BONE CHANGES IN THE VASCULARISED FIBULAR GRAFT

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We report a retrospective review of 62 consecutive patients who had a vascularised fibular transfer to reconstruct a large skeletal defect. We were particularly interested in the bone dynamics of the vascularised graft, since fractures occurred in 25% of the cases at an average time of eight months after surgery.

Hypertrophy was more common when the limb was mechanically loaded; it was enhanced where the graft was not bypassed by internal fixation. The length of the graft and the use of additional bone graft material had no influence on the incidence of stress fracture or on hypertrophy.

We conclude that a vascularised graft should be protected against fatigue fracture during the first year, and that a gradual increase in mechanical loading will enhance remodelling and hypertrophy.

Reconstruction of large skeletal deficiencies presents a challenging problem to the orthopaedic surgeon; methods have evolved significantly during the past decades (de Boer 1988). Several studies have demonstrated the clinical usefulness of autogenous cortical bone and allograft reconstruction, but resorption of bone and fractures of the graft are possible complications (Enneking, Eady and Burchardt 1980; Mankin, Doppelt and Tomford 1983; Mnaaymneh et al. 1985).

Vascularised bone grafts, by virtue of more rapid healing and hypertrophy, may tolerate mechanical loading better and reduce the incidence of resorption and stress fracture. Although several clinical studies have shown the usefulness of vascularised grafts with regard to union and resistance to infection (Weiland, Moore and Daniel 1983; Wood, Cooney and Irons 1985; Jupiter, Bour and May 1987), we have found no studies of bone dynamics in vascularised grafts.

We have reviewed our experience with 62 consecutive patients who had such grafts and have been followed up for a minimum of one year with particular reference to the incidence of stress fracture and graft hypertrophy.

PATIENTS AND METHODS

We made a retrospective study of 62 consecutive patients who had a vascularised fibular transfer for the reconstruction of a skeletal defect at the Mayo Clinic between 1979 and 1985. Patients had radiographs taken at operation, six weeks after operation and then at three, six, nine, 12, 18 and 24 months and finally at their latest follow-up attendance. The diameter of the graft was measured in each of these films. Only radiographs taken within a month of the planned times were evaluated. No hypertrophy was assumed if radiographs were not available at the time (two cases at 12 months; 10 cases at 24 months).

Radiological magnification. To exclude error due to radiological magnification we determined the graft and recipient bone diameters as shown in Figure 1, providing an index which was used to calculate the percentage hypertrophy at different intervals.

Variation in projection. The fibular graft is triangular in section, so radiography at different angles can give a false impression of hypertrophy. We studied 10 cadaver fibulae to demonstrate this variation. Each fibula was mounted in a lathe and rotated through 10° intervals over 180°. The diameter at various points along the length of the fibula was measured and recorded in tenths of a millimetre using a caliper. From these data the maximum percentage increase in diameter over all angles was determined with the fibula rotated 10° to either side; an apparent increase in diameter of the fibula of as much as 20% was shown. Therefore, for the purposes of our study, the graft was said to have hypertrophied only if the graft index increased by more than 20%.
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Mode of hypertrophy. The type of hypertrophy was determined from the radiographs. This was termed periosteal if the increase in diameter was due to irregular bone formation 'around' the graft (Figs 2 and 3). If the cortex and medullary canal had increased in diameter, we called this endosteal hypertrophy (Figs 4 and 5). Lastly, a combination of periosteal and endosteal hypertrophy could occur.

Graft stress fractures. A fracture line in the graft or localised periosteal callus formation indicated a stress fracture. The location, the time of occurrence after surgery and coincidental clinical signs were recorded.

The incidence of stress fracture and the degree of hypertrophy were analysed in relation to the age of the patient, and the location and length of the graft. The influence of additional bone graft and of internal fixation by intramedullary nail or metal plate bypassing the graft were also evaluated.

We were particularly interested in those cases in which we were reasonably sure that the graft was truly vascularised. Bos (1979) and Berggren, Weiland and Østrup (1982) have demonstrated that a positive bone scan in the first postoperative week is evidence of sustained patency of the vascular anastomoses. Therefore we analysed only those 35 patients with vascular anastomoses who had a positive bone scan in the first

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\text{% Hypertrophy} = \frac{\text{index}^2 - \text{index}^1}{\text{index}^1} \times 100
\]

Fig. 1

To show the method calculating the amount of hypertrophy. \(A^1\), diameter of recipient bone and \(B^1\), diameter of the graft soon after operation. \(A^2\), diameter of recipient bone and \(B^2\), diameter of the graft at follow-up.

Fig. 2

Fig. 3

An example of periosteal hypertrophy. Figure 2 - Six months postoperatively. Figure 3 - Two years postoperatively. The cortex of the graft can still be distinguished through the hypertrophy.

Fig. 4

Fig. 5

A combination of a vascularised graft and a conventional graft after surgery and two years later. Two years after surgery, the vascularised graft had reached a hypertrophy rate of 60%. After the intramedullary nail had been removed, and mechanical loading had been increased gradually, a hypertrophy of more than 100% was reached. The conventional fibular graft, used to give early stability, has almost completely resorbed, and shows multiple stress fractures.
postoperative week and five with a pedicle vascularised fibular transfer, in whom a bone scan was not done. We excluded eight patients with a negative or equivocal bone scan and 14 patients with a free graft, who had not had a bone scan.

We found evidence of fracture only after union or fixation of both graft junctions. Therefore, when we came to analyse the factors that may influence the incidence of stress fracture we included only those cases where both graft junctions had united, or had been stabilised with internal fixation. For this reason one patient with a tibial reconstruction was excluded.

