RECONSTRUCTION OF THE HUMERUS WITH AN INTRAMEDULLARY FIBULAR GRAFT

A CLINICAL AND BIOMECHANICAL STUDY

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Nine patients with nonunited humeral shaft fractures were treated by open reduction and internal fixation with an intramedullary fibular bone graft and a compression plate. Fixation of the screws was enhanced by passing them through the fibula as well as the two humeral cortices (quadricortical fixation). Eight of the nine fractures united at an average of 3.5 months.

Tests on cadaver bones showed that quadricortical fixation was as strong as methylmethacrylate augmentation and significantly better than bicortical fixation.

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Nonunion of a fracture of the humerus presents a difficult reconstructive problem because those factors which contributed to the development of nonunion may continue to act. They include obesity, bone loss and osteopenia. Torsional and shear forces at the fracture site make it difficult to achieve good immobilisation and the geometry of the humerus, particularly at its proximal and distal ends, limits the choice of implant.

A variety of operative techniques has been used including compression plates, intramedullary nails and external fixators, with or without bone grafts (Jupiter 1990; Rosen 1990; Epps and Grant 1991; Taylor 1992). The site of the nonunion may make stable intramedullary fixation difficult even with the use of locking screws. In some cases of nonunion exposure of the humerus is needed to correct angular or rotational deformity, to explore or repair the radial nerve, to remove a failed implant, or to apply a bone graft. In these instances plate fixation is often used. This relies on the purchase of the screws which varies with the quantity and quality of the bone (Ansell and Scales 1968; Schatzker, Sanderson and Murnaghan 1975; Trader, Johnson and Kalbfleisch 1979). Screw purchase can be enhanced by the use of nuts, cortical bone grafts, or by augmentation with bone cement, but these techniques all require very wide exposure and their use increases the risk of damage to the soft tissues and to the blood supply of the bone. We have used intramedullary fibular bone grafts to increase the bone available for purchase of the screw thread. In this paper we report our clinical experience and the results of some biomechanical tests.

MATERIALS AND METHODS

Nine patients with nonunited humeral shaft fractures were treated between 1986 and 1991 (Table I). Eight had had one or more (three had had three or more) previous operations in attempts to achieve union. Intramedullary fixation had either already been tried and failed or plate fixation was preferred because of the need to expose the fracture site.

Operative technique. The fracture was exposed through a posterior or an anterolateral approach. The radial nerve was identified and protected. Any dead bone was excised and the medullary canal was opened using a drill or a hand reamer. Either a fresh frozen allograft (cases 2, 3, 8 and 9) or an autograft (cases 1, 4, 5, 6 and 7) fibula was fashioned to fit into the medullary canal. The graft was first inserted into the proximal canal and then moved distally as the fracture was reduced. On two occasions half of a split fibula was used to fit a narrow canal; in these cases there was only tricortical screw fixation. Two patients (cases 6 and 7) had a segmental defect of more than two inches. To preserve the length a segment of intercalary allograft (one patient) or a tricortical autogenous iliac crest graft (one patient) was used; the fibula was placed through the allograft or beside the tricortical graft.

A broad or narrow dynamic compression plate was used, depending on the size of the humerus. Each screw hole was drilled and tapped through all cortices, two in

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The operative organ inserted has also been augmented with exercises concentration between the periods. Biomechanical study. A biomechanical study was done to compare the screw purchase strength of quadricortical with that of bicortical screw fixation and with cement-augmented screw fixation. The tests were in two groups. In group A we used 18 formalin-fixed humeri removed from 11 male and 7 female cadavers; their average age was 77 years. These old bones were thought to simulate the poor quality of bone often associated with nonunited fractures. Group B consisted of 12 humeri which had been removed, for use as fresh-frozen allografts, from organ donors (six male and six female), whose average age was 32 years.

The screw holes were prepared as described in the operative technique. Bicortical screws (4.5 mm) were inserted after drilling a 3.2 mm hole using a 4.5 mm tap. The cement-augmented construct was achieved by drilling and tapping of the screw hole and injection of liquid cement into the hole followed by placement of the screw before the cement polymerised. Quadricortical fixation involved insertion of a fibula into the medullary canal followed by drilling, tapping and placement of the screw through all four cortices. The screws were torqued to 6 ft-lbs (8.14 Nm). Ultimate screw pushout strengths were measured using an Instron machine with a crosshead speed of 0.2 mm/sec. Because the pushout test was destructive, the same site could not be used for each type of screw fixation on the same bone. Three diaphyseal locations (proximal, middle and distal) were used in each humerus. The location for each fixation method was randomised to minimise any effect of longitudinal position. The cortical thickness at each screw hole was measured with a caliper to allow the pushout strength to be normalised as the force in Newtons divided by the cortical thickness in mm.

