THE JOURNAL OF BONE & JOINT SURGERY (BR)

Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia

S. Gopal, S. Majumder, A. G. B. Batchelor, S. L. Knight, P. De Boer, R. M. Smith

From St James's University Hospital, Leeds and York District Hospital, York, England

We performed a retrospective review of the case notes of 84 consecutive patients who had suffered a severe (Gustilo IIIb or IIIc) open fracture of the tibia after blunt trauma between 1990 and 1998. All had been treated by a radical protocol which included early soft-tissue cover with a muscle flap by a combined orthopaedic and plastic surgery service. Our ideal management is a radical debridement of the wound outside the zone of injury, skeletal stabilisation and early soft-tissue cover with a vascularised muscle flap. All patients were followed clinically and radiologically to union or for one year.

After exclusion of four patients (one unrelated death and three patients lost to follow-up), we reviewed 80 patients with 84 fractures. There were 67 men and 13 women with a mean age of 37 years (3 to 89). Five injuries were grade IIIc and 79 grade IIIb; 12 were site 41, 43 were site 42 and 29 were site 43. Debridement and stabilisation of the fracture were invariably performed immediately. In 33 cases the soft-tissue reconstruction was also completed in a single stage, while in a further 30 it was achieved within 72 hours. In the remaining 21 there was a delay beyond 72 hours, often for critical reasons unrelated to the limb injury. All grade-IIIc injuries underwent immediate vascular reconstruction, with an immediate cover by a flap in two. All were salvaged. There were four amputations, one early, one mid-term and two late, giving a final rate of limb salvage of 95%. Overall, nine pedicled and 75 free muscle flaps were used; the rate of flap failure was 3.5%. Stabilisation of the fracture was achieved with 19 external and 65 internal fixation devices (nails or plates). Three patients had significant segmental defects and required bone-transport procedures to achieve bony union. Of the rest, 51 fractures (66%) progressed to primary bony union while 26 (34%) required a bone-stimulating procedure to achieve this outcome. Overall, there was a rate of superficial infection of the skin graft of 6%, of deep infection at the site of the fracture of 9.5%, and of serious pin-track infection of 37% in the external fixator group. At final review all patients were walking freely on united fractures with no evidence of infection.

The treatment of these very severe injuries by an aggressive combined orthopaedic and plastic surgical approach provides good results; immediate internal fixation and healthy soft-tissue cover with a muscle flap is safe. Indeed, delay in cover (>72 hours) was associated with most of the problems. External fixation was associated with practical difficulties for the plastic surgeons, a number of chronic pin-track infections and our only cases of malunion. We prefer to use internal fixation. We recommend primary referral to a specialist centre whenever possible. If local factors prevent this we suggest that after discussion with the relevant centre, initial debridement and bridging external fixation, followed by transfer, is the safest procedure.

J Bone Joint Surg [Br] 2000;82-B:959-66.
Received 18 August 1999; Accepted 8 February 2000

An open fracture is contaminated, and usually results from a high-energy injury, which may threaten the limb and occasionally life.[1,2] The question of amputation or salvage for the more severe injuries still generates heated debate.[3-5] While limb salvage is the initial aim, medium- and long-term problems with soft-tissue cover, infection and union are all too common and result in serious disability.[1,2,6-10] The unique anatomy of the tibia with its associated soft tissues and their vulnerability to severe injury produces most of these problems.[11,12] Most orthopaedic surgeons work outside a referral centre and although called on to manage these injuries, with subsequent referral to a department of plastic surgery for delayed soft-tissue reconstruction, individually they usually have limited personal experience of the more serious injuries.[13]

S. Gopal, BSc, MS Orth, Specialist Registrar
R. M. Smith, MD, FRCS, Consultant Orthopaedic Surgeon
Department of Orthopaedics and Trauma
S. Majumder, FRCS Ed, FRCS G, Specialist Registrar
A. G. B. Batchelor, FRCS, FRCS (Plastic Surg), Consultant
S. L. Knight, FRCS, Consultant
Department of Plastic and Reconstructive Surgery
St James's University Hospital, Beckett Street, Leeds LS9 7TF, UK.

P. De Boer, FRCS, Consultant
York District Hospital, Wiggington Road, York YO3 8HE, UK.

Correspondence should be sent to Mr R. M. Smith.

