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Predicting the fate of free tissue transfers*

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Summary
Accurate and objective assessment of blood flow in microvascular free tissue transfers both at the time of surgery and during the postoperative period is vital. An experimental study is presented in which four methods of evaluating flow were tested in an animal model. Based on this work clinical free tissue transfers have been successfully monitored using an ultrasound Doppler flowmeter at operation and a laser Doppler flowmeter afterwards. The use of these instruments has significantly improved the reliability of microvascular reconstructions and greatly simplified their postoperative management.

Introduction

In 1665, at about the same time as the Arrissian endowment and Gale annuity were founded, Robert Hooke published his Micrographia, or 'some physiological descriptions of minute bodies made by magnifying glasses', in which he describes a compound monocular microscope. Two hundred and fifty years passed before Professor Carl Nylen introduced the microscope to surgery in 1921. He used the instrument when operating on patients with middle ear disease.

Vascular and transplantation surgery was pioneered by Alexis Carrell in Lyon who received a Nobel prize in physiology and medicine in 1912. Peripheral vascular surgery was popularised during the late 1940's and early fifties, but problems of low patency rates were encountered when small vessels were anastomosed. Although careful attention to technique produced some improvement, it was not until the concepts of microsurgery and vascular surgery were combined in 1960 by Jacobson and Suarez working in Professor Peardon Donaghy's unit at Burlington Vermont that 100% patency was achieved. They used a binocular microscope and 7/0 silk sutures to anastomose carotid vessels in dogs and rabbits, the smallest of which were 1.4 mm in diameter *(1)*. The pioneering work of John Cobbett and Bob Acland in Great Britain resulted in reliable anastomosis of vessels as small as half a millimetre in diameter. Parallel advancements in the understanding of the anatomy and physiology of the microcirculation has opened new horizons in reconstructive surgery. Soft tissue and composite defects which would previously have required many operations for their repair may now be reconstructed in a single operation. Amputated limbs and digits may be replanted or toes transplanted to the hand to restore function following injury or congenital deformity. Each of these procedures depends on the restoration and maintenance of blood flow in the transplanted or replanted part by microvascular anastomosis of its nutrient arteries and draining veins.

Although patency rates of close to 100% had been achieved for very small vessels in the laboratory, published clinical series of free tissue transfers do not achieve this goal, survival figures ranging from 71–92% *(2)*. Why should this be? Is there a failure to detect unsatisfactory flow at operation, or does vascular occlusion occur during the postoperative period?

Experimental study

MODEL

With the aim of answering this question, a study was made to see whether there was a means to predict the outcome of a free flap at the time of surgery. The epigastric island flap in the rat was chosen as the experimental model. It is supplied by a single vascular pedicle with vessels approximately 1 mm in diameter, corresponding in size to those encountered in many clinical microvascular procedures. Having anaesthetised the animal standard 7 × 5 cm flaps were raised deep to the panniculus carnosus revealing the pedicle. All branches of the femoral vessels were divided except the inferior epigastrict artery and vein, and the femoral vessels themselves distal to the epigastric pedicle (Fig. 1).

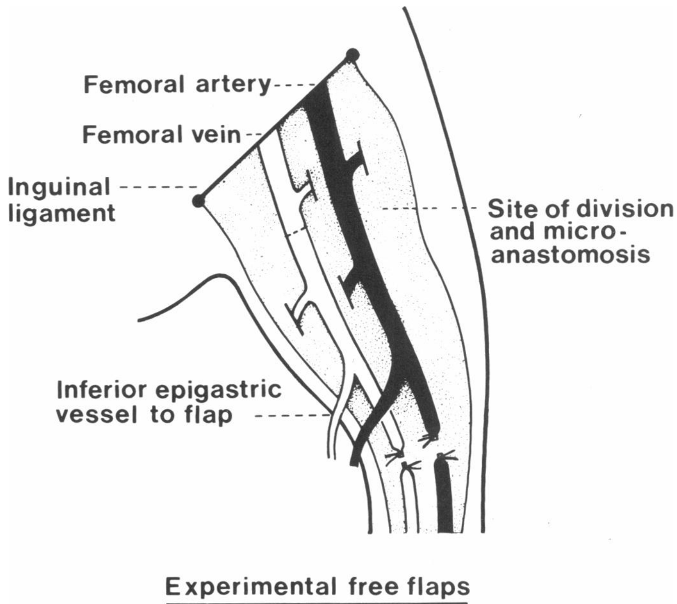

FIG. 1 Diagram of epigastric free flap pedicle.

* Based on an Arris & Gale Lecture delivered on 7th March, 1984 at the Royal College of Surgeons of England.

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After occluding the femoral vessels with microclamps they were divided to produce a free flap and then end to end in situ microvascular anastomoses were completed using 10/0 nylon sutures. In order to provide sufficient control data, in some animals one or other vessel was deliberately occluded. After suturing the flap in position, the animal was returned to its cage and maintained for two weeks to observe the flap. There was a total of 105 free flaps of which 70 were successful and 35 failed. Of the failures, 18 were arterial, 16 of these being produced deliberately, and 2 accidentally; 17 were venous, 11 of which were deliberate and 6 accidental. So, excluding the deliberate failures, the overall success rate was 97% for arteries and 92% for veins, figures which accord very closely with those published by others.

ASSESSMENT OF FLOW AT OPERATION

Any test for assessing flow through microanastomoses at operation should be objective, recordable, atraumatic, and applicable to end to end or end to side anastomoses. Those currently used entail lifting, squeezing or simple observing the vessels after anastomosis and conform to none of these criteria. Vascular surgeons have used instrumental methods to evaluate anastomoses for some time and although the electromagnetic flowmeter has been discarded by many because of practical problems in use, its bulk and expense, the ultrasound Doppler flowmeter has proved relatively simple and effective *(3)*.

Although it is theoretically possible to calculate absolute flow from Doppler shift frequencies, this entails complex mathematics and strict control of variables such as the angle between probe and vessel, and the vessel's cross sectional area, so it is practically impossible.

