LOCKED INTRAMEDULLARY NAILING OF HUMERAL SHAFT FRACTURES

IMPLANT DESIGN, SURGICAL TECHNIQUE, AND CLINICAL RESULTS

ANTHONY M. INGMAN, DARREN A. WATERS

From the Royal Adelaide Hospital, South Australia

We report our experience with a modified implant and a new technique for locked intramedullary nailing of the humerus in 41 patients. Locking was by cross-screws placed from lateral to medial in the proximal humerus, and anteroposteriorly in the distal humerus. Early in the series, 11 nails were inserted at the shoulder, but we found that rehabilitation was faster after retrograde nailing through the olecranon fossa, which was used for the other 30. We used a closed technique for 29 of the nailings.

Of the 41 patients treated, 21 had acute fractures, five had nonunion, and 15 had pathological fractures.

Secure fixation was obtained for comminuted and osteoporotic fractures in any part of the humeral shaft, which allowed the early use of crutches and walking frames. Two nails were locked at only one end, and one of these became the only failure of union after an acute fracture.

Many fractures of the humeral shaft can be managed without operation, but internal fixation is commonly used when there is major soft-tissue damage or multiple trauma, persistent malalignment, nonunion, or pathological fracture. The advantages and disadvantages of plate fixation and intramedullary nailing have been well summarised by Foster et al (1985). Plate fixation has given high rates of union (Bell et al 1985; Foster et al 1985; Vander Griend, Tomasin and Ward 1986), but requires an extensive open operation, with stripping of soft tissues from the bone. It also provides less secure fixation, especially in osteoporotic bone and if crutch walking is required. Closed intramedullary nailing theoretically avoids these problems, but various unlocked nails have given a poor rate of union, and have a tendency to back out (Durbin, Gottesman and Saunders 1983; Stern et al 1984; Foster et al 1985; Pritchett 1985; Hall and Pankovich 1987; Rush 1987).

The Seidel humeral locking nail (Howmedica GmbH, Schönikirchen, Germany) has an expanding mechanism to provide distal locking, but rotational control and the rate of union are poor for difficult fractures (Bain and Sandow 1992; Robinson et al 1992). Seidel (1989) reported good results in a few patients as did Habernek and Orthner (1991), but most of their cases were rather benign skiing injuries.

Rotary stability is most reliably achieved by using transverse locking screws near each end; the advantages of this technique in the lower limb are well recognised. We aimed to determine whether this method would improve the results for humeral shaft fractures, and provide a simple, safe, and reliable technique with regard to the proximity of the radial and axillary nerves and effects on shoulder and elbow function.

PATIENTS AND METHODS

The implants were modified Grosse-Kempf 9 mm tibial nails, with a length range of 270 to 330 mm. These nails are cannulated but not slotted. The proximal 60 mm of each nail was removed; the cut end was machined and fitted with an internal screw thread and keying slot. Holes for the proximal locking screws were then drilled at 90° to the plane of the existing distal holes. At first two holes were made at 15 mm and 30 mm from the end, but later we used only a single hole at 20 mm. The nail was bent to a 5° angle at 50 mm
Table I. Details of 41 humeral shaft fractures treated by locked nailing: A, acute trauma; N, nonunion; P, pathological fracture