©2000 British Editorial Society of Bone and Joint Surgery
0301-620X/00/710482 $2.00

Primary collaboration by orthopaedic and plastic (microvascular) surgeons in a central unit has many potential advantages and has been widely recommended.[14-21] Unfortunately, in practice, this facility is often unavailable. We are fortunate to work in a hospital in which close co-operative management of these injuries has been practised for some years and there is an established regional referral system. This has given us considerable experience of these difficult problems and the opportunity to document the results.

The established management of severe open fractures is based on a philosophy of initial wound debridement and lavage, stabilisation of the fracture and delayed wound closure.[13] Debridement may need repeating because of the difficulty of assessing tissue viability. The bone is usually stabilised with an external fixator because of concerns regarding the implantation of metal into a contaminated field. Soft-tissue cover is delayed to allow for wound swelling and facilitates a second-look procedure to reassess tissue viability. Although widely accepted, this treatment has been challenged, as repeated debridement and delayed closure may lead to additional tissue loss because of desiccation and infection.[14,15,21,22]

The orthopaedic management of this injury has changed considerably in recent years. While there remain enthusiasts for external fixation,[20] the use of larger hollow nails inserted after reaming and thinner solid unreamed nails has also become more popular, and each has their advocates.[23,24] While there has been a progressive change from external to internal fixation as experience has increased, most reports of internal fixation or primary nailing describe the technique in grade-I to grade-IIIa fractures and very few grade-IIIb injuries are included.[25,26]

Plastic surgery has progressed from the difficulties of the tubed pedicle to modern microvascular techniques for free-tissue transfer, as initially championed by Godina.[27] This has revolutionised the potential for reconstruction. Use of a vascularised muscle flap rapidly and reliably converts the severe open fracture from an open to a closed injury in a single stage. This facilitates the use of any appropriate implant for skeletal stabilisation. Using these techniques, our group has developed a protocol of immediate radical debridement by an experienced multidisciplinary team. The fracture is stabilised by the implant most suited to the local anatomy, with early, preferably immediate, soft-tissue reconstruction with a muscle flap, subsequently covered by a split-skin graft. We have been encouraged by the results of this technique and now present our experience with open, grade-IIIb and grade-IIIc fractures of the tibia.

Patients and Methods

We retrospectively reviewed the records of 84 patients who had been seen primarily or referred to our department between 1990 and 1998 with an open fracture of the tibia graded OIIIb or OIIIc. Three patients had left our region or consistently failed to attend follow-up and were excluded from analysis, as was an elderly patient who died from unrelated causes before her fracture united. The remaining 80 patients (84 fractures) had received successful reconstruction of their soft tissue by a muscle flap and had progress to bone union or amputation. All had been jointly managed by our orthopaedic and plastic surgical services. Some had initial or later management outside our unit.

Protocol. Ideally, we treated a grade-IIIb injury by immediate radical wound debridement outside the zone of injury with profuse lavage, skeletal stabilisation by the implant appropriate to the anatomy of the fracture (using biological AO techniques), and immediate, definitive soft-tissue cover with a vascularised muscle flap with a split-skin graft. The choice between a pedicle and a free muscle flap depends on the anatomy of the injury to the soft tissue. In a grade-IIIc injury vascular reconstruction took priority but otherwise the protocol was the same. If immediate reconstruction of soft tissue was impractical our aim was to obtain soft-tissue cover within 72 hours of the accident.

The routine postoperative rehabilitation included initial support with a plaster slab until soft-tissue stability allowed fitting of a bivalved, below-knee, light-weight cast. The patients were allowed to move their joints out of the cast but weight-bearing was supported by it until early bony stability was obtained. In all cases at least toe-touch contact was encouraged, with the importance of weight-bearing emphasised and increased as soon as possible. Mobilisation was only limited if prevented by additional injuries.

Antibiotics (cefuroxime and metronidazole) were prescribed for the first five days. Subsequent antibiotics were given according to the indications from cultures from swabs usually from the areas of superficial skin graft. All the patients were followed up until union of the fracture (defined as full weight-bearing without pain and radiological callus in two planes at right angles to each other) or for a minimum of one year. Secondary bone-stimulating procedures were performed early whenever problems of union were considered likely as judged by the condition of the bone at the initial surgery. These included exchange nailing, autogenous bone grafting and transport techniques. No allograft was used.