An experimental study of anastomoses in 1 mm diameter arteries had found the Doppler to be 100% accurate in assessing patency *(4)*. A directional device was used, simply as a positive or negative test; if any flow was detected with it after anastomosis, then the vessel remained patent. The same test applied to free flaps would indicate whether the arterial anastomosis is patent. It might be expected that outflow venous obstruction would in turn prevent arterial inflow, producing a negative result if either vessel was obstructed.

Having raised the epigastric flap, the inferior epigastric artery was insonated with an 8 megahertz directional Doppler probe. There was an audible pulse signal which disappeared when the vessel was occluded either proximal or distal to the probe.

Having divided and anastomosed the femoral vessels the procedure was repeated ten minutes after removing the clamps (Fig. 2). A positive arterial signal implied that flow through the flap was satisfactory. By briefly occluding the femoral artery, one could ensure that the pulse did not arise from an adjacent vessel. Of 22 flaps so tested, 18 were successful and 4 failed, but the Doppler only predicted the outcome correctly in 77% of cases. In particular, it became clear that arterial flow could be detected even when the venous outflow was completely obstructed. This implied that greater accuracy should be achieved if a means existed to test both arterial and venous anastomoses.

Venous flow is difficult to detect with a Doppler because of its low velocity, but if this is increased by momentary compression of the veins distal to the site of insonation a 'woosh' is produced. Such is the basis of the clinical Doppler tests for deep venous thrombosis and it seemed reasonable to use this principle to evaluate venous microanastomoses. In a further 20 free flaps, the artery was assessed as before, but then the femoral vein was insonated proximal to the anastomosis and gently compressed momentarily distally (Fig. 3). A 'woosh' from the Doppler indicated patency. I termed this procedure *the venous flow augmentation test*. Using this method of separate arterial and venous testing, the Doppler was 100% accurate in predicting the outcome of the free flap at the time of surgery. There were no late failures which suggests that the patency of anastomoses in healthy 1 mm diameter vessels as tested by the Doppler is an all or none phenomenon. If they are patent ten minutes after restoring flow, they will remain so.

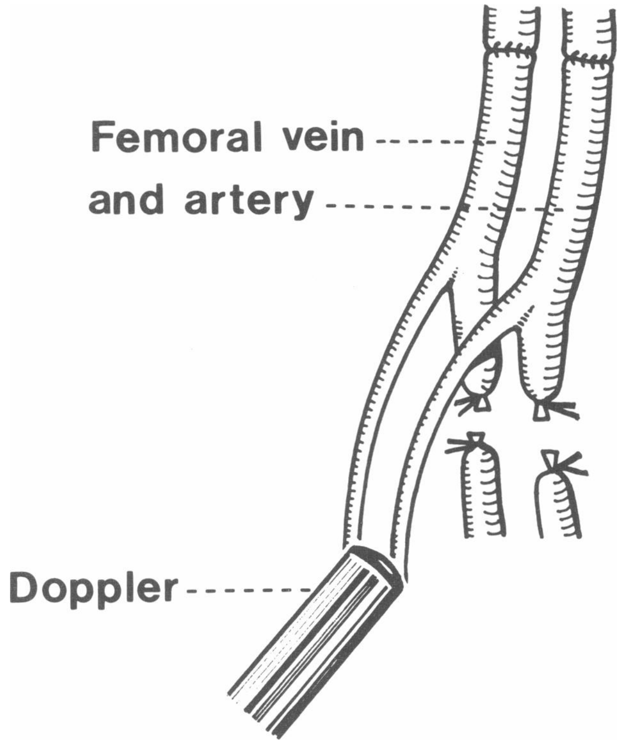

FIG. 2 Insonation of inferior epigastric artery distal to microvascular anastomosis.

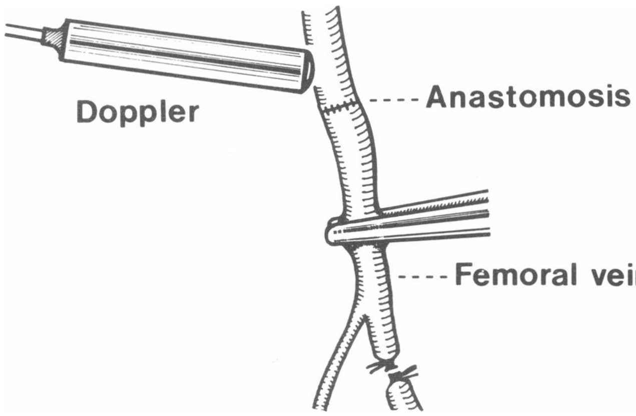

FIG. 3 Venous flow augmentation test.

It had been noticed that the arterial pulse in venous obstructed flaps was abrupt and shortened, rather than the usual smooth swishing sound. This suggested the possibility that a more detailed display of Doppler shift frequencies may provide information relating to the quality of venous drainage. A technique for displaying a detailed waveform velocity profile known as spectral analysis had been developed and used extensively for noninvasive assessment of peripheral vascular disease *(5)*. Directional Doppler signals are processed in such a way as to give separate and continuous outputs for forward and reverse velocities, then displayed graphically by a spectral analyser similar to that used for speech display. With the help of an outphase processor, it was possible to process the simple directional Doppler output to provide truly directional data, suitable for spectral analysis after recording onto standard magnetic tape. As a result of increased sensitivity it was now possible to hear forward arterial flow and venous flow in the opposite direction simultaneously. Fig. 4 shows simultaneous insonation of both inferior epigastric artery and vein supplying

