British Journal of Plastic Surgery (1993), **46**, 665–669

BRITISH JOURNAL OF PLASTIC SURGERY

Cutaneous blood flow in the free TRAM flap

H. P. Tuominen, S. Asko-Seljavaara and N. E. Svartling

Departments of Plastic Surgery and Anaesthesia, Töölö Hospital, Helsinki University Central Hospital, Helsinki, Finland

SUMMARY. **According to clinical studies there are fewer circulatory complications with the free TRAM flap than with the pedicled TRAM flap. In this haemodynamic study, we measured perioperative cutaneous blood flow in 11 free TRAM flaps with laser Doppler flowmetry (LDF) and transcutaneous oxygen tension (ptcO$_2$). We also studied 4 pedicled TRAM flaps with an additional microvascular anastomosis. Our results suggest that skin blood flow in the free TRAM flap is superior compared to our previously presented results of the pedicled TRAM flaps, and also superior to pedicled TRAM flaps with additional microvascular anastomoses of the inferior epigastric vessels to "supercharge" them.**

The conventional pedicled TRAM flap has become popular for breast reconstruction in recent years.[1] It does have disadvantages, though, such as partial cutaneous and fat necrosis of the random portion of the flap. The pedicled TRAM flap is based on its nondominant pedicle, the superior epigastric artery.[2] In a haemodynamic study we have shown that skin blood flow decreases significantly on the random side of the flap after ligation of the inferior pedicle and remains low in patients who develop skin necrosis. The superior epigastric system can adequately nourish the skin of the conventional TRAM flap of only about half of the patients.[3]

Circulatory disturbances manifesting as cutaneous or fat necrosis have been less common in the free TRAM flap based on the inferior epigastric vessels.[4–7] The more reliable skin blood flow in the free microvascular TRAM flap has, however, not previously been demonstrated in a haemodynamic study.

Patients and methods

Breast reconstruction with a free microvascular TRAM flap was performed in 11 women. Four women with a conventional pedicled TRAM flap with an added microvascular anastomosis of the inferior epigastric vessels in the axilla also participated in the study. The informed consent of the patients was obtained and the study was approved by the Töölö Hospital Ethical Committee.

The 11 free TRAM flap patients had had a mastectomy for carcinoma of the breast 2–19 (mean 6.2) years earlier. None of the free flap patients smoked. Three of the conventional TRAM flap patients had had a mastectomy for carcinoma 3–19 years earlier and one for melanoma of the breast skin 22 years earlier. One of the free flap patients was hypothyroid and one of the pedicled flap patients had hypertension. Two patients took tamoxifen (Tamofen®, Leiras, Finland) for nodal metastases found at the primary operation. The patients were otherwise healthy.

The patients were operated on under general anaesthesia as described previously.[3] In brief, ventilation was controlled (Servo Ventilator 900, Siemens-Elema, Stockholm, Sweden) and the anaesthesia was maintained with nitrous oxide in oxygen and isoflurane. Mild hypervolaemic haemodilution was obtained by infusing 500 ml of 6% hydroxyethylstarch (Plasmafusin®, Leiras-Kabi Infusion Oy, Finland) after induction of anaesthesia and Ringer acetate during the operation. 500–1000 ml of dextran 40 (Rheomacrodex®, Kabi Infusion A/S, Norway) were infused by the next morning. Haematocrit was maintained at 0.30–0.35.

Operative technique

1. The free microvascular TRAM flaps. All the operations were performed by the same surgeon. The cutaneous part of the flap was designed below the umbilicus. The height of the skin island varied from 11–14 cm. The random side of the flap, on the mastectomy side, was first elevated to the linea alba. Thereafter the axial side of the TRAM flap was dissected, 2.5 cm of the anterior rectus sheath and 5 cm of the rectus muscle being taken above the arcuate line with the flap. A lateral strip (1.5 cm in width) of the rectus muscle was left in place to avoid contraction of the muscle edges. The rectus muscle was cut below the deep inferior epigastric pedicle. The rectus muscle was then cut at a level below the umbilicus, and the superior epigastric pedicle was ligated. The deep inferior epigastric artery was dissected down to the iliac vessels. The pedicle was about 8 cm long. The deep inferior epigastric vessels were then ligated. The abdominal wall was closed by nonabsorbable sutures. The assistant dissected the scar on the chest wall and the skin to the inframammary fold. Axillary vessels were exposed. The deep inferior epigastric pedicle was anastomosed end to end either to the thoracodorsal vessels (9 cases) or to the scapular circumflex vessels (2 cases). The free TRAM