Before December 1992 a more conservative policy, with external fixation, some repeated debridements and often delayed flap cover, was employed. After December 1992 a more aggressive approach was introduced, with immediate bony stabilisation and flap cover. Our earlier patients, those referred for reconstruction after a primary procedure elsewhere (and often followed up elsewhere), and our own patients whose management deviated from our ideal protocol, were also included in the study, to allow comparison of the results.

Results

We reviewed 80 patients with 84 severe open fractures (79 IIIb (94%) and 5 IIIc (6%)). All had been followed up to

the end of their clinical course, amputation, union or death for a minimum of one year. There were 67 men (80%) and 13 women (15%) with a mean age of 37 years (3 to 89). Table I gives the basic data, including age, open classification,[2] AO fracture classification, method of stabilisation, type of flap, timing of surgery and the results. The fractures included 12 site-41, 43 site-42 and 29 site-43 injuries as shown in Table II. The timings of the various procedures are shown in Table III. Analysis of the results by the method of fixation is summarised in Tables IV and V and with regard to the timing of the soft-tissue cover in Tables VI and VII.

Limb salvage. All patients with grade-IIIc injuries had immediate vascular reconstruction. In two the flap was incorporated into the same operation, with vascular anastomosis, while in the other three the soft-tissue cover was completed at a further procedure within 72 hours. All were saved and united with excellent function. Two were children, and at the last review both had functioning epiphyseal plates in the injured tibia.

There were four amputations. One followed the failure of a primary flap in an elderly patient with arterial disease and one after a serious acute infection in a farmyard injury associated with a defect of the distal femur; both patients had early amputations. Two further patients elected to have amputations over a year after injury, but both decisions were made outside our unit. All other patients had good functional outcomes, walking freely on united fractures, with no evidence of infection at final follow-up. The salvage rate of the functional limb was 95%.

Soft-tissue reconstruction. Soft-tissue cover was achieved with nine pedicle flaps (seven gastrocnemius and two soleus) and 75 free muscle-flap procedures (58 latissimus dorsi, seven gracilis and ten rectus abdominis)

On four occasions a combination of flaps (three gastrocnemius + latissimus dorsi and one serratus anterior + latissimus dorsi) were used to cover extensive defects. On 33 occasions (39%) a single acute procedure was performed. In a further 20 (24%) the soft-tissue cover was completed within two days, and in ten (12%) within three days. Therefore soft-tissue cover was established within 72 hours in 75% of patients and in a further 13 within a week. In eight patients it was delayed by over one week, with a maximum of 20 days, because of clinical circumstances independent of the leg injury. Three of 84 flaps failed (3.5%). One elderly patient with arterial disease required amputation and two others were rescued with a second free tissue flap.

Bony stabilisation and healing. Nineteen patients had stabilisation of the fracture with external fixation and 65 with an internal device (28 AO unreamed tibial nails, three reamed tibial nails, 34 with plates and screws). After exclusion of the four limbs which were amputated, 76 patients with 80 fractures were available for analysis of the long-term results. All the fractures had united. Detailed results according to the fixation device employed are shown in Tables IV and V.

Internal fixation group. After exclusion of the four with amputations, 58 patients with 61 fractures were available for follow-up. Two, who had primary nailing, had segmental defects requiring bone transport over the nail. Both united. All the remaining 59 fractures united at a mean of 25 weeks. While 40 (66%) united primarily, 19 (33%) required a bone-stimulating procedure (17 autogenous bone grafts and two exchange tibial nails) to obtain union. Most of these bone-stimulating procedures were performed early when problems with union were anticipated. In two patients it was delayed because of other problems until 15 months (united three months later) and 18 months (united six months later). Bone grafts were also applied early for partial circumferential defects and in one case used successfully to bridge a 9 cm tibial defect.

External fixation group. Nineteen patients were available for analysis. One had a segmental defect requiring transport which subsequently united (noted below). One elderly man developed a hypertrophic nonunion, which was painless, such that he was able to mobilise in a brace. He elected not to have a bone graft and eventually his fracture united while braced approximately four years after injury. All of the other 17 patients had union of their fractures in a mean time of 30 weeks. Secondary bone-stimulating procedures were performed in seven patients: five had autogenous bone graft alone, one a graft with plating and one exchanged to a reamed nail. In addition, there were four cases of malunion, with an angular deformity >10°, two of which required corrective osteotomies.