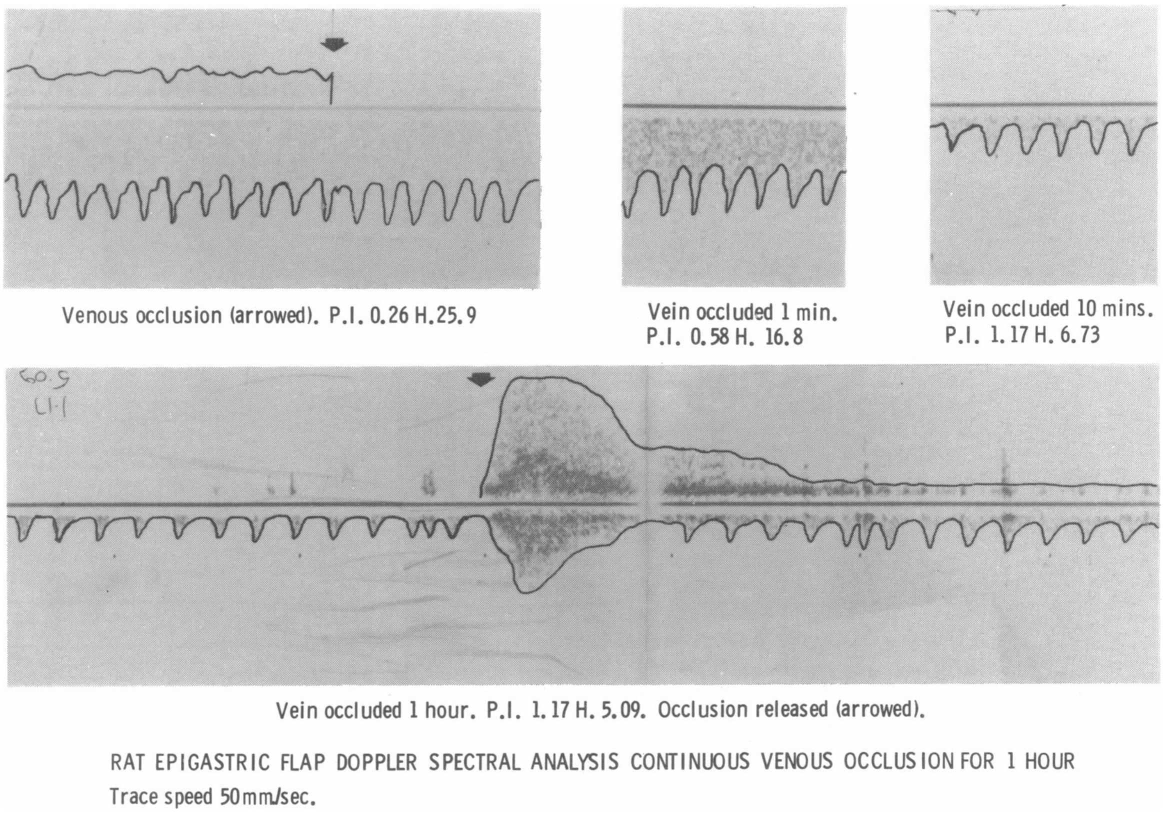

FIG. 4 Spectral analysis of inferior epigastric artery and vein. Venous flow above zero line, arterial flow below zero line. PI = Pulsatility index. H = Mean trace height.

an island flap. When the femoral vein was occluded with a microclamp for one hour, its trace disappeared and the arterial pattern changed from a smooth 'woosh' to an abrupt 'damped' sound. On removal of the clamp, venous flow returned with a 'woosh' and the arterial pattern began to revert. These changes can be documented from a mathematical analysis of linear velocity known as the pulsatility index (P.I.). The waveforms resemble those found in patients with Raynaud's disease before and after sympathetic blockade and indicate a changing distal peripheral resistance. Traces from a successful rat free flap before and after vascular anastomosis (Fig. 5) show that venous flow is present, together with a smooth low resistance arterial waveform. In contrast, a flap with an occluded venous anastomosis had no venous flow and a damped, high resistance arterial waveform. If a spectral analyser were available in an operating theatre, it could undoubtedly provide useful detail when assessing microanastomoses with the Doppler, but it is expensive. Its greatest benefit in this study was in learning to recognise and interpret low resistance and high resistance or damped arterial waveforms and infer information from this as to the resistance to blood flow in the flap.

Although the outcome of experimental flaps could be predicted by the ultrasound Doppler flowmeter at operation, it became clear that there is an important difference between experimental and clinical flaps postoperatively. The flap pedicle is unlikely to become obstructed in the rat model; however blood flow in a clinical flap may be reduced by a physiological low perfusion state or compression of its pedicle because of oedema, kinking, postural change or obstructive dressings. Consequently the clinical microsurgeon must also have a method of quickly detecting a deterioration in the flap's circulation during the postoperative period so that this may be rectified before irreversible tissue damage occurs.

POSTOPERATIVE FLOW MONITORING

It is absolutely vital that any postoperative monitor be capable of interpretation by nursing or junior medical staff since however diligent the surgeon he cannot observe the flap constantly and, according to Murphy's law, most problems will arise in the middle of the night. It must respond rapidly to circulatory change, be capable of prolonged constant monitoring and indicate when the circulation is compromised, whether the problem is primarily arterial or venous. A variety of possible methods were considered. Clinical tests consisting of observation of flap colour, capillary refill and bleeding characteristics are all objective and inaccurate, although if there were a means of measuring subtle colour change this may be useful. Injection of intravital dyes and radio-isotope clearance studies give a measurement at one particular instant only. Of the available instrumental methods, skin temperature measurement is capricious, but cheap and apparently simple; it was not possible to produce any meaningful data from a photoplethysmograph in the rat model and others had found transcutaneous gas measurement unreliable *(6)*. The electromagnetic flowmeter is not dependable when used with very small vessels except under minutely controlled conditions, and percutaneous use of the ultrasound Doppler postoperatively is inappropriate since it is impossible to know with certainty whether it is correctly positioned over the flap pedicle. Three methods warranted further investigation: interstitial fluid pressure measurement, differential thermometry and reflection spectrophotometry. It was impossible to leave monitors permanently attached to a rat, so the animal was re-anaesthetised each time a measurement was taken.