Table 1 The measurement phases

Phase 1	On the preoperative day
Phase 2	Patient anaesthetised, before incision
Phase 3	Contralateral side of the flap elevated
Phase 4	The whole flap elevated and rectus muscle cut
Phase 5	The superior pedicle ligated*
Phase 6	The flap on the chest, before anastomosis
Phase 7	Recovery room
Phase 8	Third postoperative day

* In the patients with a conventional TRAM flap and an additional anastomosis Phase 5a = inferior pedicle ligated

flap was placed on the chest wall, the umbilicus caudally and the random side medially. Excessive skin and subcutaneous tissue were removed and the breast was shaped.

2. *The pedicled TRAM flaps with the additional microvascular anastomosis.* The four pedicled TRAM flaps were designed in the same way as the free TRAM flaps, but the superior epigastric vessels of course not ligated. The contralateral rectus muscle was dissected up to the costal margin. The rectus muscle was cut above the arcuate line, and the deep inferior epigastric vessels were ligated. The flap was pulled to the thoracic wall. The inferior epigastric vessels were anastomosed end to end to the thoracodorsal vessels (3 cases) or the scapular circumflex vessels (1 case) in the axilla.

Measurements

The measurement phases at different times during the procedures are listed in Table 1.

Cutaneous blood flow was monitored with laser Doppler flowmetry (LDF) (Periflux 2 B, Perimed, Stockholm, Sweden) and transcutaneous oxygen tension ($ptcO_2$) (Transcom 807, Novametrix Medical Systems, Inc., Conn., USA). As in our previous paper,[3] the measurement sites were on the axial skin over the rectus muscle of the TRAM flap (ipsilateral) and on the random side skin of the flap (contralateral). The $ptcO_2$ measurement sites were about 1 cm cranial to the LDF measurement sites on both sides of the flaps. The LDF probe holders were kept on the measuring sites between phases 2 and 8. LDF was not measured in phase 1. Each LDF measurement lasted for at least 10 min.

Before each replacement, the $ptcO_2$ probe was calibrated against an oxygen-free zero solution and ambient pressure. $PtcO_2$ was measured at phases 1, 7 and 8 on both sides of the flap. The intraoperative measurements (phases 2–6) were performed only contralaterally and between them the $ptcO_2$ probe was kept in place.

The inspired oxygen concentration was 21% at phases 1 and 8 and 35% at other times.

Rectal and peripheral temperatures were continuously measured during the operation with thermocouple probes (Exacon MC 8700, Exacon, Copenhagen, Denmark). The values at phases 2 and 6 and at the end of operation were included in the study. Arterial oxygen tension (paO_2) was measured at phases 3 and 7.

Wound healing and development of cutaneous necrosis was observed clinically postoperatively. A postoperative ultrasound was performed in every patient and signs of fat necrosis were noted.

Statistical analysis

The LDF values at each site are expressed as a percentage of the reference value at phase 2. The $ptcO_2$ values were obtained in mm of mercury (mmHg). The respective values in kPa are given in brackets. All values are given as mean ± SD.

The statistical differences between the measuring times within one group were analysed with the non-parametric Wilcoxon-Pratt test. Differences between the free TRAM flaps and the pedicled TRAM flaps with additional anastomosis were tested with two-sample rank sum test (Mann–Whitney test). P values of 0.05 or less were considered significant.

Results

The characteristics of the patients and the operations are shown in Table 2.

The LDF values

The changes in the LDF values of the free TRAM flap patients are illustrated in Figure 1. The LDF measurements were obtained from only 10 free TRAM flap patients, since there were technical problems with one patient.