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>AO code</th>
<th>Indication for fixation</th>
<th>Days after injury</th>
<th>Nail entry site</th>
<th>Time to union (mth)</th>
<th>Follow-up (mth)</th>
<th>Active shoulder flexion</th>
<th>Passive elbow extension</th>
<th>Complications/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>22</td>
<td>M</td>
<td>12B2.2</td>
<td>Fractured femur and ankle</td>
<td>16</td>
<td>Shoulder</td>
<td>3</td>
<td>3</td>
<td>Full</td>
<td>Full</td>
<td>Occasional shoulder pain</td>
</tr>
<tr>
<td>A2</td>
<td>20</td>
<td>M</td>
<td>12A1.2*</td>
<td>Head injury</td>
<td>13</td>
<td>Shoulder</td>
<td>3</td>
<td>2</td>
<td>Full</td>
<td>Full</td>
<td>No symptoms, normal function</td>
</tr>
<tr>
<td>A3</td>
<td>24</td>
<td>M</td>
<td>12A3.2</td>
<td>Fracture of both tibiae</td>
<td>16</td>
<td>Elbow</td>
<td>2</td>
<td>2</td>
<td>Full</td>
<td>Full</td>
<td>Bone graft after 1 year</td>
</tr>
<tr>
<td>A4</td>
<td>18</td>
<td>M</td>
<td>12B3.2</td>
<td>Grade III compound</td>
<td>2</td>
<td>Elbow</td>
<td>2</td>
<td>10</td>
<td>Full</td>
<td>Full</td>
<td>Mild weakness from muscle injury</td>
</tr>
<tr>
<td>A5</td>
<td>63</td>
<td>F</td>
<td>12A2.1</td>
<td>Became compound</td>
<td>10</td>
<td>Shoulder</td>
<td>2</td>
<td>6</td>
<td>150'</td>
<td>Full</td>
<td>Occasional shoulder pain</td>
</tr>
<tr>
<td>A6</td>
<td>69</td>
<td>F</td>
<td>12A1.2</td>
<td>Parkinson's disease,</td>
<td>17</td>
<td>Elbow</td>
<td>2</td>
<td>3</td>
<td>130'</td>
<td>Full</td>
<td>Walking with frame after 1 week</td>
</tr>
<tr>
<td>A7</td>
<td>51</td>
<td>M</td>
<td>12B2.2</td>
<td>Fractured tibia and foot</td>
<td>7</td>
<td>Elbow</td>
<td>2</td>
<td>2</td>
<td>Full</td>
<td>Full</td>
<td>No symptoms, normal function</td>
</tr>
<tr>
<td>A8</td>
<td>21</td>
<td>M</td>
<td>12A3.2</td>
<td>Fractured femur and olecranon</td>
<td>4</td>
<td>Elbow</td>
<td>3</td>
<td>9</td>
<td>Full</td>
<td>Full</td>
<td>Minor elbow weakness</td>
</tr>
<tr>
<td>A9</td>
<td>16</td>
<td>M</td>
<td>12B2.2</td>
<td>Fractured femur and olecranon</td>
<td>5</td>
<td>Elbow</td>
<td>2</td>
<td>12</td>
<td>Full</td>
<td>Full</td>
<td>No symptoms, normal function</td>
</tr>
<tr>
<td>A10</td>
<td>22</td>
<td>F</td>
<td>12A3.3*</td>
<td>Fractured femur</td>
<td>0</td>
<td>Elbow</td>
<td>2</td>
<td>11</td>
<td>Full</td>
<td>Full</td>
<td>No symptoms, normal function</td>
</tr>
<tr>
<td>A11</td>
<td>48</td>
<td>M</td>
<td>12A3.3*</td>
<td>Severe forearm fracture</td>
<td>4</td>
<td>Elbow</td>
<td>2</td>
<td>12</td>
<td>Full</td>
<td>Full</td>
<td>Minor forearm pain</td>
</tr>
<tr>
<td>A12</td>
<td>29</td>
<td>M</td>
<td>12A3.2</td>
<td>Severe forearm fracture</td>
<td>0</td>
<td>Elbow</td>
<td>3</td>
<td>5</td>
<td>Full</td>
<td>Full</td>
<td>No problem with humerus</td>
</tr>
<tr>
<td>A13</td>
<td>19</td>
<td>M</td>
<td>12A3.2*</td>
<td>Head injury</td>
<td>9</td>
<td>Elbow</td>
<td>2</td>
<td>9</td>
<td>Full</td>
<td>Full</td>
<td>No symptoms, normal function</td>
</tr>
<tr>
<td>A14</td>
<td>16</td>
<td>M</td>
<td>12A2.3</td>
<td>Fractured femur</td>
<td>1</td>
<td>Elbow</td>
<td>6</td>
<td>11</td>
<td>Full</td>
<td>Full</td>
<td>Union time estimated</td>
</tr>
<tr>
<td>A15</td>
<td>48</td>
<td>F</td>
<td>12A3.3</td>
<td>Fractured pelvis</td>
<td>22</td>
<td>Elbow</td>
<td>6</td>
<td>11</td>
<td>Full</td>
<td>Full</td>
<td>Slight weakness, occasional ache</td>
</tr>
<tr>
<td>A16</td>
<td>51</td>
<td>M</td>
<td>12A2.1</td>
<td>Grossly displaced</td>
<td>2</td>
<td>Shoulder</td>
<td>4</td>
<td>5</td>
<td>30'</td>
<td>Full</td>
<td>Good function but stiff shoulder</td>
</tr>
<tr>
<td>A17</td>
<td>63</td>
<td>F</td>
<td>12B2.2</td>
<td>Grossly displaced</td>
<td>20</td>
<td>Elbow</td>
<td>3</td>
<td>6</td>
<td>130'</td>
<td>20'</td>
<td>Some ache, good function</td>
</tr>
<tr>
<td>A18</td>
<td>80</td>
<td>F</td>
<td>12A3.3</td>
<td>Fractured femur</td>
<td>1</td>
<td>Elbow</td>
<td>3</td>
<td>3</td>
<td>50'</td>
<td>15'</td>
<td>Previous shoulder stiffness</td>
</tr>
<tr>
<td>A19</td>
<td>41</td>
<td>F</td>
<td>12A3.3</td>
<td>Fractured femur</td>
<td>61</td>
<td>Elbow</td>
<td>2</td>
<td>4</td>
<td>Full</td>
<td>8'</td>
<td>No symptoms, normal function</td>
</tr>
<tr>
<td>A20</td>
<td>27</td>
<td>M</td>
<td>12A3.3</td>
<td>Fractured feet, psychotic</td>
<td>0</td>
<td>Elbow</td>
<td>2</td>
<td>4</td>
<td>Full</td>
<td>Full</td>
<td>Cerclage wiring after 2 weeks</td>
</tr>
<tr>
<td>A21</td>
<td>37</td>
<td>F</td>
<td>12A2.3</td>
<td>Fractured femora, tibiae</td>
<td>7</td>
<td>Elbow</td>
<td>3</td>
<td>150'</td>
<td>150'-15'</td>
<td>150'-15'</td>
<td>Radial nerve recovering</td>
</tr>
</tbody>
</table>