Interstitial fluid pressure (IFP) should be governed by Starling's forces, so that if osmotic forces are constant, in a specific tissue, an obstructed venous drainage would cause a rise in capillary hydrostatic pressure which in turn would lead to an increased interstitial fluid pressure to maintain equilibrium and limit oedema. Conversely, a reduced arterial input should produce opposite changes. IFP is negative and small therefore difficult to measure. Several techniques have been used for subcutaneous pressure measurement, but in order to monitor free flaps it is necessary to measure intradermal pressures. A principle originally devised in Bergen, Norway, known as the 'wick in needle' technique

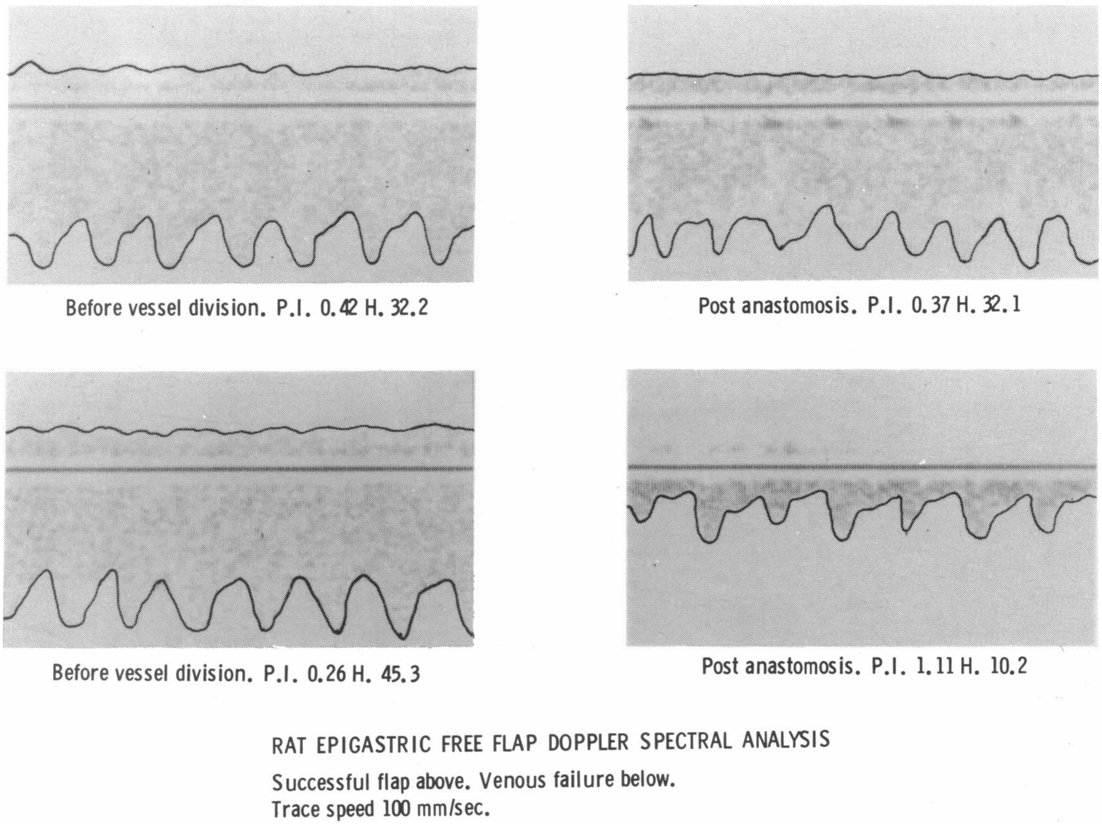

FIG. 5 Spectral analysis for free flaps before (left) and after (right) vessel anastomosis, successful flap above, venous failure below.

(7) was adapted for the purpose (Fig. 6). This entailed filing a sidehole 3 mm long, 5 mm from the end of a standard 27 gauge hypodermic needle, which was then filled with nylon fibres teased from fishing twine under the operating microscope. After connecting this to a pressure transducer, the

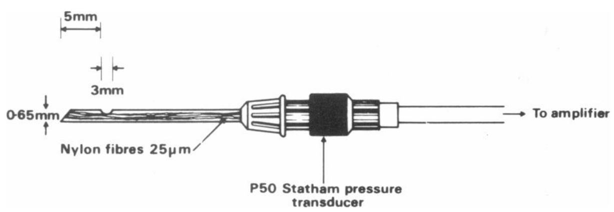

FIG. 6 'Wick in needle' technique.

whole system was filled with saline, great care being taken to exclude any air *(8)*. The presence of only one connection reduced the risk of pressure leakage. To validate the system, it was fixed between the leaves of a folded sheet of filter paper soaked in saline with its end dipping into a dish of saline. The pressure recorded by the needle should equal atmospheric less its measured height above the surface of the saline. In fact, the recorded pressures overestimated the measured height by a factor of 4–12%, but were repeatable. This is due to evaporation from the filter paper, and can be prevented by repeating the experiment in an atmosphere of 100% humidity. To estimate intradermal interstitial fluid pressure in the rat epigastric flap, having calibrated the equipment, it was inserted into the skin one hour after operation in four groups of animals. A mean pressure of −1.71 mmHg was obtained from fifteen readings in 3 animals' normal epigastrium. In fifteen epigastric flaps with a normal circulation, the mean pressure was −2 mmHg. There is no statistical difference between these groups, and the values are similar to those published for subcutaneous pressure *(7)*, so simply raising a flap and resuturing it did not affect the pressure. Nine flaps with an occluded venous drainage recorded a mean pressure of −4.37 mmHg and nine with obstructed arterial inflow −5.73 mmHg. A reduced pressure had been expected in the arterial group, but the reduction after venous occlusion also was the opposite of our predictions. Other investigators studying subcutaneous pressures in the rat hind limb noted that while arterial obstruction produced a fall in pressure to −4 mmHg after one hour, positive values did not occur in response to increasing venous pressure for twenty four hours and unless the venous pressure was greater than 12 mmHg with obvious oedema *(7)*. This seemed to be due to fluid and protein compartment shifts and increased lymph flow. An attempt was made to explain this apparently anomalous result of venous occlusion by measuring protein, red cell, and fluid shifts under varying flow conditions with radiolabelled isotopes. It was not possible to draw definite conclusions, but shifts of all three do occur from the intravascular to the extravascular space when the venous drainage of a flap is occluded. These changes will certainly affect tissue oncotic pressure, and so indirectly interstitial fluid pressure and may account for our results. Certainly the physiological changes which occur in a congested flap are far more complex than is often assumed. When monitoring flaps for prolonged periods with this system, problems with blockage of the needle were encountered which could not be overcome and, in view of these two difficulties it was not pursued further.