Elevation of the random side of the flap at phase 3 caused an increase in the LDF values contralaterally to 150 ± 95% and ipsilaterally to 170 ± 137% from the

Table 2 Characteristics of the patients and operations (mean ± SD)

	Free flaps	*Pedicled flaps with microvascular anastomosis*
N	11	4
Age of the patients (years)	46 ± 8	46 ± 9
Weight (kg)	66 ± 9	62 ± 11
Height (cm)	165 ± 4	159 ± 5
Duration of operation (min)	396 ± 66*	402 ± 114**
Ringer acetate given intraoperatively (l)	3.6 ± 0.9	3.7 ± 0.6
Whole blood given (units)	2.2 ± 0.9	2.6 ± 1.4
Preoperative haemoglobin concentration (g/l)	132 ± 8	137 ± 10
Postoperative haemoglobin concentration (g/l)	95 ± 10	93 ± 12
PaO_2 at phase 3 (kPa)	24.3 ± 4.3	25 ± 3
PaO_2 at phase 7	16.8 ± 5.1	10.7 ± 4
T_{rect} at phase 2 (°C)	36.1 ± 0.4	36.2 ± 0.4
T_{rect} at phase 6	35.7 ± 0.6	36 ± 0.4
T_{rect} at the end of operation	36 ± 1.1	36.3 ± 0.6
T_{periph} at phase 2	34.3 ± 1.1	35 ± 0.3
T_{periph} at phase 6	34.3 ± 0.9	34.9 ± 0.6
T_{periph} at the end of operation	29 ± 2.8	31.1 ± 4.3

PaO_2 = arterial oxygen tension.
T_{rect} = rectal temperature.
T_{periph} = peripheral temperature.
* mastopexy to the other breast in 4 cases.
** mastopexy to the other breast in 1 case.