Bone-transport group. Three patients had a bone-transport procedure performed for extensive segmental defects, one after primary external fixation and two after initial unreamed nailing. Transport frames were fitted after stability of soft tissue had been obtained. All defects had healed at the final follow-up. Bone transport in the presence of the muscle flap or of unreamed nails did not produce additional problems.

Infection. The rate of superficial infection was 6% (5/84 fractures); these problems resolved with antibiotics and local care of the skin graft. The rate of deep bony infection at the site of initial fracture site was 9.5% (8/84). The number in each implant group was too small to identify a significant difference, but the rate seemed higher when the flap was applied later. The best results were with the single-stage procedure with internal fixation in which the only deep infection (3%) was in an elderly diabetic with a severe open pilon fracture. In the late flap group the rate of deep bony infection was 19% (4/21).

In the external fixator group pin-track infection occurred in ten out of 19 (53%); seven (37%) became chronic. In the nailing group the most severe deep infection was associated with an inadequate, initial bony debridement and a late flap. The addition of an Ilizarov ring fixator to provide additional stability to the proximal element of a complex 41-42 segmental fracture in one patient led to deep infection after unsatisfactory primary stabilisation with an unreamed nail.

Table I. Details of the 84 patients with open fracture of the tibia

Age (yr)	Gustilo classification	Injury severity score	OTA/AO classification	Fixation*	Flap†	Flap timing (hr)	Secondary procedures‡	Union (wk)
27	IIIb	18	42.C3.3	UTN	LD	48	Amputation	-
29	IIIb	9	42.B1.3	UTN	LD	48		30
32	IIIb	9	43.C1.1	ORIF	GRA	48		50
52	IIIc	9	43.A1.3	ORIF	LD	24	Bone graft 7 wks	18
41	IIIb	10	42.A3.3	ORIF	LD	24	Bone graft 5 wks	38
41	IIIb	10	41.B2.3	EF	GAS	24		25
60	IIIb	9	42.B3.2	UTN	LD	24		28
71	IIIb	13	43.C2.2	ORIF	RA	48		30
42	IIIb	4	43.C1.2	ORIF	LD	24		12
32	IIIb	34	41.B3.1	ORIF	LD	72	Amputation	-
89	IIIb	9	43.B2.3	UTN	LD	5 days	Amputation	-
24	IIIb	9	43.B3.2	ORIF	LD	48	Bone graft 6 wks	50
25	IIIb	10	42.B2.3	RTN	LD	5 days		28
30	IIIb	9	42.B1.2	UTN	LD	48		21
3	IIIc	25	42.A1.1	ORIF	LD	48		14
26	IIIb	9	43.B2.3	UTN	LD	5 days		36
18	IIIb	9	42.A3.3	UTN	LD	72		42
37	IIIb	13	42.C1.2	ORIF	LD	24		25
59	IIIb	9	43.C3.3	ORIF	LD	5 days	Bone graft 16 wks	44
49	IIIb	9	41.B3.1	ORIF	LD	72		32
61	IIIb	9	43.C1.1	ORIF	LD	6 days		32
54	IIIb	29	42.B1.3	UTN	LD	6 days	Bone graft 6 wks	27
22	IIIb	9	42.A1.2	RTN	SOL	24		16
60	IIIb	10	42.C2.1	UTN	RA	72		30
27	IIIb	10	43.B2.2	ORIF	LD	24		14
22	IIIb	9	43.C1.1	UTN	LD	13 days		20
28	IIIb	14	43.B3.2	UTN	LD	24		26
31	IIIb	9	43.B1.3	UTN	LD	48		22
20	IIIb	9	42.C2.1	UTN	LD	24	Bone graft 17 wks	45
25	IIIb	9	43.B2.2	ORIF	LD	24		30
33	IIIb	9	42.B3.3	ORIF	LD	24	Bone graft 6 wks	24
11	IIIb	41	43.A3.2	ORIF	RA	24		26
67	IIIb	9	43.C3.1	ORIF	GRA	48	Bone graft 2 wks	52
65	IIIb	10	43.C3.2	ORIF	LD/RA	16 days		13
30	IIIb	13	42.B2.3	UTN	RA	6 days		35
45	IIIb	10	41.B3.3	ORIF	LD	48		8
30	IIIb	4	43.C1.1	ORIF	LD	48		19
28	IIIb	9	42.A3.3	UTN	GRA	72		19
12	IIIc	9	43.C3.2	ORIF	LD	24	Bone graft 64 wks	78
56	IIIb	10	43.B2.2	UTN	LD	24	Bone graft 9 wks	50
64	IIIb	9	43.C3.2	ORIF	LD	18 days	Amputation	-
43	IIIb	13	43.C2.3	ORIF	GRA	6 days	Bone graft + plate	34
79	IIIb	9	43.B2.1	ORIF	LD	16 days		32
22	IIIb	9	42.C3.2	UTN	LD+GAS	7 days	Bone graft 10 wks	25
26	IIIb	10	42.A1.2	ORIF	LD	48	Bone graft + flap	12
26	IIIb	10	42.A1.2	ORIF	LD	48	Bone graft + flap	36
48	IIIb	9	42.A2.1	UTN	LD	24		24
23	IIIb	9	42.A1.2	UTN	RA	24		20

