ACUTE COMPARTMENT SYNDROME IN TIBIAL DIAPHYSEAL FRACTURES

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We reviewed 25 patients with tibial diaphyseal fractures which had been complicated by an acute compartment syndrome. Thirteen had undergone continuous monitoring of the compartment pressure and the other 12 had not.

The average delay from injury to fasciotomy in the monitored group was 16 hours and in the non-monitored group 32 hours ($p < 0.05$). Of the 12 surviving patients in the monitored group, none had any sequelae of acute compartment syndrome at final review at an average of 10.5 months. Of the 11 surviving patients in the non-monitored group, ten had definite sequelae with muscle weakness and contractures ($p < 0.01$). There was also a significant delay in tibial union in the non-monitored group ($p < 0.05$).

We recommend that, when equipment is available, all patients with tibial fractures should have continuous compartment monitoring to minimise the incidence of acute compartment syndrome.

J Bone Joint Surg [Br] 1996;78-B:95-8.
Received 12 January 1995; Accepted after revision 27 June 1995

Acute compartment syndrome is a potentially devastating complication of tibial diaphyseal fractures, and early diagnosis is important for the prevention of disability. In the past, diagnosis has depended on the clinical symptoms and signs, including pain which is more severe than would be expected from the fracture. Pain may be an unreliable indication; it can be very variable (Eaton and Green 1975; Whitesides et al 1975; Matsen and Krugmire 1978), and may be absent in an established acute compartment syndrome associated with nerve injury (Holden 1979; Wright, Bogoch and Hastings 1989), or minimal in the deep posterior compartment syndrome (Matsen and Clawson 1975; Matsen and Krugmire 1978). Sensory symptoms and signs are often the first indication of nerve ischaemia, and if a motor deficit develops full recovery is rare (DeLee and Stiehl 1981; Rorabeck 1984; Schwartz et al 1989; Willis and Rorabeck 1990).

Delay in diagnosis is often due either to inexperience and lack of suspicion, or to an indefinite and confusing clinical presentation. Delay in treatment can be catastrophic leading to contracture, infection and occasionally amputation. McQuillan and Nolan (1968) reported four of 15 cases of acute compartment syndrome in which the diagnosis was delayed by more than 24 hours; because of this all four patients had persistent motor and sensory deficits. This warning is repeated in many other reports (Matsen and Clawson 1975; Rorabeck and Macnab 1976; Sheridan and Matsen 1976; Matsen and Krugmire 1978; DeLee and Stiehl 1981; Rorabeck 1984). The critical delay is considered to vary from 6 to 24 hours.

Current opinion is that there is a variety of indications for compartment pressure monitoring. These include an unconscious patient (Whitesides et al 1975; Gelberman et al 1981; Hargens et al 1989; Schwartz et al 1989), a patient difficult to assess, such as a young child (Whitesides et al 1975; Willis and Rorabeck 1990), patients with equivocal symptoms and signs (Gelberman et al 1981), particularly in the presence of concomitant nerve injury (Whitesides et al 1975; Wright et al 1989) and those with multiple injuries (Bourne and Rorabeck 1989; Schwartz et al 1989; Willis and Rorabeck 1990). Both Shereff (1990) and Myerson (1991) state that the clinical diagnosis of compartment syndrome in the foot is so unreliable that compartment pressure monitoring is essential.

Others consider that routine pressure monitoring may be unnecessary because of the infrequent occurrence of compartment syndrome, the fact that pressure measurements are cumbersome, and because the need for fasciotomy is clinically apparent (Rollins, Bernhard and Towne 1981). Despite this statement five of the patients in the study of Rollins et al had sequelae of acute compartment syndrome because the diagnosis had been delayed.

We have reviewed the effect of compartment pressure monitoring on the outcome of tibial diaphyseal fractures

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0301-620X/96/11110 $2.00

Table I. Classification of the tibial fractures complicated by acute compartment syndrome according to Oestern and Tscherne (1984) and Gustilo and Anderson (1976)

	Number
Tscherne (closed)	
0	2
1	12
2	8
3	1
Gustilo (open)	
I	1
II	1
Total	25

complicated by acute compartment syndrome.

PATIENTS AND METHODS

From January 1988 to July 1992 a total of 25 patients with tibial diaphyseal fractures complicated by acute compartment syndrome were admitted to the Orthopaedic Trauma Unit of the Royal Infirmary of Edinburgh. There were 23 male and two female patients with an average age of 28 years (15 to 83). Sixteen had sporting injuries and seven had been involved in road-traffic accidents. One had had a simple fall and one had fallen from a height of 30 feet.