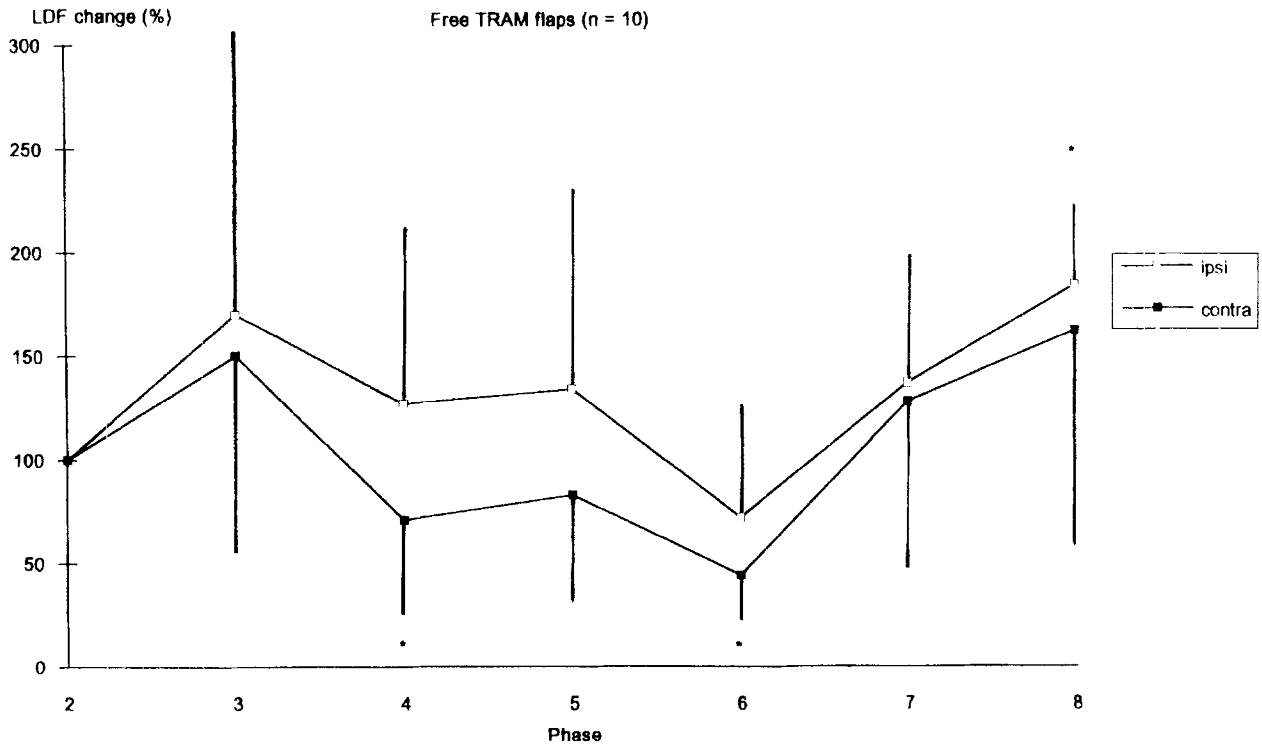

Fig. 1

Figure 1 Change in the LDF values as a percentage of the initial value (phase 2) on the ipsilateral and contralateral sides of the free microvascular TRAM flaps. * represents $p < 0.05$ for difference from the initial value on each side of the flap. Measuring times are as in Table 1. Values are given as mean ± SD.

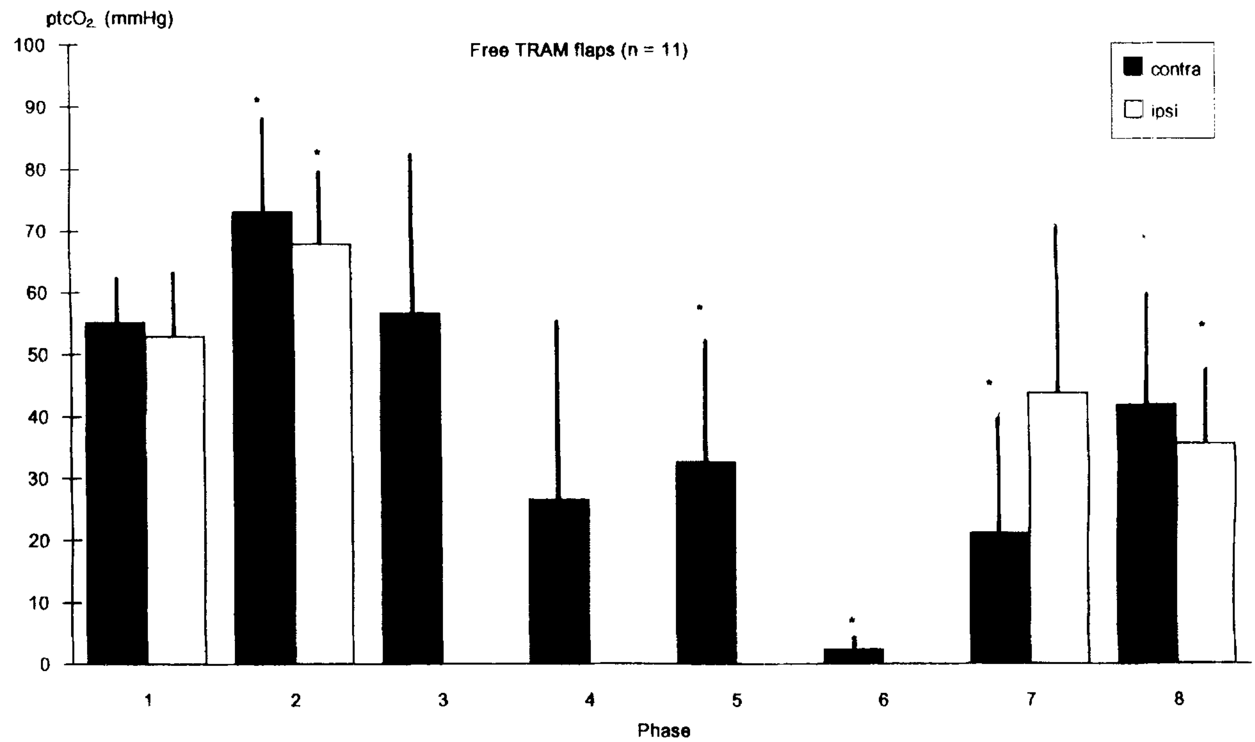

Fig. 2

Figure 2 The transcutaneous oxygen tension ($ptcO_2$) on the contralateral and ipsilateral sides of the free microvascular TRAM flaps. * represents $p < 0.05$ for difference from the initial value on each side of the flap. Measuring times are as in Table 1. Values are given as mean ± SD.