Table I (cont'd). Details of the 84 patients with open fracture of the tibia

Age (yr)	Gustilo classification	Injury severity score	OTA/AO classification	Fixation*	Flap†	Flap timing (hr)	Secondary procedures‡	Union (wk)
58	IIIb	26	42.A2.1	UTN	LD	24	Bone graft + flap	28
21	IIIb	26	42.B1.2	UTN	GRA	48		52
14	IIIb	9	41.A2.2	ORIF	SOL	24		10
14	IIIb	9	42.A2.2	ORIF	LD	48		10
27	IIIb	9	41.B2.2	UTN	GAS	36	Suppl. Ilizarov	66
27	IIIb	9	42.C2.3	UTN	LD+SA	36	Ex. RTN 40 weeks	66
28	IIIb	25	42.C2.3	RTN	LD	17 days		36
62	IIIb	22	41.B1.1	ORIF	GAS	4 days		37
51	IIIb	13	41.B2.3	ORIF	LD	24	Bone graft + plate	20
16	IIIb	26	42.B2.1	UTN	LD	24	Ex. RTN 21 weeks	50
8	IIIb	9	42.B2.2	ORIF	RA	24		8
32	IIIb	4	43.C1.2	ORIF	LD	24		13
83	IIIb	9	42.B1.2	ORIF	GRA	48		28
19	IIIb	50	42.A2.3	UTN	GAS	72		28
27	IIIb	14	42.B3.3	UTN	LD	24		48
36	IIIb	9	43.C2.2	ORIF	RA	48	Bone graft 76 wks	100
71	IIIb	9	41.C3.1	EF	GAS	72	Shortening + flap	53
10	IIIb	10	42.A1.2	EF	RA	24		12
50	IIIb	9	41.C2.1	EF	LD+GAS	24		34
42	IIIc	9	41.B2.2	EF	GAS	24		78
50	IIIc	18	43.C1.3	EF	LD	72	Ex. RTN 62 weeks	80
16	IIIb	9	42.B2.3	EF	LD	48		48
38	IIIb	13	42.C2.3	EF	LD	4 days	Bone graft 19 wks	88
71	IIIb	9	42.B2.1	EF	LD	72		4 years
28	IIIb	9	42.B2.1	EF	LD	7 days		10
33	IIIb	9	43.C3.3	EF	LD	15 days	Bone graft + plate	56
67	IIIb	27	42.C3.1	EF	LD	24		11
9	IIIb	9	42.A3.3	EF	GRA	7 days		12
23	IIIb	9	42.B2.3	EF	RA	72	Bone graft 18 wks	56
29	IIIb	9	43.B3.2	EF	LD	24	Bone graft 21 wks	72
18	IIIb	9	43.A1.2	EF	LD	24	Bone graft 20 wks	104
6	IIIb	9	42.A3.1	EF	LD	24		12
30	IIIb	9	42.C3.1	EF	LD/RA	9 days	Bone graft + flap	112
54	IIIb	9	41.C3.2	EF	GAS	20 days	UTN + Ilizarov BT	78
36	IIIb	9	42.C3.1	UTN	RA	24	Ilizarov BT	70
38	IIIb	9	42.C3.2	UTN	LD+GAS	24	Ilizarov BT	61

