THE MICROSURGICAL REVASCULARISATION OF RESECTED SEGMENTS OF TIBIA IN THE DOG

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A segment of tibia 4.5 centimetres long was removed from one hind limb of fifteen dogs. It was then replaced and the main vasculature was restored by a microsurgical technique. In eight controls the segment was replaced without such restoration. In two-thirds of the former cases the microvascular reconstruction was successful; the rate of infection was found to be reduced, bone union was guaranteed and the rate of union accelerated. Success or failure of the reconstruction was clearly demonstrated in five cases by early bone scanning using technetium-labelled polyphosphate.

Cortico-cancellous bone grafts have a wide application in reconstructive orthopaedic surgery. The success of all standard procedures is totally dependent on slow revascularisation of the graft from the bone ends and soft tissues, followed by slow resorption of the old bone within the existing framework and its replacement with new Haversian systems. The risks of failure are considerable because of infection and loss of fixation, and the new bone formation takes at least three to six months and often longer.

Pedicle bone grafts have been widely employed (Davis 1954; Davis, Fagan and Beals 1971). McCulough and Fredrickson (1973) and Östrup and Fredrickson (1974) have successfully performed microvascular free transfers of the posterior part of the ninth rib for mandibular defects in dogs. McKee (1975) carried out much experimental work on microvascular bone grafts in the late sixties and in 1970 started to correct mandibular deficiencies by using those parts of the sixth and seventh ribs whose blood supply is provided by the internal mammary vessels and their anterior intercostal branches. A large amount of soft tissue was sometimes carried with the rib in order to correct a contour defect of the neck after radical block dissection. Vascularised rib grafts were also transferred for non-union of the tibia. Taylor, Miller and Ham (1975) have used a vascularised fibula to bridge a traumatic defect of the tibia in two cases, one being successful.

This study was undertaken to assess the rate of success of microsurgical revascularisation of a segment of tibia in the dog. Altogether sixteen dogs were used. In fifteen of them a segment about a third of the overall length was completely removed on one side and replaced in the same site; the nutrient vessels were then repaired by microvascular anastomosis. In eight more limbs the fragments were replaced without restoration of the circulation.

OPERATIVE TECHNIQUE

Medium-sized dogs were anaesthetised with intravenous Nembutal. The skin of one hind limb was shaved and prepared with iodine under strict asepsis. An incision was made extending from the head of the fibula along the lateral border of the tibial tubercle and down the subcutaneous border of the tibia to the point of crossing of the saphenous vein. The tibialis cranialis muscle (tibialis anterior in man) was detached from its origin proximally and the exposure was improved by division of the tendon of extensor digitorum longus. The whole muscle mass was then reflected laterally and held there by stay sutures.

The cranial tibial artery and vein were exposed lying on the extensor digitorum longus. In 80 per cent of cases these vessels gave origin to the nutrient vessels at the level of the tibial tubercle. This ratio contrasts with the statement made by Miller, Christenson and Evans (1964) that the nutrient artery arises from the caudal tibial artery. The diameters of the vessels were of the order of 1.0 to 1.25 millimetres. In the remaining 20 per cent the nutrient artery arose from the caudal tibial artery behind the tibia, running behind the bone on the deep surface of the flexor hallucis longus muscle and accompanied by the nutrient vein, which always drained into the vein running with the cranial tibial artery. Under the microscope, these vessels were carefully dissected from the deep surface of flexor hallucis longus.

When the nutrient artery arose from the cranial tibial artery, all the branches of this artery and the tributaries of the accompanying veins were coagulated, apart from the most proximal muscular branches which were preserved. The continuation of the artery beyond the nutrient branch, and the larger venous channel distal to the point of entry of the nutrient vein, were divided between ligatures. This latter manoeuvre did not seriously jeopardise the nutrition of the muscle mass as there was sufficient collateral circulation.

In the 20 per cent of cases with a long nutrient artery arising from the caudal tibial artery, the veins were dealt with in identical fashion, but the branches of the cranial tibial artery were left undisturbed except for one of the same diameter as the nutrient artery which was dissected free to act as a donor vessel for restoration of the circulation.

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Anastomosed cranial tibial vessels immediately after removal of the clamps, showing good filling. The Bagby compression plate is also shown.

A six-hole Bagby direct compression plate was then bent to fit the lateral surface of the tibia. Drill holes were made so as to facilitate good fixation with compression. With careful protection of the nutrient vessels, a 4.5 centimetre segment of bone and periosteum, centred 2 centimetres below their point of entry, was removed by a hand saw. Freeing of this segment on its vascular pedicle entailed careful detachment of the origin of tibialis anterior. Intramedullary circulation was shown by free bleeding from the cut ends of the segment. Soft clamps were placed on the vascular pedicle, which was then divided to sometimes hindered the technique of anastomosis. The time of ischaemia ranged from one and a quarter to one and three quarters of an hour.

Restoration of the circulation was confirmed by a pulsatile flow in the drill hole previously made in the segment. Once haemostasis had been achieved, the muscle mass was reattached to its tibial origin and the tendon of extensor digitorum longus repaired. After closure a radiograph was taken and the limb immobilised in a padded plaster. From thigh to just above the paw with the knee in flexion, until wound healing was complete. All the dogs received one vial of Bicillin daily for five days after operation.

The dogs were permitted to bear weight and nearly all of them placed the foot on the ground; if they did not do so this was a sign of developing infection. In the absence of sepsis wound healing was rapid and took about a week. It was possible to note this time because the cast required changing frequently as it very easily became wet. A control operation on the opposite leg was performed only in cases of primary healing and a month after the first operation, when the hind limb was out of plaster.

