Double-crush syndrome after acetabular fractures
A SIGN OF POOR PROGNOSIS

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Injury to the sciatic nerve is one of the more serious complications of acetabular fracture and traumatic dislocation of the hip, both in the short and long term. We have reviewed prospectively patients, treated in our unit, for acetabular fractures who had concomitant injury to the sciatic nerve, with the aim of predicting the functional outcome after these injuries.

Of 136 patients who underwent stabilisation of acetabular fractures, there were 27 (19.9%) with neurological injury. At initial presentation, 13 patients had a complete foot-drop, ten had weakness of the foot and four had burning pain and altered sensation over the dorsum of the foot. Serial electromyography (EMG) studies were performed and the degree of functional recovery was monitored using the grading system of the Medical Research Council. In nine patients with a foot-drop, there was evidence of a proximal acetabular (sciatic) and a distal knee (neck of fibula) nerve lesion, the double-crush syndrome.

At the final follow-up, clinical examination and EMG studies showed full recovery in five of the ten patients with initial muscle weakness, and complete resolution in all four patients with sensory symptoms (burning pain and hyperaesthesia). There was improvement of functional capacity (motor and sensory) in two patients who presented initially with complete foot-drop. In the remaining 11 with foot-drop at presentation, including all nine with the double-crush lesion, there was no improvement in function at a mean follow-up of 4.3 years.

Neurological injury is one of the more serious complications of fracture and dislocation, both in the short and long term. The prevalence of injury to the sciatic nerve after acetabular fracture or fracture-dislocation of the hip has been reported to be between 10% and 25%.1,2 The type of fracture and the method of stabilisation widely influence the incidence of neurological injury. There is a higher incidence of injury to the sciatic nerve in posterior-column fractures, posterior-lip fractures and those with a posterior dislocation of the femoral head.3,4

There have been varied reports in the literature regarding the outcome of injury to the sciatic nerve after acetabular fracture.1,5-7 We found no detailed guidelines which describe prognostic factors for determining the probability of recovery. We have, therefore, undertaken a prospective study of all the patients treated in our unit with acetabular fractures who had concomitant injury to the sciatic nerve in order to determine the factors which affect the pattern of recovery.

Patients and Methods

We identified 27 patients with neurological lesions from among 136 who had undergone surgical stabilisation of displaced acetabular fractures in our department between December 1996 and November 2000. There were 20 men and seven women with a mean age of 33.8 years (16 to 66) (Table I). The median injury severity score8 (ISS) was 10.6 (9 to 34). The injuries resulted from road-traffic accidents in 24 patients and from a fall from a height in three. None of the patients had injury to the spinal cord or to the head which was severe enough to complicate neurological examination of the lower limbs. Three patients had sustained superficial injuries to the knee but none had dislocation or had clinical features consistent with instability of the knee. There were no coexistent injuries in the ipsilateral lower limb. All patients had a posterior-column or a posterior-lip fracture of the acetabulum. In 12 the femoral head was dislocated posteriorly in addition to the acetabular fracture.

Open reduction and internal fixation of the acetabular fractures was performed using...
standard operative techniques.\textsuperscript{7,9,10} During and after surgery, the knee was kept flexed to lessen the risk of a traction injury.\textsuperscript{11} The mean interval of time before surgical stabilisation was five days (24 hours to 14 days). The intra-operative appearance of the nerve was recorded in most of the cases. Any iatrogenic injury to the nerve was also reported. All patients received three doses of prophylactic second-generation cephalosporin. Of the 27 patients studied, 17 received indometacin (50 mg daily) as a prophylactic against heterotopic ossification. After operation, the patients were mobilised, toe-touch weight-bearing, for three months and subsequently progressed to full weight-bearing.

The mean follow-up was 48.6 months (3 to 6 years). All were reviewed in the orthopaedic outpatient department at regular intervals after discharge from hospital.

A standard protocol was followed for the clinical and neurophysiological evaluation of nerve injuries. Clinical examination was performed at presentation, in the immediate post-operative period and at follow-up visits at three, six, nine and 12 months, and yearly thereafter. The following were recorded: any abnormality of feeling, including absent or diminished sensitivity to light touch and pinprick, and dysesthesia or hyperaesthesia of the dorsal and plantar aspects of the foot; and the strengths of dorsiflexion and plantar flexion of the ankle and toes were graded according to the standard Medical Research Council scale (MRC grades 0 to 5).\textsuperscript{12}

Electromyography (EMG) was performed on every patient. The initial readings were usually taken after six weeks, when the immediate orthopaedic problems had