* ORIF, plating; UTN, unreamed tibial nail; RTN, reamed tibial nail; EF, external fixation
† GAS, gastrocnemius; SOL, soleus; GRA, gracilis; LD, latissimus dorsi; RA, rectus abdominis; SA, serratus anterior
‡ Ex., exchange nailing; BT, bone transport; Suppl., supplementary

Table II. Summary data of fracture anatomy and initial treatment

OTA/AO classification	Total	Nails	Plates	External fixator	Free flap	Pedicle flap
41 (proximal metaphysis)	12	1*	6	6*	5†	8†
42 (diaphysis)	43	24	9	10	42†	4†
43 (distal metaphysis)	29	6	19	4	29	0

* nail + supplementary external fixator for one segmental OTA 41 + 42 injury
† three patients had combination free + pedicle flap and one patient had two free flaps for extensive defects

Table III. Details of the timing of treatment

	Days			Weeks					
	1	2 to 3	4 to 7	2	3	4 to 5	6 to 10	11 to 15	>15
Bone stabilisation	83	0	1	0	0	0	0	0	0
Flaps	33	30	13	3	6	0	0	0	0
Bone stimulation	3	2	0	2	0	1	6	0	12*

* two patients had bone grafting after one year -- both initial ORIF (plating)

Table IV. Details of the results according to the fixation device used

Fixation device	Number	Amputation	Union time (wk)*
Nail	31 (2 RTN)	2 (1 early, 1 late)	29 (7)
Plates	34	2 (1 mid, 1 late)	22 (12)
External fixator	19	-	30*† (7)

* (number stimulated)
† four malunion >10° in external fixator group; two corrective osteotomies

While the diaphyseal fractures healed without complications, one severe pin-track infection required surgical treatment and delayed recovery. The contralateral grade-IIIb fracture was treated by nailing alone with free flap cover and healed uneventfully.

There were no deep infections in the grade-IIIc fractures.

Discussion

Our results show that this aggressive management of the severe open fracture of the tibia was effective. We accept that this approach is radical, and that it has been claimed that immediate soft-tissue cover is not safe.[2,28-30] However, analysis of our cases shows excellent union and low rates of infection, supporting the concept that delay is not necessary if healthy soft tissue can be imported reliably into the zone of injury. It should be emphasised that in previous reports 'early soft-tissue cover' usually means within 72 hours.[27] Many of our cases were completed as a single primary procedure; only Hertel et al[21] have presented a comparable, but smaller, series. Most of our problems were associated with deviations from this protocol, particularly because of delay in soft-tissue cover and the use of external fixation devices.

Table V. Details of infections according to the fixation device used

	Acute		Chronic		Pin site	
Fixation device	Skin graft	Fracture site	Skin graft	Fracture site	Minor	Chronic
Nails	2	0	0	1*	0	0
Plates	2	2†	0	3‡	0	0
External fixator	1	0	0	2	3	7

* late flap
† one farmyard accident and one late flap
‡ one diabetic and two late flaps

Table VI. Details of the results related to the timing of soft-tissue cover

Timing of cover (hr)	Number	Amputation	Time to union (wk)*		Skin infection	Deep infection
			Internal fixation	External fixation		
Immediate (<24)	33	0	28 (9)	44 (2)	2 (*6%*)	1 (*3%*)†
Early (<72)	30	2	36 (6)	60 (2)	4 (*13%*)	3 (*10%*)‡
Late (>72)	21	2	31 (4)	56 (3)	7 (*33%*)	6 (*30%*)

* (Number stimulated)
† patient with external fixation
‡ one severe farm accident; one diabetic; one external fixator

Table VII. Details of infections related to the timing of the soft-tissue cover

Timing of cover (hr)	Acute		Chronic	
	Skin graft	Fracture site	Skin graft	Fracture site
<24	1	0	0	1*
24 to 72	1	1†	0	2‡
>72	3	1	0	3

* external fixation
† farmyard accident
‡ one external fixation

In the late group delay was associated with difficult clinical problems. This included some patients with serious associated injuries which delayed treatment and increased the risk of infection. Late referral because of personal clinical practices also contributed to this group, but even these results were acceptable.

