Microsurgery*, **5**, 357.

Pate, J. W., Sherman, R. T., Jackson, T. and Wilson, H. (1965). Cardiac failure following traumatic arteriovenous fistula: a report of fourteen cases. *Journal of Trauma*, **5**, 398.

Takato, T., Zuker, R. M. and Turley, C. B. (1991). Prefabrication of skin flaps using vein grafts: an experimental study in rabbits. *British Journal of Plastic Surgery*, **44**, 593.

Voukidis, T. (1982). An axial-pattern flap based on the arterialised venous network: an experimental study in rats. *British Journal of Plastic Surgery*, **35**, 524.

Yoshimura, Y., Shimada, T., Imura, S., Shimamura, K. and Yamauchi, S. (1987). The venous skin graft method for repairing skin defects of the fingers. *Plastic and Reconstructive Surgery*, **79**, 243.

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