Twenty-three of the fractures were closed and two were open and their classifications are shown in Table I. Most of the closed fractures were in Tscherne grades 1 or 2, which is a similar distribution to that of all tibial diaphyseal fractures in Edinburgh (Court-Brown, Christie and McQueen 1990). Seventeen fractures were treated by intramedullary nailing and eight by external fixation.

Six patients had additional injuries, and two of them had fractures of the ipsilateral femur, which implies major limb injury.

Pressure monitoring was at the discretion of the surgeon in charge. A slit catheter (Rorabeck et al 1981) was placed in the anterior compartment. The clinical diagnosis of acute compartment syndrome was made depending on the presence of some or all of the clinical indications (severe pain, stretch pain, sensory deficit, motor deficit), a differential pressure (ΔP) of less than 30 mmHg between the diastolic and compartment pressures (McQueen and Court-Brown 1996) or a combination of both clinical and pressure indications.

Twenty-three patients had measurement of the compartment pressure: in 13 this started within eight hours of injury. In ten patients it began only immediately before fasciotomy to confirm the clinical diagnosis. Two had no monitoring. There were therefore 12 patients who did not have early continuous monitoring.

Twenty-four patients had double incisions with fasciotomy of all four compartments. One patient had fasciotomies of the anterior and lateral compartments only with no monitoring of the superficial or deep posterior compartments. Twenty-four hours later, exploration prompted by pain and stretch pain of the toe flexors revealed necrosis of the muscles of the deep posterior compartment.

Two patients died from other injuries leaving 23 available for review after a mean of 10.5 months (4 to 32). The time to bone union was assessed by one observer (CCB) with no knowledge of whether monitoring had been used. Bone union was defined as the ability of the patient to bear weight without pain on the unprotected leg and by the presence on radiographs of bridging callus.

Statistical analysis used the Wilcoxon rank-sum test, the chi-squared test and multiple logistic regression.

RESULTS

The average delay from admission to fasciotomy was 23 hours (4 to 80). In the 12 patients who had late or no monitoring the delay averaged 32 hours (4 to 80). In the 13 who had early monitoring the average delay was 16 hours (4 to 28). The difference is statistically significant (Wilcoxon rank-sum test, $p < 0.05$). The average delay from fracture manipulation and fixation to fasciotomy in the non-monitored group was 24 hours (4 to 64); in the monitored group it was 7 hours (0 to 24).

Four patients in the monitored group had delayed onset of the compartment syndrome at 14, 16, 18 and 24 hours, respectively after surgery, all being diagnosed by pressure monitoring. In two patients there was a clear association between reduction and fixation of the fracture and a rise in pressure to critical levels. One had been treated by intramedullary nailing and the other by closed external fixation.

One patient in the non-monitored and one patient in the monitored group died from their other injuries, leaving 11 and 12 patients respectively in the two groups. In the former, 10 of the 11 patients had continuing problems secondary to their acute compartment syndrome; there was muscle weakness in six, muscle contractures in three and soft-tissue infection in one. One patient with muscle weakness also had a permanent sensory deficit.

None of the 12 patients in the early monitored group had any sequelae of acute compartment syndrome, and the difference between groups is statistically significant (chi-squared test = 10.36, $p < 0.01$; Table II). As regards the severity of the original injury the Wilcoxon rank-sum test showed no significant differences between the two groups for either fracture type or the number of compartments

Table II. Complication rates for monitored and non-monitored patients with acute compartment syndrome after tibial fracture

	Complications	No complications	p value
Monitored patients (n = 12)	0	12	
			< 0.01
Non-monitored patients (n = 11)	10	1	

involved. Multiple logistic regression showed that the use of early monitoring still predicted fewer complications ($p < 0.05$) even after adjustment for delay and the number of compartments involved.

The average time to union in the 23 patients was 21 weeks (Table III). The 11 Tscherne grade-1 fractures had a mean time to union of 19 weeks (9 to 42) and the 7 Tscherne grade-2 fractures united at a mean of 23 weeks (12 to 29). For the monitored fractures mean union was at 17 weeks (9 to 26) and for the non-monitored fractures 25 weeks (13 to 42). Three fractures in the non-monitored group required further surgery to achieve union, but no fractures in the monitored group were considered to show delayed union. The Wilcoxon rank-sum test showed that the use of early compartment monitoring had a significant influence in reducing time to union ($p < 0.05$), as did a shorter time to fasciotomy ($p < 0.05$).

Table III. Union rates (weeks; range) for monitored and non-monitored patients with acute compartment syndrome after tibial fracture

Tscherne grade	All	Monitored	Non-monitored
1 (n = 11)	19 (9 to 45)	14 (9 to 16)	29 (13 to 42)
2 (n = 7)	23 (12 to 29)	20 (12 to 26)	26 (18 to 31)

In all 25 patients the anterior compartment was involved. Six of these had positive surgical findings in all four compartments, three had involvement of the anterior and the lateral compartments and four of the anterior and deep posterior compartments. Twelve had isolated involvement of the anterior compartment.