* radial nerve lesion
† loss of passive extension

from the threaded end (Fig. 1). Standard 4.5 mm Grosse-Kempf tibial screws were used. The proximal screws or the distal screws were usually inserted with a nail-mounted guide. In some cases a freehand technique was used.

From September 1990 to September 1992, we have used the locked humeral nail for shaft fractures in 41 patients. There were 21 acute fractures (A), five cases of nonunion (N) and 15 pathological fractures (P) (Table I). The ages of the patients ranged from 16 to 90 years (mean 53). In all except cases A2 and A3, the fractures were statically locked. Four fractures were compound: two Gustilo type I, one type II, and one type III (Gustilo and Anderson 1976). Six patients had preoperative radial nerve lesions, but no nerve was explored.

Of the five cases of nonunion, cases N1, N2, and N3 had previous Seidel nails; cases N1 and N3 had also had previous plate fixations. Case N4 had had previous Rush pin fixation for a histiocytoma, and case N5 had nonunion in a hemiplegic arm, but no previous surgery. Open reduction and bone grafting were used for all the cases of nonunion. Cases A2, A4, A5, A13, A16, A20 and P9 also had open reduction.

**Operative technique.** In our earlier cases the nail was inserted at the shoulder with the patient in a lateral position, and the distal screw or screws were placed from posterior to anterior. Later, we used a shoulder approach only for proximal fractures at or near the metaphyseal. In these cases open reduction was usually needed, for which a supine position was preferable, but necessitated placing the distal screws from anterior to posterior (LaVelle et al. 1991). In most of our later cases the nail was inserted at the elbow, using a specially designed radiolucent support.

**Elbow approach.** The patient is placed supine with the shoulder projecting beyond the edge of the operating table, so that the vertical part of the elbow support lies close to the
The final design of the nail.

Fig. 1

The position of the patient showing the elbow support and the image intensifier for the elbow approach. The diagonal dashed line gives the position of the overhead rail for a one-piece plastic drape. Figure 3 - Diagrams to show the development of the entry hole in the olecranon fossa. The shadow of the radiolucent elbow support is superimposed. From left to right: a) the position of the starting awl, b) enlargement of the entry hole with hand reamers, c) power reaming to produce further proximal extension of the entry hole and d) the final position of the nail with its anterior corner deep to the oblique cortex of the olecranon fossa.

Fig. 2

Fig. 3a
Fig. 3b
Fig. 3c
Fig. 3d

LOCKED INTRAMEDULLARY NAILING OF HUMERAL SHAFT FRACTURES

The final design of the nail. The patient's neck (Fig. 2). The elbow is flexed over the support, which is adjusted so that the fracture is under traction and the humerus is about 60° from the horizontal. The elbow is flexed to at least 120° to provide access to the olecranon fossa. The position is then held by a wrist strap and the reduction of the fracture is checked by the image intensifier (Fig. 2).

The incision extends from the tip of the olecranon proximally for 3 to 4 cm, and the triceps tendon is split to expose extrasynovial fat, but the joint is not entered. A 7 mm awl is passed blindly into the proximal slope of the olecranon fossa, and its position is checked on a lateral view (Fig. 3a). The hollow of the olecranon fossa helps to maintain the awl in the midline. The cortex is pierced and the hole enlarged with hand reamers (Fig. 3b), making an oblique entry.

A 3 mm guide wire is passed into the proximal humerus and flexible reamers are used with care so that they remain in the line of the shaft. The oblique entry hole is allowed to migrate more proximally as it enlarges (Fig. 3c). Frequent radiographic checks are made on the lateral view to avoid excessive reaming of the anterior cortex. The shaft is reamed to 9 mm and the entry hole to 9.5 mm.

The instruments used to insert the nail and screws are similar to those used for the femur and tibia. The nail is inserted until the anterior edge of its end is beneath the oblique cortex of the olecranon fossa (Fig. 3d) as checked radiographically. One distal screw is placed anteroposteriorly in the distal humerus, and one or two screws from lateral to medial in the proximal humerus. Two proximal screws are

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used for fractures in the wider proximal shaft, but only one is necessary for mid-shaft fractures. The region of the axillary nerve is avoided by the choice of the length of the nail, and by using drill sleeves which are passed by blunt dissection only.

Shoulder approach. The patient lies supine with the shoulder and arm on a radiolucent board. The upper humerus is exposed through either a short anterolateral deltoid split or a formal deltopectoral incision. The entry hole for the nail is posteromedial to the greater tuberosity, and the proximal screw is placed into the head of the humerus, from lateral to medial. A single distal screw is placed from anterior to posterior. Use of the longest possible nail and the most distal of the two holes minimises the risk of damage to the radial nerve.

The shoulder approach was used in 11 cases and the elbow approach in 30. Most operations were performed by or under the supervision of the senior author (AMI) but ten were done by various orthopaedic trainees without direct supervision.

We assessed functional results by clinical review with particular regard to shoulder and elbow movement; fracture union was confirmed radiographically. No patient was lost to follow-up, but some of those with metastatic disease could not attend for review and were interviewed by telephone.

RESULTS

Techniques. The first five patients all had insertion of nails at the shoulder. This is a simpler operation, but all five had significant interference with shoulder function during the first two months. Those who also had lower-limb fractures were unable to use crutches for this period. With increasing experience and the development of the elbow support, we later used the elbow approach more and more frequently. Postoperative elbow pain was not a problem, and patients

Figure 5 – The most distal fracture (case P3), before (a) and after nailing (b and c). Figure 6 – A proximal fracture nailed from the elbow (case P6). Two proximal screws were used because of the wide medullary canal.
with lower-limb fractures were able to use crutches within two weeks. This applied even to cases A8 and A9 who had simultaneous internal fixation of olecranon fractures on the same side through an extended incision.

In later cases, the shoulder approach was used only for fractures within 2 to 3 cm of the proximal metaphysis or to replace previous intramedullary devices in three cases of nonunion. We found it possible to stabilise fractures in any part of the humeral shaft: the most proximal and the most distal in the series are shown in Figures 4 and 5, and a proximal fracture nailed from the elbow in Figure 6. Two patients had supplementary fixation with cerclage wires, but bone cement was not used. No nailing procedure was abandoned and there was no case of malunion. We found no difficulty in stabilising a fracture with extensive comminution (Fig. 7), or one with severe osteoporosis secondary to disuse and alcoholism (Fig. 8). All but one of the preoperative radial nerve lesions recovered; the exception was in a patient who died soon after operation from his malignant disease.

**Shoulder and elbow movement.** At six weeks, all patients treated by the shoulder approach had significant restriction of active shoulder flexion. After the elbow approach, all but three of the patients aged under 60 years with acute fractures had a full range of active shoulder flexion at six weeks. The exceptions were two patients with severe soft-tissue damage and one with a radial nerve lesion and many other injuries. All but one of the patients with acute traumatic fractures had elbow extension to 30° or less by six weeks. The exception was a patient with severe damage to the biceps. The ranges of active shoulder flexion and passive elbow extension were useful indicators of overall function, and the final results are shown in Table I.

**Union.** The times to union for acute traumatic fractures, pathological fractures, and previous nonunions are shown in Table II. One acute fracture (case A3) was initially locked only at the proximal end. After two months slight rotary instability became apparent and a distal screw was inserted. This restored good function, but radiological union was achieved only after bone grafting at 12 months.