RESULTS

Eight of the nine fractures had healed within four months (Figs 2, 3 and 4). The one failure (case 5) was in an elderly, obese, alcoholic man who fell several times on his operated arm. He was treated in a splint and no further reconstructive procedure was offered.

In the eight patients who healed, there was an average range of active shoulder elevation (total shoulder abduction) of 118° and an arc of rotation greater than 45°. The average range of active flexion of the elbow was from 5° to 115°, pronation was 80° and supination 60°. At follow-up at a mean of 38.6 months (12 to 74), three
Table 1. Details of nine patients treated by an intramedullary fibular graft

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Fracture site</th>
<th>Associated surgery</th>
<th>Time to reconstruction (mth)</th>
<th>Reconstruction</th>
<th>Complications</th>
<th>Union time (mth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>66</td>
<td>M</td>
<td>(R) spiral mid-shaft</td>
<td>0</td>
<td>Diabetes Stroke</td>
<td>6</td>
<td>Fibular autograft, DCP*, iliac bone</td>
<td>Supracondylar fracture at 6 months</td>
</tr>
<tr>
<td>2</td>
<td>57</td>
<td>M</td>
<td>(R) middle third</td>
<td>2</td>
<td>Radial nerve palsy</td>
<td>8.5</td>
<td>Fibular autograft, DCP, iliac bone</td>
<td>Radial nerve palsy</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>F</td>
<td>(R) proximal and middle thirds</td>
<td>4</td>
<td>Radial nerve palsy</td>
<td>10</td>
<td>Fibular autograft, DCP, iliac bone</td>
<td>Plate impingement</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>M</td>
<td>(L) mid-shaft</td>
<td>1</td>
<td>None</td>
<td>5</td>
<td>Fibular autograft, DCP, iliac bone</td>
<td>Peroneal nerve palsy; iliac crest wound infection</td>
</tr>
<tr>
<td>5</td>
<td>62</td>
<td>M</td>
<td>(R) mid-shaft</td>
<td>2</td>
<td>Alcohol abuse</td>
<td>Unknown</td>
<td>Fibular autograft, DCP, iliac bone</td>
<td>Failed Nonunion</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>M</td>
<td>(R) proximal and middle thirds</td>
<td>2</td>
<td>None</td>
<td>3.5</td>
<td>Fibular autograft, intercalary allograft, DCP, iliac bone</td>
<td>None</td>
</tr>
<tr>
<td>7</td>
<td>67</td>
<td>F</td>
<td>(R) short oblique junction of proximal and middle thirds</td>
<td>3</td>
<td>Rheumatoid arthritis</td>
<td>16</td>
<td>Fibular autograft, tricortical iliac crest, intercalary graft, DCP</td>
<td>None</td>
</tr>
<tr>
<td>8</td>
<td>37</td>
<td>F</td>
<td>(R) junction of middle and distal thirds</td>
<td>4</td>
<td>Head injury</td>
<td>72</td>
<td>Fibular autograft, DCP, iliac bone</td>
<td>None</td>
</tr>
<tr>
<td>9</td>
<td>64</td>
<td>F</td>
<td>(L) comminuted, junction of middle and distal thirds</td>
<td>1</td>
<td>Stroke</td>
<td>9</td>
<td>Fibular autograft, DCP, iliac bone</td>
<td>None</td>
</tr>
</tbody>
</table>

* dynamic compression plate

patients had no pain, five had mild occasional pain and the patient with nonunion had persistent pain. Four patients returned to work (three to heavy labour and one as a housewife) and four did not, either because of their age or other medical problems.

Complications occurred in five of the patients. Case 5 had failure of fixation and case 1 suffered a fracture below the plate six months after the operation. In this instance the plate and the fibula ended distally at the same level. The fracture was successfully treated by open reduction and internal fixation. Placement of the fibula relative to the plate was modified in subsequent patients. Case 2 had an incomplete radial nerve palsy before surgery and a complete palsy after. He subsequently regained partial nerve function. Case 4 had a transient peroneal nerve palsy in the leg from which the fibula had been removed, and an infection of the iliac crest donor site which resolved with antibiotics. Case 3 had symptoms from impingement of the plate on the acromion; these resolved when the plate was removed after healing of the fracture.