Differential thermometry Many inaccuracies of cutaneous thermometry may be eliminated by comparing the skin under test with a control area, so reducing the effects of changing ambient and physiological conditions. The flap's absolute temperature is irrelevant for monitoring, so an instrument was designed to indicate only the difference in temperature between flap and control skin. This we termed a *differential thermometer*. It consisted simply of two copper constantan thermocouple junctions connected to a high resistance chart recorder. One was attached to the centre of the flap and the other to a geometrically similar point on the opposite side of the animal's abdomen *(9)*. Accuracy was within 0.2 °C temperature difference. When continuous recordings were made in ten animals during the free flap procedure, it appeared that conduction of heat from the deep tissues had great influence on flap temperature as it fell rapidly when the flap was raised, and increased again when it was replaced. Occluding and restoring the circulation produced little change. Consequently, in subsequent flaps the temperature was measured at the end of the procedure and on the following day only. In the early postoperative period it was not possible to distinguish between success and failure, all the flaps being cooler than control skin (Fig. 7). Twenty four hours later the successful flaps had become relatively warmer, while the failures remained cool. This difference is highly significant statistically, but the thermometer could not discern arterial from venous failures. When either artery or vein was temporarily occluded, differential temperature changes were small and inconsistent indicating that although the differential thermometer could determine whether or not a flap would survive 24 hours after operation, its response to circulatory change was too slow to make it of practical value. However, it may have a place in monitoring transplanted or replanted digits since there is no heat conduction from underlying muscles.

Reflection spectrophotometry Observation of skin colour is the most frequently used clinical sign to assess flap circulation, becoming paler with reduced arterial input and darker with venous congestion. Subjective assessment is difficult and liable to error, not least because there is great variation in the colour of healthy flaps depending on their donor site. Reflection spectrophotometry is a technique for measuring colour change which has been investigated to monitor the treatment of haemangiomas *(10)*. The principle is that light of specific wavelengths is directed at the skin where a portion is absorbed, and the remainder reflected back. This is detected by a photocell. The amount of light absorbed depends on its wavelength and the amount of oxygenated and reduced haemoglobin present in the dermis.

It is known that human and rat skin have similar light absorbing properties between wavelengths 460 and 660 nanometres *(11)*, so initially the percentage of incident light which was reflected at each of eleven wavelengths was measured at 20 nm intervals in this range *(12)*. This technique was time consuming, because calibration of the machine was necessary at each wavelength for each measurement, but after statistical analysis comparing readings before and after operation for twenty free flaps, three wavelengths emerged as being most useful in distinguishing success from failure: 500, 560 and 640 nanometres. Immediately after operation, both successful and failing flaps had reduced reflectance compared to their preoperative reading and there was considerable overlap (Fig. 8). Twenty four hours later, the successful flaps had an increased reflectance, those with arterial failure a reduced value, but little changed from the immediate postoperative readings, and those with venous occlusion a greatly reduced reading.

Statistically, success could be distinguished from arterial or venous failure, which in turn could be distinguished from each other with a high degree of confidence. Paired testing showed that an increasing reflectance reading over this twenty four hour period always indicated a successful flap, a slight reduction or no change indicated arterial occlusion and a marked reduction, venous occlusion. These findings were confirmed by reflectance measurements taken at two hourly intervals after a free flap in the rat, which approximated to continuous monitoring. The instrument responded very quickly to circulatory change; this was demonstrated by producing temporary occlusion of either artery or vein supplying an island flap and measuring reflectance change. Arterial occlusion resulted in an immediate increase in reflectance, the reverse occurring with venous obstruction.

SUMMARY OF EXPERIMENTAL RESULTS

The ultrasound Doppler flowmeter reliably predicted the outcome of free flaps at operation when both arterial and venous anastomoses were tested. There were no late failures, indicating that flow through anastomoses in healthy 1 mm diameter vessels is an all or none phenomenon, so that if they are proved patent with the Doppler at operation, they will remain so.

Since blood flow to a clinical free tissue transfer may be reduced by central physiological changes or by compression

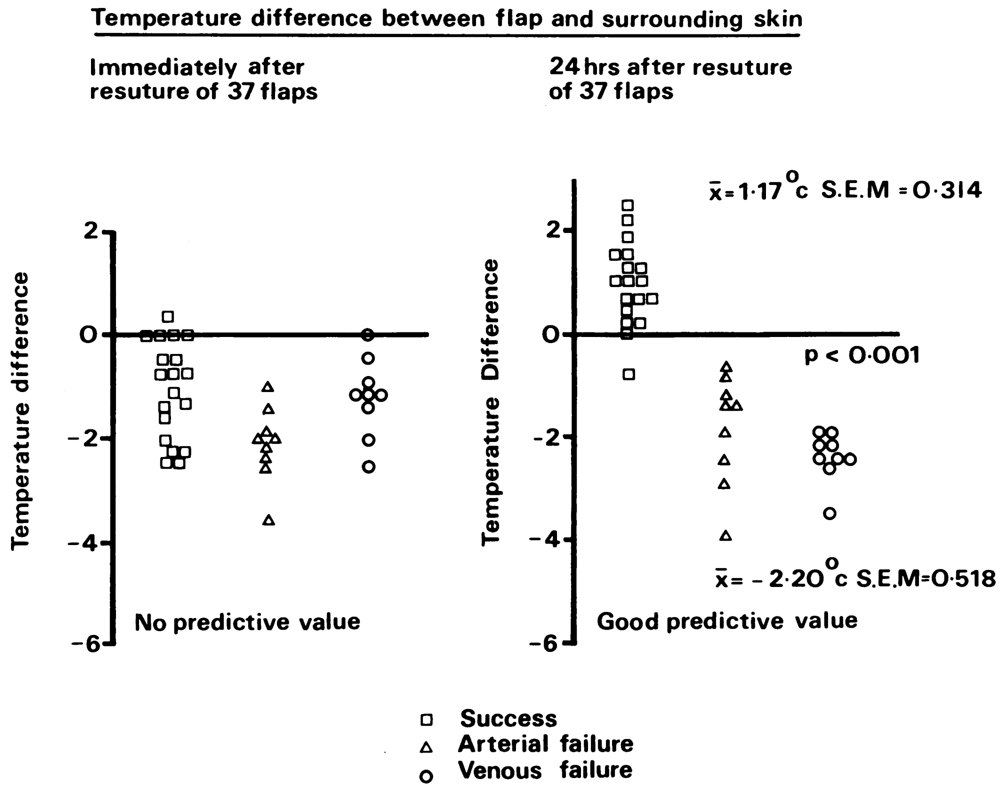

FIG. 7 Temperature difference between free flap and control skin (T) immediately after operation (left) and 16–24 hours later (right).