initial level. At phase 4, after dissection of the whole flap the LDF values fell contralaterally significantly to 71 ± 45% ($p = 0.048$) and remained above the initial level ipsilaterally (127 ± 85%). After ligation of the superior epigastric pedicle (phase 5) the LDF values remained near the level at phase 4 on both sides of the

Table 3 The contralateral and ipsilateral LDF and $ptcO_2$ values of the patients with a pedicled TRAM flap with an additional microvascular anastomosis ($n = 4$). Values are given as mean ± SD

	LDF (% of initial value)		*$ptcO_2$ (mmHg)*	
	contra	*ipsi*	*contra*	*ipsi*
Phase 1			51 ± 6	45 ± 1
Phase 2	100	100	64 ± 26	42 ± 24
Phase 3	260 ± 255	163 ± 47	47 ± 37	
Phase 4	87 ± 56	83 ± 21	14 ± 16	
Phase 5a	54 ± 30	73 ± 30	10 ± 18	
Phase 6	77 ± 59	76 ± 17	0 ± 0	
Phase 7	236 ± 258	93 ± 36	20 ± 18	23 ± 13
Phase 8	145 ± 70	158 ± 56	19 ± 13	32 ± 4

flap (contralaterally 83 ± 53%, ipsilaterally 134 ± 96%). When the flap was without circulation on the chest in phase 6, the LDF values decreased contralaterally significantly to 44 ± 23% ($p = 0.003$) and ipsilaterally to 72 ± 56% of the initial level. At phase 7 in the recovery room the LDF values had increased over the base line level, contralaterally to 128 ± 85% and ipsilaterally to 137 ± 67%. On the third postoperative day (phase 8) the LDF values increased further, contralaterally to 162 ± 101% and ipsilaterally significantly to 184 ± 41% ($p = 0.008$) of the base line level.

The $ptcO_2$ values

The $ptcO_2$ values of the free TRAM flap patients are illustrated in Figure 2. The $ptcO_2$ values were obtained from all 11 patients. The preoperative $ptcO_2$ was contralaterally 55 ± 8 mmHg [6.9 ± 1 kPa] and ipsilaterally 52 ± 10 mmHg [7 ± 1.4 kPa] (phase 1). After induction of anaesthesia (phase 2), $ptcO_2$ increased significantly to 73 ± 14 mmHg [9.7 ± 1.9 kPa] contralaterally ($p = 0.005$) and to 67 ± 12 mmHg [9 ± 1.7 kPa] ipsilaterally ($p = 0.006$). After elevation of the random side of the flap (phase 3) the contralateral $ptcO_2$ fell to the initial level. The ipsilateral $ptcO_2$ was not measured in phases 3–6. The contralateral $ptcO_2$ decreased to 26 ± 29 mmHg [3.5 ± 3.9 kPa] when the whole flap was dissected and both pedicles were intact (phase 4). At phase 5, after ligation of the superior pedicle, it had decreased significantly to 32 ± 20 mmHg [4.3 ± 3.9 kPa] ($p = 0.001$ compared to phase 1). When the flap was without perfusion in phase 6 the contralateral $ptcO_2$ fell to 2 ± 2 mmHg [0.3 ± 0.2 kPa] ($p = 0.001$). It was still low compared with the initial level in the recovery room (phase 7), 21 ± 18 mmHg [2.7 ± 2.4 kPa] ($p = 0.002$) and on the third postoperative day, 41 ± 19 mmHg [5.5 ± 2.6 kPa] ($p = 0.008$). The ipsilateral $ptcO_2$ in the recovery room was 43 ± 27 mmHg [5.8 ± 3.6 kPa] and on the third postoperative day 35 ± 12 mmHg [4.7 ± 11.6 kPa] ($p = 0.002$ compared to phase 1).

The LDF and $ptcO_2$ values of the four patients with the pedicled TRAM flap and an additional microvascular anastomosis are given in Table 3. There were too few patients for us to be able to deduce any statistically significant differences.