During the period of the study, 622 tibial diaphyseal fractures were treated in our Orthopaedic Trauma Unit, giving an incidence of acute compartment syndrome after tibial fracture of 4%. Of these, 166 were open tibial diaphyseal fractures and the incidence of acute compartment syndrome in these was 1.2%. The difference in incidence between closed and open tibial fractures is not significant (chi-squared test, $p < 0.1$).

There were 342 tibial fractures in patients aged 35 years or younger and 280 in those aged over 35 years; 22 of the cases of acute compartment syndrome were in the younger group and only three in the older group. All three of the older patients had multiple injuries and one was hypotensive. There was a significantly higher risk of acute compartment syndrome in the younger group ($p < 0.01$, chi-squared). This was not related to the incidence of high-energy injury; 43% of the younger group had high-energy injuries compared with 55% of the older group.

DISCUSSION

Our results show that the use of early continuous compartment monitoring significantly reduced the delay to fasciotomy and therefore the long-term sequelae of acute compartment syndrome. The absence of complications in the early monitored group clearly indicates its advantages.

It is widely accepted that delay is disastrous. McQuillan and Nolan (1968) considered that delay to fasciotomy was the only cause of failure in their series, and this view has been reinforced by others (Matsen and Clawson 1975; Sheridan and Matsen 1976; Gelberman et al 1981; Rorabeck 1984; Schwartz et al 1989). The use of compartment monitoring heightens awareness of the possibility of the syndrome and confirms clinical findings. It also significantly reduces delay to fasciotomy and the incidence of complications. We therefore recommend that all tibial fractures, when equipment is available, should have continuous monitoring.

It was a surprise to find that the use of monitoring alone has a significant effect on the outcome even when the effects of delay and severity of fracture are eliminated. One explanation may be that the patients who were monitored tended to be those treated by orthopaedic trauma specialists; the direct influence of monitoring on outcome may be a reflection of awareness of the problem and better surgery.

Firm criteria for the patient 'at risk' would help to allow selective use of compartment monitoring, which may be a limited resource in many centres. We have shown that young patients with tibial fractures are at a higher risk: in our series 7% of this group developed the syndrome as against 1% in the older age group. It is possible that this is due to the relatively large muscle volume in young patients.

We found a significant delay in bone union in fractures which were not monitored; all these injuries had longer-term sequelae and therefore by implication significant muscle necrosis. These patients may have lacked the normal extraosseous blood flow derived from the muscle (Gothman 1960), which supplies developing callus. This clinical observation supports our previous retrospective study (Court-Brown and McQueen 1987) and is confirmed by experimental work which demonstrated both a reduction in bone blood flow (McQueen and Fleming, unpublished data) and a delay in bone union (McQueen et al, unpublished data) after acute compartment syndrome.

It is difficult to define the exact time of onset of acute compartment syndrome; the time of injury is not necessarily the time of onset of the syndrome. This is demonstrated in the four patients in whom onset occurred from 14 to 24 hours after surgery. Two patients with a rise in compartment pressure soon after fracture reduction and fixation also serve to illustrate the 'finger-trap' phenomenon (Matsen and Clawson 1975).

In open fractures, we found a 1.2% incidence of acute compartment syndrome. This is lower than the incidence of 6% quoted by DeLee and Stiehl (1981) and of 9.1% quoted by Blick et al (1986). The latter made the diagnosis on pressures of 30 mmHg or more and may have overdiagnosed. It is clear that the belief of Rorabeck and Macnab (1976) that the presence of an open fracture prevents a

significant rise in intracompartmental pressure is mistaken.

Fasciotomy of all four compartments is always required in the absence of compartment monitoring to avoid serious complications. The need for this is illustrated by the patients who had decompression initially only of the anterior and lateral compartments and 24 hours later required excision of the deep posterior compartment.

We found that the anterior compartment is consistently affected in tibial fractures complicated by acute compartment syndrome. Sheridan and Matsen (1976) also reported that the anterior compartment was most commonly involved. Gershuni et al (1987) found that 30 of 32 tibial fractures complicated by an acute compartment syndrome had anterior compartmental involvement, but they did not use pressure measurements. The monitoring of all four compartments is cumbersome and it seems unlikely that the anterior compartment will not be involved in an acute compartment syndrome. The anterior compartment should be monitored routinely; other compartments need be investigated only if there is clinical suspicion of involvement.

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.

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