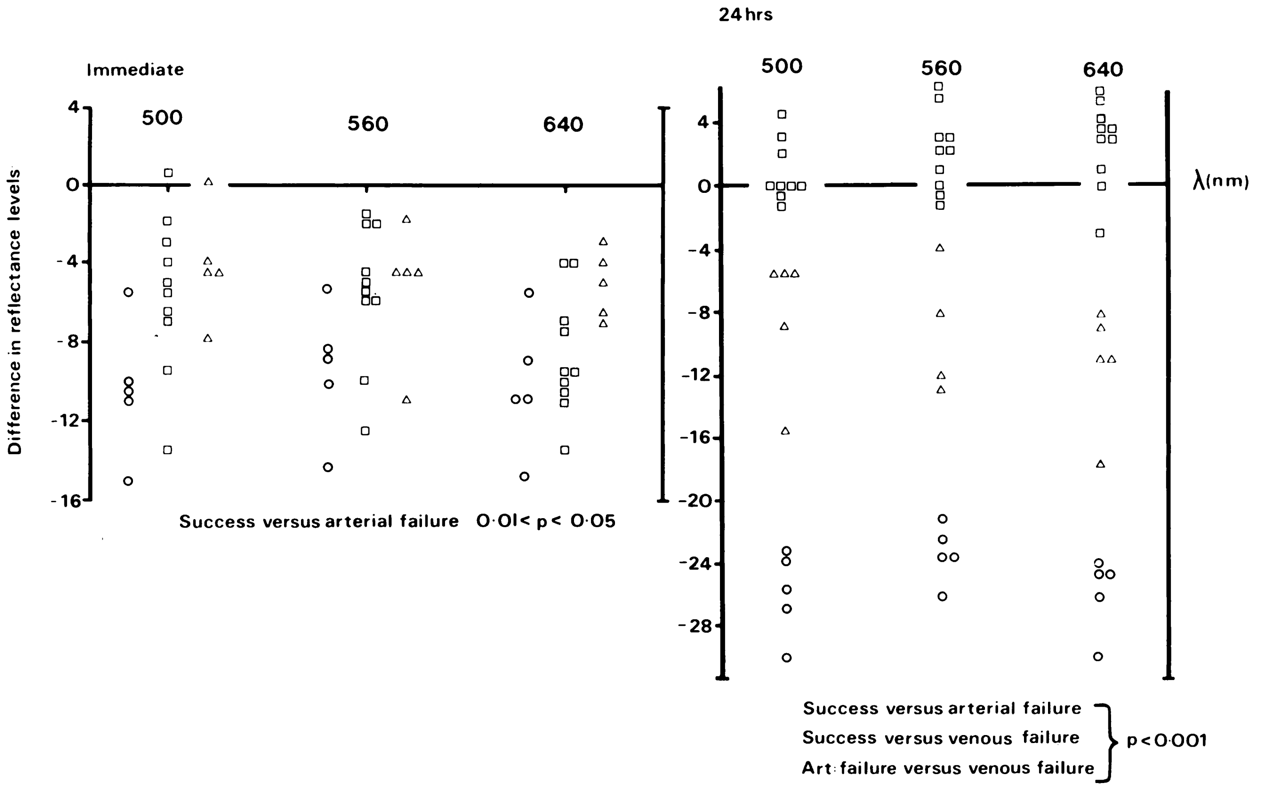

FIG. 8 Difference in pre and postoperative reflectance levels for free flaps at wavelengths 500 nm, 560 nm and 640 nm. Immediately after operation (left) and 16–24 hours later (right). □ Successful flap, △ Arterial failure, ○ Venous failure.

of its pedicle, a postoperative monitor is necessary. Of the methods tested, spectral reflectance measurement was the only one which achieved the dual aims of responding rapidly to circulatory change and indicating whether an inadequate circulation was primarily due to arterial or venous occlusion.

Clinical study

Unfortunately, the spectrophotometer used in the experimental work was unsuitable for clinical use. A system for clinical application was designed but not pursued because a new photoelectric capillary flow detector which offered a theoretical advantage over spectrophotometry by giving a dynamic assessment of flow became available. This was the laser Doppler flowmeter. Earlier designs had been unsuitable for clinical use because of their size and interference laser noise rendering measurements inaccurate *(13)*. These difficulties had been overcome by a combination of fibre optic technology and a novel amplification system producing a compact, sensitive, easily applied unit *(14)*. A good correlation had been shown between this and Xenon clearance methods for measuring capillary flow in the human forearm *(15)*, which suggested that it would be appropriate to use clinically as a flap monitor. The principle is identical to ultrasound Doppler flowmetry, but uses light instead of sound. Red helium neon laser light is directed at the skin by fibre optic guides. Since by definition this is of a single discrete wavelength, when it strikes moving red cells its frequency will be shifted by an amount proportional to their velocity, according to the Doppler principle. The reflected frequency shifted light is then transmitted to photodetectors, whose output is related to the red cell flux.