Radiological assessment of bone union was made at two, six, twelve and sixteen weeks. At three to four months the bone was explored, and if union had occurred the plate was removed. A central biopsy of the graft was taken and a corresponding specimen removed from the adjacent shaft. The wound was loosely closed and an angiogram performed via the femoral artery. At the completion of the experiment all anastomoses were examined directly. The tibiae were recovered, denuded of soft tissue, radiographed and photographed.

In the latter part of the experiment bone scans were performed with a gamma camera. The technique involved the intravenous injection of 5 millicuries of technetium-labelled polyphosphate two hours beforehand. This permitted early assessment of the patency of the anastomoses and allowed an accurate evaluation of the vascular status of the graft up to the time of exploration.

**RESULTS**

In ten of the fifteen experiments the anastomosis was patent at the time of exploration three to four months after operation. The probable reason for the five failures was thrombosis related to poor anastomotic technique due to difficult access for suture.

<table>
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<tr>
<th>Group</th>
<th>At 6 weeks</th>
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<th>At 12 weeks</th>
<th></th>
<th>At 16 weeks</th>
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<tr>
<td></td>
<td>Proximal</td>
<td>Distal</td>
<td>Proximal</td>
<td>Distal</td>
<td>Proximal</td>
<td>Distal</td>
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<tr>
<td>Patent anastomoses (10)</td>
<td>4</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Failed anastomoses (5)</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Controls (8)</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
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At three months 95 per cent of the successfully revascularised bone grafts had united clinically and radiologically, the only site of delayed union being related to poor fixation proximally (Table I). This compared with a rate of only 50 per cent in the failed microvascular group and 31 per cent in the controls. At four months the incidence of bone union in the three respective groups had increased to 100, 80 and 56 per cent. The appearance of a control leg at three months made a striking contrast with the appearance of a successfully revascularised bone segment at five months,
even allowing for the difference in time from operation (Figs 2 and 3).

Infection from soiling was common and was mainly due to coliform bacilli. All the infections could be regarded as deep, and those grafts certainly liable to sequestrate. In two cases the plate was exposed and remained so until the dogs were killed. Of limbs with patent anastomoses 20 per cent had infection, compared with 80 per cent of those with failed anastomoses and 75 per cent in the controls (Table II).

All biopsy specimens were examined histologically by standard techniques. The number of lacunae filled with viable osteocytes was counted in a representative field and expressed as a percentage. In all cases the adjacent 'normal' bone had at least 76 per cent of the lacunae filled with viable osteocytes, compared with 55 per cent in successful grafts (Table III). However, the range in the results was individually wide and did not give an accurate indication of successful or failed revascularisation.

Table II. Incidence of infection

<table>
<thead>
<tr>
<th>Group</th>
<th>Numbers</th>
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<tr>
<td>Patent anastomoses (10)</td>
<td>2 (20 per cent)</td>
</tr>
<tr>
<td>Failed anastomoses (5)</td>
<td>4 (80 per cent)</td>
</tr>
<tr>
<td>Controls (8)</td>
<td>6 (75 per cent)</td>
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Angiography was unsatisfactory in demonstrating a patent vessel. In part this was due to the number of vessels which seemed to mask the nutrient artery, together with the short distance between the nutrient foramen and the site of anastomosis. However, in isolated cases a patent vessel was well demonstrated at three months (Fig. 4).

Bone scanning was employed for the evaluation of early revascularisation of the graft in the last five cases of
microvascular repair, and accurately differentiated between success in two and failure in three. In a successful case a marked increase in blood supply could be readily seen in both the adjacent normal bone and in the segment (Fig. 5), in contrast with the obvious "cold" defect in the case of a failed anastomosis (Fig. 6). Later scans demonstrated abundant "irritation" callus helping to splint the avascular segment of a failed graft, in marked contrast with the appearance in a successful case.

Table III. Histopathological assessment of viability of the graft

<table>
<thead>
<tr>
<th>Group</th>
<th>Numbers biopsed at 12 weeks</th>
<th>Percentage of lacunae filled with viable osteocytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patent anastomoses (10)</td>
<td>7</td>
<td>55</td>
</tr>
<tr>
<td>Failed anastomoses (5)</td>
<td>3</td>
<td>28</td>
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<tr>
<td>Controls (8)</td>
<td>5</td>
<td>5</td>
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<tr>
<td>Infected cases (6)</td>
<td>4</td>
<td>2.5</td>
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DISCUSSION

These experiments on dogs demonstrated that a 4.5 centimetre segment of tibia could be removed, replaced, and, in two-thirds of the cases, successfully revascularised through its nutrient vessels using microsurgical techniques. Viability of the graft was easily and accurately demonstrated by bone scanning after the injection of a small quantity of isotope with a rapid rate of decay. The risk of infection was greatly reduced in those cases where the circulation had been successfully restored; bone union was guaranteed and the rate of union accelerated. One technical problem was a tendency to loss of fixation in the cancellous bone of the proximal tibia; this might have been avoided by the use of cancellous bone screws.

The experiments suggest that microsurgical techniques can be adopted clinically to restore the vascularity of grafts from bones such as the fibula and rib, with a success rate probably greater than 80 per cent, as the diameters of the peroneal vessels and the posterior intercostal vessels in man are 1.5 to 2.0 millimetres compared with 1 to 1.25 millimetres for the tibial craniais vessels in the dog. It is envisaged that vasculised large bone grafts will come to be employed in many of those areas where avascular allografts have been used, for example, congenital pseudarthrosis of the tibia, thereby enhancing the rate of bone union and reducing the period of convalescence.

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REFERENCES