Healing and complications

Nine of the 11 free TRAM flap patients healed without complications. One of the 11 developed a minor random side skin necrosis. With the exception of the breast cancer she had previously been healthy. Another patient developed fat necrosis, which was observed in the postoperative ultrasound investigation. She took tamoxifen for axillary nodal metastases found in the primary operation 2 years earlier. This patient also sustained a pulmonary embolism necessitating anticoagulant medication. Both flaps healed spontaneously.

Exploration and reanastomosis of the vein were performed in two free flaps during the postoperative period. A postoperative haematoma was evacuated from one flap the next day.

A minor skin necrosis, which healed without surgical intervention, developed in one of the four conventional TRAM flaps with the additional anastomosis. This patient was a smoker. She did not take any medication.

Discussion

This study indicates that, compared to our previous study on pedicled TRAM flaps,[3] the free TRAM flap has a more reliable cutaneous blood flow. It confirms the clinical observations of the free TRAM flap demonstrating very few circulatory complications.[4-7] In this study only one of 11 patients developed a minor skin necrosis and one a fat necrosis. In our previous haemodynamic study of pedicled TRAM flaps, 8 of 14 patients showed signs of minor cutaneous necrosis.[3]

The $ptcO_2$ is an indirect indicator of blood flow. Low levels indicate either low oxygen delivery or high oxygen consumption in the skin.[8] LDF has been widely used as a monitor of microcirculation.[9,10] It has yielded, however, conflicting results.[11,12] According to Jones, LDF is useful only when the recorded values are compared with the base line values,[13] which is the way we present the results of our LDF measurements.

In a recent haemodynamic study of the pedicled TRAM flap, Harris *et al.*[14] showed that gentle occlusion of the superior epigastric system during the operation caused a reduction in blood flow through the deep inferior epigastric artery in two thirds of the patients. In the present haemodynamic study, in contrast, the cutaneous blood flow in the lower abdominal TRAM flap did not decrease when the superior epigastric vessels were ligated at the level of the umbilicus. Our results confirm that the deep inferior epigastric vessels are the dominant pedicle of the lower abdominal integument.

Total separation of the free TRAM flap from the body by ligating the deep inferior epigastric vessels induced significant decreases in both the $ptcO_2$ and LDF values contralaterally. The failure of the LDF values not reaching zero when the tissue is without perfusion has been attributed to the inability of LDF to distinguish between nutrient blood flow and the random motion of cells in a nonperfused tissue.[15] In the recovery room, when the anastomoses were functioning, the contralateral $ptcO_2$ was still low compared with the initial level, but had increased markedly compared with the values measured before the anastomoses were formed. The changes in the contralateral LDF values were similar. On the third postoperative day the contralateral $ptcO_2$ and LDF levels had increased further. This finding differs clearly from the results previously obtained for patients with conventional pedicled TRAM flaps. In pedicled TRAM flaps the random side skin blood flow measured by $ptcO_2$ and LDF has been shown to be low for many days postoperatively.[3] The present study indicates that the postoperative blood flow in the free TRAM flap measured by $ptcO_2$ and LDF is more generous than in the pedicled flap. A possible explanation for this is that in the free TRAM flap the deep inferior epigastric artery supplies a smaller amount of tissue than at its original place and so the free TRAM flap gets a marked volume of blood and is well oxygenated. In addition to this, the free flap is isolated for at least the first week after the operation, and so its blood vessels are without neural control and thus remain dilated.

We also measured skin blood flow in four pedicled TRAM flaps with an additional microvascular anastomosis in the axilla. Scheflan recommended an additional microvascular anastomosis of the axial side deep inferior epigastric artery if the circulation in a conventional TRAM flap seems marginal.[16] Harashina *et al.* anastomosed the superficial or inferior epigastric vessels of the random side in three pedicled TRAM flaps with good results.[17] In our 4 patients the postoperative $ptcO_2$ and LDF levels were clearly higher than the levels in our previous study on the pedicled flaps. However, the levels in the free flaps of this study were even higher, especially on the third postoperative day. It is possible that in a pedicled TRAM flap with an additional anastomosis the blood flows from the superior and the deep inferior epigastric artery compete with each other and the flap is unequally oxygenated compared to the free flap which is supplied by the deep inferior epigastric artery alone.