Applying experience gained from the experimental study to clinical free tissue transfers a 10 megahertz truly directional ultrasound Doppler flowmeter was used to evaluate flow at operation together with a laser Doppler flowmeter afterwards. Arterial and venous anastomoses were assessed with the ultrasound Doppler approximately ten minutes after the occluding vascular clamps had been removed. Arteries were insonated both proximal and distal to the anastomosis, and the instrument indicated whether the direction of flow was correct. Having noted whether the arterial waveform was of a low or high resistance type, the venous flow augmentation test was applied. A low resistance arterial waveform and a positive venous test indicates satisfactory flow; absent arterial flow with a positive venous test indicates an inadequate arterial anastomosis requiring revision; a high resistance arterial pattern with a negative venous test indicates that the venous anastomosis should be revised; a damped arterial waveform in combination with a positive venous test indicates that although the venous anastomosis is patent, drainage is inadequate. This may be due to a proximal obstruction or spasm in the recipient vein, or to having selected too small a vein. In either case, it is necessary to anastomose an additional or alternative vein to the flap. The same criteria were applied to localise the cause of inadequate flow when re-exploring a compromised flap.

At the end of each operation, either in the recovery room or on the ward, the laser Doppler light guide was attached to the centre of the flap with a plastic holder and adhesive ring *(16)*. Continuous flow recordings were facilitated by a chart recorder and a digital voltmeter provided a numerical display of the laser output which greatly simplified nursing observations.

As the instrument is not calibrated for absolute flow the readings are expressed as a percentage of a standard 10 volt calibration deflection. Fig. 9 shows traces from six successful free flaps of various types which are representative of satisfactory capillary flow. Although the instrument's output varies from one to the next, the general trend is of increasing values, and so presumably flow velocity during the early post operative period which then stabilises. Dips do occur, but they are not sustained or prolonged. The ultrasound Doppler had indicated good flow at operation in each of these cases. A contrasting picture is provided by two flaps which failed because of venous obstruction (Fig. 10). In the upper trace the laser output fell steadily very soon after surgery. The flap was for venous ulceration in the lower leg of a young man who had suffered multiple deep and superficial venous

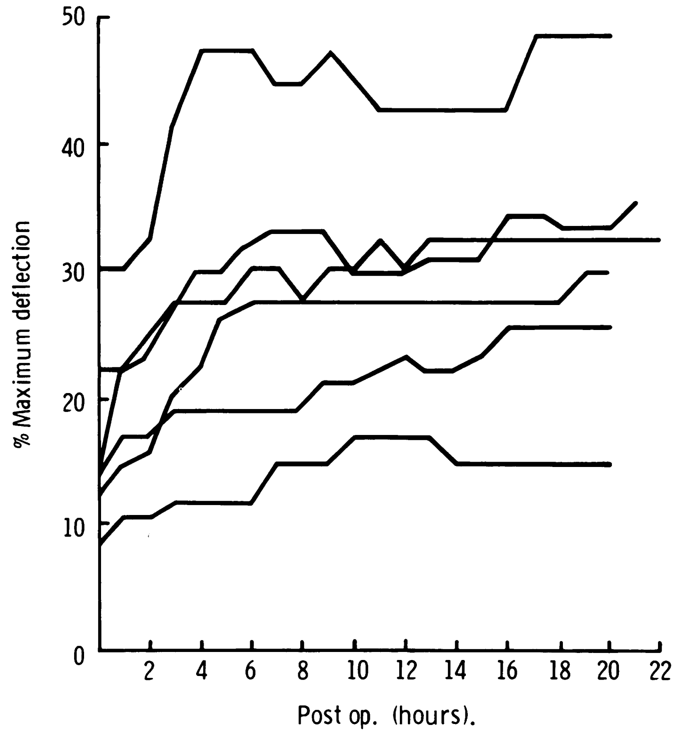

FIG. 9 Laser Doppler (LDV) traces for 6 successful free flaps.

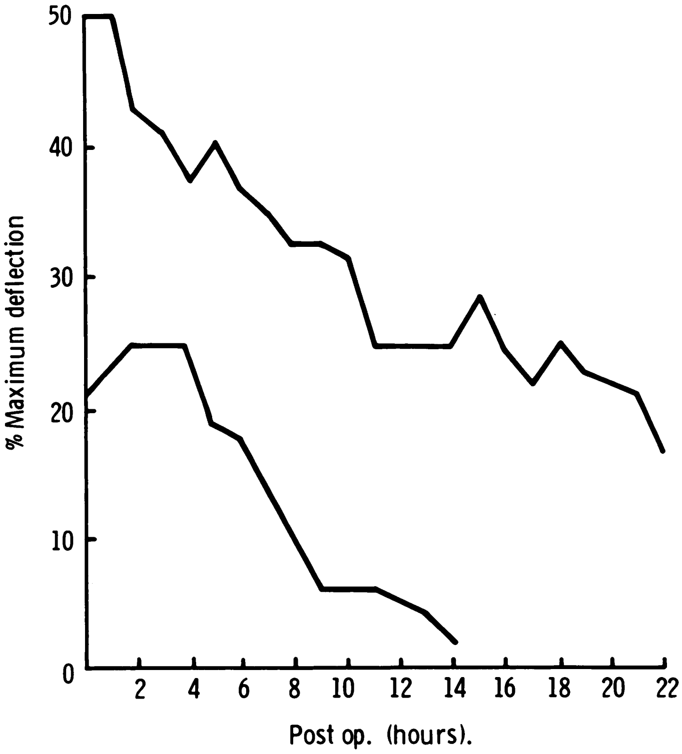

FIG. 10 LDV traces for free flaps with venous occlusion.

thromboses in the past. The peroperative ultrasound Doppler tests indicated patent anastomoses, but a high resistance to arterial flow, suggesting inadequate venous drainage proximally. Because of his past history, no alternative recipient veins were available, so we were obliged to hope that the tests would be proved wrong. Unfortunately, they were not.

The lower trace shows an initial rise in laser output followed by a rapid and sustained fall after four hours. This procedure had finished late in the evening and although flow had been adequate at operation, clearly some obstruction occurred in the recovery room. This occurred early in our experience when the nursing staff were instructed to undertake and act upon their usual clinical observation only, since we were not confident of the significance of the instrument's readings. It was not possible to salvage the flap at re-exploration after fourteen hours.

Readings from a latissimus dorsi flap to a forearm defect showed a marked reduction after a stable thirty hour period, the ultrasound Doppler criteria having been satisfied at operation. Since the defect was circumferential, when the flap became oedematous postoperatively, as all myocutaneous flaps do, a tourniquet effect was produced resulting in compression of the pedicle. We removed skin sutures which overlay the pedicle and an immediate seven fold increase in flow resulted, which was maintained after a small initial decrease.

In a latissimus dorsi free flap transferred to the lower leg in a 64 year old man, the ultrasound Doppler tests indicated satisfactory flow at operation. Postoperatively, the laser Doppler readings fell sharply, although they then remained reasonably stable until ten hours after operation, when a second fall occurred (Fig. 11). At this point we re-explored the flap surgically. At the second operation the ultrasound Doppler indicated that both anastomoses were patent, but a damped arterial waveform suggested inadequate run off in the long saphenous vein which had been chosen as the recipient. Why this should have occurred is not clear, but it may have been due to spasm. Flow improved when an additional deep vein was anatomosed to the flap pedicle, the laser readings were increased postoperatively, and the flap survived.

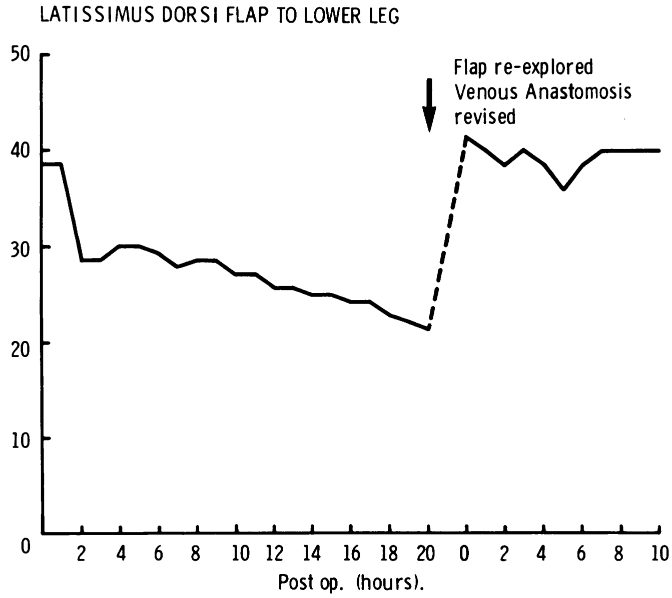

FIG. 11 LDV trace from free flap re-explored surgically after 20 hours.

Discussion

In view of its cost, further investigation is necessary before investment in a laser Doppler flowmeter can be generally recommended. However, this experience suggests that a decreasing output sustained over a two hour period indicates circulatory compromise requiring intervention. Work is proceeding to determine whether it can be applied to flaps without a cutaneous surface and to further define the results of arterial and venous occlusion.

The first fifteen free flaps carried out by the Author included patients ranging in age from 3 to 78 years. As a result of information provided by the ultrasound Doppler, one arterial and one venous anastomosis was revised at the primary operation, a revision rate of 13%.

Two flaps failed. The first, a dorsalis pedis flap to the floor of the mouth in a 65 year old man. Ultrasound Doppler flowmetry indicated satisfactory flow at operation and all was well for fourteen days. At this time his nasogastric tube was replaced. The following morning the flap was noted to be deeply cyanosed and at re-exploration a large haematoma was found in the neck as a result of a ruptured venous anastomosis. Flow was restored temporarily, but could not be maintained. The second was a free jejunal patch transfer to the pharynx in a very unfit, cirrhotic, alcoholic 54 year old woman. The intraoperative tests indicated that venous drainage was inadequate despite patent anastomoses, but concern over her general condition truncated the operation and prevented further revision. When this was attempted eight hours later, the jejunum was obviously congested and cyanosed, and again flow was restored for a period, but could not be maintained.

Two flaps were re-explored with a successful outcome. Both were latissimus dorsi myocutaneous free flaps to the lower leg and in each case the revision was prompted by the laser Doppler. Traces from a 64 year old man whose long saphenous vein was an inadequate recipient are shown in Fig. 10. The problem was solved by anastomosing an additional deep vein to the flap. The second, a young man with a land mine injury to his lower leg and foot thrombosed his recipient vein because of compression resulting from oedema of the flap. Flow was restored by excision and re-anastomosis to an alternative vein and tension was relieved by a skin graft over the pedicle.

As with any other technique a learning curve is involved in the acquisition of microsurgical skills and certainly no surgeon should undertake clinical reconstructions with their variable and complex problems until he can reliably anastomose small vessels in animals. The number of complications in this small series is high and it must be said that some of them could have been avoided by more careful flap design. But it represents the initial work of an inexperienced clinical reconstructive microsurgeon and is not dissimilar from that described by others *(2)*. By using objective tests of blood flow, an acceptable overall success rate of 87% was achieved. Without them five more flaps may have been lost, reducing this to an unacceptable 54%.

Two of the world's most respected microvascular surgeons Don Serafin and Harry Buncke have stated that partial occlusion of an arterial microanastomosis does not occur; that is to say, it either functions fully or not at all *(2, 17)*. Rollin Daniel, who performed the first clinical free flap, comments that most vascular complications are postoperative confirmations of intraoperative suspicions; they should be recognised and corrected at the time, not six to twelve hours later *(18)*. Buncke has also confirmed that although a flap threatened by an inadequate circulation may be saved by re-exploration, the success of such a procedure is inversely related to the time lapse between the suspicion of vascular insufficiency and surgery *(17)*. Great advances have been made in the field of microvascular reconstruction since the days of Jacobson and Suarez in the early 1960's, but in these times of increasing accountability and surgical audit, it is vital that we monitor our work closely and objectively. By using an ultrasound Doppler flowmeter at operation the surgeon can be quite certain that his reconstruction is functioning adequately and will continue to function in the absence of a generalised low perfusion state or compression of the vascular pedicle. Should either of these occur, a laser Doppler flowmeter used continuously during the early post-operative period will detect it quickly enough to enable him to intervene and salvage the jeopardised flap.

Christian Johann Doppler first described the frequency shift which bears his name in relation to the movements of stars and planets; application of the same principle to the contemporary technologies of ultrasound and laser light has provided us with instruments to objectively assess the function of free tissue transfers and assist us in our aim of achieving 100% success in microvascular reconstructions.

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