RESULTS

The average follow-up was 2.5 years (range one to four years).

Stress fractures. In the 40 cases assessed, 10 fractures (25%) occurred at an average of eight months (three to 21 months) after surgery. Only one fracture occurred after nine months from surgery. A competitive wrestler fractured his reconstructed tibia 21 months postoperatively, even though the graft had already hypertrophied by 100%. All stress fractures were in the lower limb (Table I), but four of the 10 patients were asymptomatic, fracture occurring during mobilisation in a cast, and being recognised retrospectively on radiographs only after the fractures had united. Fractures can occur without symptoms because the graft pedicle carries no innervation and the graft is protected at the time of the fracture. Of the symptomatic fractures showing mobility at the fracture site, one healed within three months with cast immobilisation, and two are still being treated for non-union. Of three patients with stress fractures in femoral reconstructions, two had amputation for non-union and one had the graft replaced by a prosthesis.

Neither the length of the graft nor the use of additional graft had a significant influence on the incidence of stress fracture (Table II). There were more fractures in the younger patients, and significantly more in those in whom the graft was not internally fixed with an intermedullary nail or plate (p = 0.03, Table II).

Hypertrophy. The results are given in Table III.
Endosteal hypertrophy was significantly more common in patients with a positive bone scan \((p = 0.03)\). Hypertrophy in patients with a negative or equivocal scan was usually of the periosteal type (Table IV).

Hypertrophy of the graft was more common in the mechanically-loaded lower extremity (43% at 52 weeks). In the upper extremity reconstructions, only three patients \((20\%)\) showed hypertrophy of the graft at 52 weeks (two humeral and one radial). In the leg, hypertrophy was significantly better in the patients under the age of 20 both at six months \((p = 0.02)\) and at one year \((p = 0.01)\) after reconstruction. At two years there was no significant difference between the age groups (Table II).

In patients in whom the graft was not bypassed by internal fixation, hypertrophy was enhanced signifi-

Table IV. Relationship between type of hypertrophy and result of bone scan

<table>
<thead>
<tr>
<th>Bone Scan</th>
<th>Positive</th>
<th>Negative or equivocal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endosteal</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Periosteal</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Combination</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

In the seven patients whose grafts were bypassed with internal fixation consisting of a long plate or intermedullary nail, no hypertrophy was seen. The length of the graft or the use of additional bone graft material had no influence on the outcome of hypertrophy.

DISCUSSION

It is accepted that mechanical stimulus or stress loading on bone is a major factor in the maintenance of the normal balance between bone formation and resorption (Wolff 1892; Jansen 1920; Scott 1957; Basset 1962). An increase of mechanical load on long bones can produce an adaptive response in which bone formation outpaces resorption (Frost 1964; Heft, Přibylová and Lišková 1972; Lanyon and Baggott 1976; Tonino et al. 1976; Goodship, Lanyon and McFie 1979; Woo et al. 1981). Conversely, repetitive mechanical loading which exceeds the strength of bone, causes stress fracture (Devas and Sweetnam 1956; Jonsson and Eriksson 1984; Orava and Hulko 1984). The ability of a vascularised or non-vascularised bone graft to resist and adapt to repetitive mechanical loading depends upon both its strength and its viability (Haw, O'Brien and Kurata 1978; Arata, Wood and Cooney 1984; Weiland, Phillips and Randolph 1984; Shaffer et al. 1985).

Stress fracture. In our series there was an incidence of 25\%, all in the lower extremity and becoming evident an average of eight months after reconstruction. Only one fracture occurred more than nine months after surgery.

In their series of non-vascularised autogenous cortical grafts Enneking et al. (1980) found a 45\% (18 out of 40) incidence of stress fracture, occurring at an average of 21 months (range six to 39). In contrast to our findings, they found stress fractures in the upper extremity in two of their six patients, as against 16 fractures in the 34 patients with lower extremity reconstruction. They also found that the incidence of stress fracture increased in longer grafts: 62\% in grafts longer than 15 cm compared with 38\% in shorter grafts (Table V).

Again in contrast to Enneking et al. (1980) we did not see fractures in any graft protected by an intermedullary nail or by a plate (Tables II and V).

The main difference in the occurrence of stress fractures in vascularised and non-vascularised grafts, appears to be the period of their development. In the vascularised grafts they occurred in the early repair phase, at about six months after operation. In non-vascularised grafts they occurred much later at an average of 21 months. This is due to significant weakening of the non-vascularised graft during the two-year period required for the completion of internal repair (Enneking et al. 1980; Shaffer et al. 1985).

Another difference is that in our vascularised series no fractures were seen in the graft after upper extremity reconstruction, nor in any case where the graft was bypassed with internal fixation.

Hypertrophy. Enneking et al. (1980) found hypertrophy of the non-vascularised graft in 32\%, but this never exceeded a 20\% increase in the diameter of the graft. As we have discussed, a 20\% increase in fibular graft diameter may be more apparent than real, and due to variation in radiographic projections.

We found hypertrophy of the graft exceeding 20\% in
15 cases out of 40. This hypertrophy was more common in the mechanically-loaded lower extremity and was achieved earlier in younger patients and in grafts that were not internally fixed with an intermedullary nail or a metal plate.

Conclusions. We have shown that vascularised fibular grafts have a 25% incidence of stress fractures, which becomes a 40% incidence in the leg. We found definite hypertrophy in 38%, and in lower extremity reconstructions this was 43% at 12 months and 80% at 24 months. Hypertrophy was related to age and imposed stress loading.

We believe that a vascularised graft should be protected against fatigue fracture during the first year, but that mechanical loading should be gradually increased to enhance remodelling and hypertrophy.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES