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yrs)</th>
<th>Gender</th>
<th>Type of fracture*</th>
<th>Type of nerve injury†</th>
<th>Surgical approach‡</th>
<th>Follow-up (mths)</th>
<th>Clinical assessment of nerve recovery</th>
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<td>K-L</td>
<td>56</td>
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| Group B |          |        |                   |                      |                   |                 |                                      |
| 14   | 29        | M      | P. wall          | S                    | K-L               | 39              | 5 3 4 Normal Normal                   |
| 15   | 55        | M      | T, P. wall+      | S                    | K-L               | 64              | 4 4 3 Slightly decreased Slightly decreased |
| 16   | 31        | F      | T-shaped         | S                    | K-L               | 69              | 4 3 4 Slightly decreased Slightly decreased |
| 17   | 47        | M      | BC               | S                    | I-I               | 42              | 5 4 4 Normal Slightly decreased       |
| 18   | 27        | M      | BC               | S                    | I-I               | 51              | 4 4+ 4+ Normal Normal                 |
| 19   | 21        | F      | P. wall          | S                    | K-L               | 42              | 5 5 4+ Slightly decreased Slightly decreased |
| 20   | 33        | M      | T, P. wall+      | S                    | K-L               | 44              | 4+ 4+ 4+ Normal Normal                |
| 21   | 27        | M      | T, P. wall       | S                    | K-L               | 56              | 5 4+ 5 Normal Normal                  |
| 22   | 16        | M      | P. wall          | S                    | K-L               | 51              | 5 5 4+ Normal Normal                  |
| 23   | 59        | M      | P. wall+         | S                    | K-L               | 39              | 5 4 4 Normal Normal                   |

| Group C |          |        |                   |                      |                   |                 |                                      |
| 24   | 25        | M      | BC               | S                    | I-I               | 39              | 5 5 5 Normal Normal                   |
| 25   | 18        | F      | T-shaped         | S                    | K-L               | 46              | 5 4 5 Normal Normal                   |
| 26   | 20        | M      | T, P. wall+      | S                    | K-L               | 41              | 5 5 5 Normal Normal                   |
| 27   | 27        | F      | P. wall          | S                    | K-L               | 59              | 5 5 5 Normal Normal                   |

* T, transverse; P. wall, Posterior wall; BC, both columns; +, posterior hip dislocation
† S, single-level lesion; D, double-level lesion
‡ K-L, Kocher-Langenbeck; I-I, Ilioinguinal
§ TA, tibialis anterior; EHL, extensor hallucis longus; EDL, extensor digitorum longus
been resolved, in order to determine the site and extent of any neurological deficit. Subsequent EMG studies were performed at nine or 12 months after the injury and then annually until the final follow-up. The level and pattern of the lesion were noted and correlated with the final outcome. The presence of lesions at two different levels was determined, one at the sciatic notch and the other at the neck of the fibula. This was categorised as the double-crush syndrome. Nerve-conduction studies were repeated on patients with lesions at two levels to eliminate artifactual results.

Depending on the clinical examination at the last review, recovery of the nerve lesion was rated as either satisfactory or unsatisfactory, a system similar to that used by Clawson and Seddon. The recovery was rated as satisfactory if the muscle strength at the time of follow-up reached MRC grade 4 or 5; otherwise it was rated as unsatisfactory. These findings were closely correlated with the neurophysiological findings to quantify any recovery.

The overall functional outcome in regard to injury to the sciatic nerve was rated according to the system described by Fassler et al. At the final follow-up, each patient was assigned a functional grade of excellent, good, fair, or poor. At the final follow-up, the presence of any radiological evidence of post-traumatic secondary osteoarthritis was documented. Heterotopic ossification, if present was graded as described by Brooker et al.

**Results**

Details of the 27 patients and their injuries are given in Table I. Twenty-five had a neurological injury at presentation. In the other two, the injury to the nerve was iatrogenic, occurring during internal fixation of the acetabular fracture. The neurological deficit was recognised post-operatively as ‘foot-drop’. At surgery, contusion of the nerve was noticed in 19 of the 25 patients with injury to the sciatic nerve at presentation. In the two patients with iatrogenic nerve injuries, the nerve was noticed to be contused at the end of surgery. Complete foot-drop was observed in 13 of the 27 patients with a nerve defect. These patients comprised group A. Ten patients had weakness of the foot dorsiflexors and formed group B and four who had altered feeling in the foot with burning pain, diminished feeling and dysaesthesia or hyperaesthesia, were classified as group C. EMG studies were performed at regular intervals until either complete recovery or to the last follow-up and in all 27 patients there were electrophysiological features consistent with sciatic nerve injury. In nine of group A, there was evidence of the double-crush syndrome.

**Neurological recovery** (Table I)

*Group A.* There was improvement in functional capacity (motor and sensory) in two patients with proximal lesions proven by EMG, after a mean interval of 4.6 years (3 to 6). There was no improvement in two patients with either proximal or distal lesions proven by EMG, after a mean interval of 4.7 years (3 to 6) or in the nine patients with the double-crush syndrome, proven by EMG, after a mean interval of 4.3 years (3 to 6).

*Group B.* There was improvement in functional motor and sensory capacity in five patients after a mean interval of 4.4 years (3 to 6) and full recovery in five after a mean interval of 3.8 years (3 to 5).

*Group C.* There was full recovery in all four patients after a mean interval of 3.8 years (3 to 5).

**Functional outcome**

*Group A.* The results were satisfactory in three patients and unsatisfactory in ten largely because of the poor recovery seen in all those with the double-crush injury. According to the grading system by Fassler et al, the results were excellent in two, fair in two and poor in nine.

*Group B.* All but two patients had a satisfactory outcome. According to the grading system of Fassler et al, seven patients had an excellent result, two good and one a fair result.

*Group C.* All patients showed an excellent functional outcome with complete neurological recovery.

**Radiological assessment.** In three patients there was radiological evidence of secondary osteoarthritis of the hip at a mean interval of 4.2 years, one in group A with a double-crush lesion and two in group B. Five patients developed Brooker grade-I heterotopic ossification without functional impairment. Two of these had received prophylaxis.

**Discussion**

Injury to the sciatic nerve is closely associated with acetabular fracture and traumatic posterior dislocation of the hip and occurs in between 10% and 25% of cases. In our study of 136 patients operated on to stabilise a displaced acetabular fracture, the incidence of nerve injury was 19.9%. It is well documented that a displaced fracture of the posterior column and fractures with posterior dislocation of the femoral head, are more commonly associated with injury to the sciatic nerve. Nevertheless this may occur with any type of acetabular fracture.

Letournel and Judet, in their extensive study of acetabular fractures, noted that 75% of patients with a posterior dislocation of the femoral head, had associated injury of the sciatic nerve. Of those who had damage to the posterior column, 17% had an injury to the sciatic nerve; other patterns of fracture were associated with a much lower incidence. Rowe and Lowell reported an incidence of 35% of injury to the sciatic nerve if the pelvic fracture involved the posterior aspect of the acetabulum. In our study, there were 12 cases of posterior dislocation of the femoral head with fracture of the acetabulum.

The incidence of iatrogenic injury in our study was less than 1% but an incidence of 5% has been reported. In the series of Letournel and Judet, 11% of the injuries to the sciatic nerve were iatrogenic. Mears, Rubash and Sawaguchi reported six cases of iatrogenic injury to the nerve in their study of 16 patients. Excessive traction on the nerve, malposition of the retractors, penetration by drill...
bits and continuous extension of the ipsilateral knee during
the operation have all been implicated. In our study, the
knee was always kept flexed to lessen the risk of traction
injury. Reports vary as to whether iatrogenic injuries of
the sciatic nerve are associated with a more or a less favour-
able prognosis for recovery than other injuries. In the series
of Letournel and Judet, there was complete motor recovery
in 14 of 25 patients with iatrogenic injury. Mears et al
reported the results in six cases of iatrogenic injury. Four
patients recovered within three months and two had per-
sistent foot-drop. None of the five patients reported by
Ruggieri et al recovered completely. In the series of Matta
et al there were four iatrogenic injuries with involvement
of the peroneal division. One resolved within a year, but
two patients were left with weakness. Of our two patients,
one made a full recovery at nine months and the other was
left with a residual weakness of the ankle dorsiflexors (MRC 4/5).

The double-crush syndrome is a general term referring to
the coexistence of dual lesions along the course of a periph-
eral nerve. This term was first used by Upton and
McComas in 1973 who suggested that proximal com-
pression of a nerve may decrease the ability of the nerve to
withstand a more distal compression. However, the litera-
ture does not record a relationship between acetabular frac-
tures, and a concomitant distal injury at the neck of the

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Diagrams of lesion of the sciatic nerve a) at the sciatic notch; b) with denervation changes in biceps femoris and
c) at the neck of the fibula; d) with denervation changes in tibialis anterior.
fibula and a proximal injury to the sciatic nerve (Fig. 1). The incidence of the double-crush syndrome in our study was 33.3%. This may suggest that it exists as a separate entity. The pathological basis of the condition is a multiple compression or traction lesion affecting the axis of the sciatic nerve (Fig. 2). From the pathophysiological viewpoint, impairment of neural excursion, loss of elasticity, underlying abnormality of the connective tissue, as well as direct pressure on the nerve may lead to disruption of axons, impairment of axonal transport, endoneurial oedema or ischaemic changes in nerves.

The sciatic nerve comprises the medial tibial fibres and lateral peroneal fibres. The mechanism of the double-crush lesion could be explained in the light of the fact that both the sciatic notch and the neck of the fibula act as points of fixation for the peroneal division. Sunderland demonstrated that the peroneal division has fewer funiculi and that these are of greater diameter compared with those of the tibial component. Also there is less supporting, connective tissue between the fibres. This results in energy being absorbed by the nerve bundles rather than connective tissues. The distal lesion could be explained by direct trauma, for example the striking of the knee on the dashboard in car accidents. In our series of patients, none had sustained dislocation of the knee and no patient required reparative surgery to the joint. In cases of double lesions, it is postulated that the energy, dissipated from the high-velocity impact, has led to nerve damage at both hip and knee. The presence of proximal compression on the nerve may decrease the ability of the nerve to withstand a more distal compression.

Upton and McComas described the double-crush syndrome in 1973 to explain nerve problems resulting from a combination of distal lesions (wrist or elbow) in conjunction with proximal (cervical root or thoracic outlet) pathology. They postulated that an impairment in the axonal flow proximally could make the distal nerve more vulnerable. This concept can be applied to acetabular fractures. Tethering of the sciatic nerve at the sciatic notch may exaggerate the traction effect on the nerve in the buttock. The common peroneal portion of the sciatic nerve is more vulnerable because of its anatomical position, its nature and internal architecture. Neurophysiological differentiation between a proximal (sciatic notch) and distal (neck of fibula) lesion can be studied by nerve-conduction studies and EMG. A lesion at the sciatic notch will produce denervation of the hamstrings. Biceps femoris is readily accessible for EMG and, since it is supplied by fascicles of the peroneal nerve, it
Table II. Features of the double-crush syndrome

| Buttock (proximal lesion) | Wasted hamstrings  
|                          | Denervation of hamstrings (biceps femoris)  
|                          | Delayed latency – sciatic notch to hamstrings  
|                          | Positive Tinel’s sign in the buttock  
|                          | Numbness in the distribution of the posterior cutaneous nerve of the thigh  
|                          | Denervation in the distribution of tibial nerve-plantar flexors of ankle affected  
| Knee (neck of fibula – distal lesion) | Delayed latency – neck of fibula to tibialis anterior  
|                          | Combination of denervation of foot plantar and dorsiflexors  
|                          | Denervation and neurogenic changes more prominent in the dorsiflexors and evertors than gastrocnemius  
|                          | Positive Tinel’s sign at the neck of the fibula  
|                          | Sensory changes, more prominent in the deep than the superficial peroneal nerve  
|                          | More significant dysfunction in the anterolateral compartment of the leg (common peroneal nerve territory)  
|                          | Foot-drop invariably present  

is useful for demonstrating proximal pathology. Furthermore, such patients will have denervation changes in the tibial nerve affecting the calf. Although denervation changes were noted in the foot dorsiflexors and evertors there was no block to conduction at the neck of the fibula. By contrast, patients with a lesion at the neck of the fibula did not demonstrate neurogenic activity in the hamstrings, but clearly showed conduction delay at the knee with distal activity of the nerve in the foot, sparing the calf musculature (Table II). Subjects with double-crush lesions will inevitably show dual pathophysiology. However, the extent of the dysfunction in the tibial nerve examination by EMG of the hamstrings and by nerve conduction studies across the neck of the fibula, and the presence of local tenderness (Tinel’s and migrating Tinel’s signs), will help to differentiate the principal site of damage.

A lesion at the level of the hip will affect the sciatic nerve with nerve-conduction and needle EMG abnormalities (Table II). Preservation of the calf and biceps femoris, with a delay in conduction across the neck of fibula, are clear pointers to a lesion at the neck of fibula. Abnormalities of the EMG above the knee can only be explained by a proximal lesion which also produces abnormalities in the calf. On the other hand, a primary lesion at the neck of the fibula will affect the anterolateral compartment of the leg while sparing the calf muscles. In dual (double-crush) lesions, the two levels will overlap (Table II).

Neuropathological examination is critical in distinguishing between a single or a double lesion, as well as determining the comparative severity of the two lesions. Follow-up nerve conduction studies and needle EMG in patients in whom the initial findings are not clear, help to identify the major site of neural dysfunction. Serial EMG is particularly helpful in order to ascertain the extent and severity of denervation in the three groups of muscles (hamstrings, calf and foot dorsiflexors).

Baba et al22 noted that proximal axonal stenosis in a rabbit tibial nerve model resulted in distal axonal atrophy and slowing of motor nerve conductivity, distally. Horiuichi23 observed reduction in the number of neurofilaments distal to the site of an experimentally applied proximal compression. Nemoto et al24 presented a direct electrical and histological study in which a gentle compression clamp was applied to the sciatic nerve of a dog, either singly or at both a proximal and distal site. No complete conduction block occurred in the single clamp group, although motor conduction velocity was only 39% of the pre-operative value. In the second group, two compression clamps, one proximal and the other distal, were applied simultaneously. A complete conduction block was present in 50% of the nerves at six weeks and motor nerve-conduction velocity was reduced to 34% of the pre-operative value. In the third group, in which proximal compression was applied initially and three weeks later a second distal clamp was applied, a complete conduction block occurred in 50% and motor conduction velocity was reduced to 14% of the pre-operative value. Histologically, increased axonal degeneration was noted in the nerve distal to the second compression lesion. This experiment provides evidence that two points of compression along a nerve trunk are worse than one, and further that dual damage exceeds the expected summation of two isolated compressions.

In our study, the presence of a neurological injury was established both by clinical and neuropathological studies. To complement our clinical examination in assessing nerve recovery, we performed serial EMG studies at regular intervals according to our protocol in order to determine the anatomical level of the lesion, the type of lesion (neuropraxia, axonotmesis or neurotmesis) and the presence of neurological recovery.

The time of recovery of the sciatic nerve after acetabular fractures, the functional outcome and the follow-up time vary greatly between different series. Fassler et al2 studied 14 patients who had injuries of the sciatic nerve associated with displaced acetabular fractures for a mean time of 27 months. All but one had a satisfactory (fair or better) functional outcome, but 11 had residual neurological sequelae which ranged from minor paraesthesiae to foot-drop. Seven patients, who had an injury to both the tibial and peroneal divisions of the sciatic nerve, had complete or nearly complete recovery of the tibial component. The patients, who had isolated, mild involvement of the peroneal nerve, had the best prognosis. Those who had severe injury of the peroneal component, whether it was isolated or associated
with an injury of the tibial component, showed poor recovery. Mears et al.18 reported the results of 16 traumatic injuries of the sciatic nerve associated with acetabular fractures and concluded that the prognosis was good since 14 of the patients had complete recovery within six months of the injury and only two needed a brace for foot-drop. Epstein25 reported 38 injuries of the nerve associated with posterior fracture-dislocations of the hip. In 23 the nerves returned to normal at between 3 and 33 months after the injury and recovery was poor (partial or none) in 11 patients (29%).25 Stewart and Milford26 and Stewart, Beeler and McConnell27 reported the results of 17 cases of injury to the sciatic nerve. Only three nerves recovered completely; nine had less than a full recovery and three had none. In our study, excluding the nerves with a double-crush injury, 11 of the 18 patients progressed to complete recovery. All four patients with sensory disturbance recovered completely over a period of 3.8 years. There was full recovery in five of the ten patients with motor weakness at 3.8 years and some improvement in the other five at 4.4 years. Only two of the 13 patients with complete foot-drop recovered at 4.6 years. In the remaining 11 with complete foot-drop (nine with double-crush at presentation) there was no improvement at 4.3 years.

Comparable situations have been reported in the upper limb with similar results expected from the double-crush syndrome in which there is carpal tunnel compression with concomitant cervical radiculopathy. Osterman et al.28 observed that 18% of patients with carpal-tunnel compression had concomitant cervical radiculopathy. The recovery from symptoms of pain, paraesthesia and weakness after carpal-tunnel decompression in this group was found to be significantly less satisfactory compared with the single lesion; 33% of the patients with double-crush syndrome considered that surgery was a failure compared with 7% of the isolated carpal-tunnel group. This highlights the importance of identifying patients with a double-crush injury preoperatively, allowing this entity to be added to the list of causes of failure of surgical treatment for nerve entrapment.

Supplementary material
A further opinion by Professor Rolfe Birch is available with the electronic version of this article, on our website at www.jbjs.org.uk

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References