Biomechanical findings. Multifactorial analysis of variance (ANOVA) was used to determine the effect of the fixation method (bicortical, cement-augmented and quadricortical) and fixation position (proximal, middle and distal humeral shaft) on the strength of the construct. It showed significant differences between the three fixation methods and between the three fixation positions, both for formalin-fixed and for fresh-frozen cadaver bone (p < 0.05).

Differences between fixation methods and positions were then determined using the Tukey multiple comparison test (Fig. 5). In group A (formalin-fixed cadaver samples) there were significant differences in the normalised pushout strengths, in all positions, between bicortical fixation and cement-augmented fixation, bicortical and quadricortical fixation, and cement-augmented and quadricortical fixation (p < 0.05). Bicortical fixation yielded the lowest and cement-augmented fixation the highest normalised strengths. The proximal position...
produced significantly lower normalised pushout strengths for all fixation methods when compared with the middle and distal fixation positions (p < 0.05). There was no significant difference in pushout strength between the middle and distal positions.

In the fresh-frozen cadaver samples (group B) there was also a significant difference in the normalised pushout strength, at all positions, between bicortical fixation and quadricortical fixation (p < 0.05). No significant difference was found in the normalised pushout strengths between either bicortical and cement-augmented fixation or between cement-augmented and quadricortical fixation. The last yielded the highest normalised strength. The proximal position, as in group A, showed a significantly lower normalised strength than did the middle and distal positions.

As expected, fresh frozen specimens obtained from young individuals had significantly higher normalised strength when compared with the specimens obtained from the older cadavers for all positions and all fixation methods (p < 0.05). In general, the screw pushout strengths using quadricortical fixation were similar to those with cement-augmented screw fixation and were significantly better than for bicortical fixation. All the methods of fixation were weaker in the proximal part of the diaphysis than in more distal positions.

DISCUSSION

The limitation of plate fixation in the humerus is screw purchase in the bone. Methylmethacrylate cement has been used to augment screw fixation (Cameron et al. 1975; Trotter and Dobozi 1986) but it may have deleterious effects on the blood supply of the bone and on healing, especially if it extrudes into the fracture site. The use of methylmethacrylate also makes later reconstructions or removal of the implant more difficult.

Hoglund (1917) used an intramedullary graft in conjunction with bone screws but to our knowledge there have been no previous reports of the use of an intramedullary bone graft to enhance screw fixation with compression plating.

Screw purchase is directly related to cortical thickness (Ansell and Scales 1968; Schatzker et al. 1975) and to bone mineralisation (Trader et al. 1979). The intramedullary fibula enhances screw purchase by providing additional cortical bone of good quality, as was confirmed by the biomechanical tests.

In addition to improving screw purchase, the fibula may add some stability to the fracture site by acting as an intramedullary strut, and it also functions as a bone graft. The large contact area between the fibula and the endosteal surface of the humerus facilitates union.

A possible disadvantage of using an intramedullary graft and a compression plate is the disruption of both the periosteal and the endosteal blood supply. This, however, is already compromised at the site of nonunion and it is usual to ream the medullary canal regardless of the method of fixation used. We did not ream the canal extensively but opened it only enough to allow placement of the fibular graft.

The biomechanical tests showed that the screw fixation was best when there was a tight fit between the fibula and the humerus. In the proximal portion of the humeral diaphysis, where the canal is widest, the fibula did not fit tightly and the quadricortical screws failed first at the humeral interface and secondly at the fibular interface. This sequence was not seen in the mid-shaft or distal humerus. At the proximal screw hole in the young bones, no particular advantage was seen with any of the different constructs. In the osteopenic bones, however, the methylmethacrylate construct was stronger than the quadricortical construct.

Clinical and biomechanical investigation has shown the efficacy of using an intramedullary bone graft to improve screw fixation. The technique is appropriate for established nonunion especially when previous fixation methods have failed or when the bone is osteopenic. It can also be used in conjunction with an intercalary graft in patients who have significant bone loss. Humeral length can be maintained, early mobilisation is possible, and a high rate of union can be anticipated.

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