The duration of operation and the need for transfusions and infusions is about equal in these two groups of procedures, at least in our small numbers. Since the pedicled TRAM flap with an additional anastomosis offers no exceptional advantages over the free TRAM flap, our recommended method for autogenous breast reconstruction is the free TRAM flap.

References

1. Hartrampf CR, Bennett GK. Autogenous tissue reconstruction in the mastectomy patient. A critical review of 300 patients. Ann Surg 1987; 205: 508.
2. Boyd JB, Taylor GI, Corlett R. The vascular territories of the superior epigastric and the deep inferior epigastric systems. Plast Reconstr Surg 1984; 73: 1.
3. Tuominen HP, Asko-Seljavaara S, Svartling N, Härmä M. Cutaneous blood flow in the TRAM flap. Br J Plast Surg 1992; 45: 261.
4. Grotting JC, Urist M, Maddox WA, Vasconez LO. Conventional TRAM flap versus free microsurgical TRAM flap for immediate breast reconstruction. Plast Reconstr Surg 1989; 83: 828.
5. Arnež ZM, Bajec J, Bardsley AF, Scamp T, Webster MHC. Experience with 50 free TRAM flap breast reconstructions. Plast Reconstr Surg 1991; 87: 470.
6. Schusterman MA, Kroll SS, Weldon ME. Immediate breast reconstruction: Why the free TRAM over the conventional TRAM flap? Plast Reconstr Surg 1992; 90: 255.
7. Yamada A, Harii K, Hirabayashi S, Kawashima T, Asato H. Breast reconstruction with the free TRAM flap after breast cancer surgery. J Reconstr Microsurg 1992; 8: 1.
8. Achauer BM, Black KS. Transcutaneous oxygen and flaps. Plast Reconstr Surg 1984; 74: 721.
9. Heden PG, Hamilton R, Arnander C, Jurell G. Laser Doppler surveillance of the circulation of free flaps and replanted digits. Microsurgery 1985; 6: 11.
10. Klitzman B. Discussion. Regional variations of laser Doppler blood flow in ischemic skin flaps. Plast Reconstr Surg 1990; 86: 327.
11. Walkinshaw M, Holloway A, Bulkley A, Engrav LH. Clinical evaluation of laser Doppler blood flow measurements in free flaps. Ann Plast Surg 1987; 18: 212.
12. Banic A, Kouris K, Lewis DH. Evaluation of the microcirculation in a sheep island pedicle flap with laser Doppler flowmeter and ^{99m}-Tc-labelled red blood cells. J Reconstr Microsurg 1990; 6: 345.
13. Jones NF. Intraoperative and postoperative monitoring of microsurgical free tissue transfers. Clin Plast Surg 1992; 19: 783.
14. Harris II, NR, Webb MS, May JW. Intraoperative physiologic blood flow studies in the TRAM flap. Plast Reconstr Surg 1992; 90: 553.
15. Marks NJ, Trachy RE, Cummings CW. Dynamic variations in blood flow as measured by laser Doppler velocimetry: A study in rat skin flaps. Plast Reconstr Surg 1984; 73: 804.
16. Scheflan M. The transverse abdominal island flap: What you should do when the flap turns blue. Eur J Plast Surg 1988; 11: 69.
17. Harashina T, Sone K, Inoue T, Fukuzumi S, Enomoto K. Augmentation of circulation of pedicled transverse rectus abdominis musculocutaneous flaps by microvascular surgery. Br J Plast Surg 1987; 40: 367.

The Authors

Hanna P. Tuominen, MD, Consultant Anaesthetist
Sirpa Asko-Seljavaara, MD, Docent, Head of the Department of Plastic Surgery
Nils E. Svartling, MD, Consultant Anaesthetist

Departments of Plastic Surgery and Anaesthesia, Töölö Hospital, Helsinki University Central Hospital, Helsinki, Finland.

Requests for reprints to: Dr H. Tuominen, Töölö Hospital, Topeliuksenkatu 5, 00260 Helsinki, Finland.

This study was supported by a grant from The Finnish Medical Foundation and The Association for the Development of and Education in Plastic Surgery and Burn Treatment in Finland.

Paper received 15 February 1993.
Accepted 15 June 1993, after revision.