**Complications.** Four patients sustained additional comminution during the nailing, but this caused problems only in case A20. The operation was done by an inexperienced surgeon who achieved only poor stability in a psychotic patient. Early activity led to displacement, but cerclage wiring at two weeks gave a good final result.

There was one case of wound infection in a compound fracture which required readmission after three weeks for successful treatment with intravenous antibiotics. One preoperative radial nerve lesion was improving, but recurred after surgery. Full recovery was achieved after six months.
DISCUSSION

Implant design. The humeral shaft will admit a straight nail, but a bend is needed to compensate for the deviation of the entry portal from the centre line of the medullary canal. At the olecranon fossa, this deviation is small and a 5° bend, 50 mm from the end, provides an offset of approximately 4 mm. This has allowed easy insertion and extraction and provides good alignment from both shoulder and elbow approaches. The slight bend does not hinder the passage of a standard 3 mm guide wire.

In the proximal humerus, screws placed from lateral to medial present the least risk to soft tissues, avoiding the danger of injuring the long tendon of biceps. In the distal humerus, the radial nerve may be injured by laterally inserted screws, and the main neurovascular bundle also lies medially. Distal screws are therefore best placed posterolaterally or anteroposteriorly. These considerations require a nail with proximal and distal holes at 90° to one another. We found that two screw holes were useful at the far end of the nail as it is inserted (Fig. 6), but only one was found necessary near the threaded, bent end of the nail.

Considerations of cost and convenience require that the instruments and screws should be the same as those used to nail the lower limb. The 9 mm tibial nail is a convenient size, and locks with standard tibial screws. A slightly smaller 8 mm size would be useful for patients with narrow medullary canals, but would require a set of smaller screws and drills. We found no need for larger humeral nails.

Operative technique. Our technique for shoulder insertion of the nail is similar to that described by LaVelle et al (1991) for the Russell-Taylor humeral interlocking nail (Richards, Memphis, Tennessee), but we use a more distal entry point at the elbow. This point in the olecranon fossa is near the centre line of the medullary canal, and the shape of the fossa tends to centre the starting awl in the medial to lateral direction. The more proximal starting points described by Hackethal (1961), Brumback et al (1986), Rush (1987) and LaVelle et al (1991) are more suitable for smaller flexible nails. At the level which we use, the nail passes between strong supracondylar ridges and there is less risk of iatrogenic fracture (Hackethal 1961; Foster et al 1985). The nail, however, must be seated deeply to avoid impingement on the olecranon and the elbow must be flexed to at least 120° during nail insertion. Our elbow support is simple and effective in maintaining this position, and also provides traction to reduce the fracture without tension on the brachial plexus. Rotational alignment is secured and there is good access for the image intensifier.

Clinical results. Our reported series includes a learning curve, but the results compare favourably with those for other methods. The only loss of fixation was due to technical error and complications were few. The nonunion in case A3 may have been due to the omission of distal locking, and we now routinely lock both ends. Closed reaming carries a theoretical risk of damage to the radial nerve but we have not seen this. Care is needed but our use of small-diameter nails minimises reaming.

For pathological fractures, locked nailing has clear advantages and 14 of our 15 patients were stabilised by a closed technique using only a short incision. All regained useful function but the range of movement was influenced by the site and size of the tumours.

The patients treated for nonunion all had joint stiffness before our operation. The poor shoulder flexion in case N2 was thought to be due to damage to the rotator cuff caused by a loose and protruding Seidel nail.

Persistent pain after a shoulder approach is common (Stern et al 1984; Foster et al 1985; Brumback et al 1986; Bain and Sandow 1992; Robinson et al 1992), but we hoped that this would be reduced by the smaller proximal end of our nail, minimal dissection and prevention of backing out. Our patients still had shoulder symptoms, however, and it was clear that the elbow approach was more satisfactory, except for fractures within 2 to 3 cm of the proximal metaphysis, when open reduction was usually needed. We do not recommend the use of this nail for surgical neck fractures of the proximal humerus (AO Code 11A3). In five cases, gross displacement was controlled, but fixation was poor because the screw did not hold well in the soft centre of the humeral head.

Conclusions
1) Closed locked intramedullary nailing for humeral shaft fractures can reliably provide secure fixation with acceptable risks.
2) It appears to be the method of choice for internal fixation of osteoporotic and pathological fractures.
3) Nails should be inserted distally, from the olecranon fossa, for middle- and lower-third shaft fractures. Proximal shaft fractures require a limited shoulder approach.
4) A modified 9 mm tibial nail is suitable for the fixation of virtually all humeral shaft fractures.

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REFERENCES