We have noted some problems with external fixators. Those at the pin site are predictable, but some of these patients developed deep infection. This should be considered together with the other well-recognised disadvantages of external fixation, including poor access for soft-tissue reconstruction, delayed union, nonunion and malunion. It could be argued that there may have been some clinical selection of these cases, delaying or using an external fixator only in the more difficult. On review, this was not the case. The external fixators were applied for specific reasons to do with bone rather than soft tissue. We now only use an external fixation device as an occasional temporary splint (bridging frame), as an alternative to plating in the presence of open epiphyseal plates when a juxta-articular fracture is so close to the joint that a fine-wire fixator is the only device which will provide bony stability, or as a device for bone transport.

In this series a solid nail (AO-UTN) inserted by an unreamed technique was used for most of our nailed cases. It was chosen to avoid the potential dead space in a hollow nail and inserted without reaming to allow maximum preservation of the endosteal circulation in order to resist infection and improve the contribution of the bony fragments to union.[24,31] In our study, the rate of infection in the nailed cases was only 3%, and 74% united without a secondary procedure. These results compare well with other reviews of open fractures, especially as in these, lower grades of open fractures predominate,[23,25,31,32] emphasising the effectiveness of this implant in the more critical situation. The use of external fixators was associated with a higher incidence of problems with pin-site infection, increased time to bony union, malunion, and practical problems of access for the microvascular surgery and skin grafting. We note that similar incidences of these difficulties have been reported by others.[6,7,9,10]

In common with Hansen,[30] we consider that our aims are sequential namely to achieve limb salvage by the healing of soft tissues without infection, followed by early bony union. It is fortunate that the initial implant used to produce skeletal stability in order to resist infection was also effective in obtaining bony union in so many cases. Overall, the primary rate of union was 67% in the surviving limbs, excluding amputations and patients who required bone transport. This indicates that the longer-term aim of bone healing was often addressed satisfactorily with the primary bony procedure.

The prevention of infection depends on several factors. We believe that our low rate of infection is associated with the adequacy of the debridement, skeletal stabilisation[33] and the subsequent obliteration of the dead space by a healthy, well-vascularised and conforming muscle flap.[34,35] This also produces early soft-tissue cover. We consistently see cases referred after inadequate initial debridement elsewhere. This may be related to the inherent delay, and may indicate additional tissue death by desiccation before our procedure. It may also reflect the experience of the surgeon undertaking the primary treatment who does not perform an appropriate procedure. We believe that the ability to debride the wound thoroughly depends on the surgeon's confidence that the resulting defect can be reliably filled with healthy tissue within a short period. This depends on the experience of the whole team and the close working relationship between the orthopaedic and microvascular surgeons. The choice of technique for stabilisation of the fracture is facilitated by faith in the soft-tissue cover. This is illustrated by the low rate of complications seen when we used internal fixation (9%). Most of these infections had significant predisposing factors, especially delay in flap cover. We continue to select the best implant for the bony injury, as if it were a closed fracture.

Overall, these results show that in grade-IIIb and grade-IIIc open fractures of the tibia, modern techniques of management combining the skills of experienced orthopaedic and plastic surgeons can consistently restore excellent limb function in a very high proportion of patients. In some of the most severely injured limbs, salvage is possible and a useful functional limb can be obtained. It is important to understand what is possible when assessing such an injury, and it is critical to consider where the skills required are available. We believe that a regional referral system for these injuries is essential. Decisions on management should be made with knowledge of local facilities and personal experience, together with the potential treatment available in the most experienced centres. Outside the specialist unit and in more isolated geographical areas if primary transfer is not possible, we strongly recommend emergency lavage and debridement of the wound, temporary bridging, external fixation and emergency transfer after consultation with the appropriate referral centre.

We would like to acknowledge all of the staff of the Departments of Trauma and Orthopaedics and of Plastic and Reconstructive surgery at St James's University Hospital whose combined efforts we represent.

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

1. **Gustilo RB, Anderson JT.** Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analysis. *J Bone Joint Surg [Am]* 1976;58-A:453-8.
2. **Gustilo RB, Mendoza RM, Williams DN.** Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. *J Trauma* 1984;24:742-6.
3. **Hansen ST Jr.** Editorial. The type-IIIC tibial fracture: salvage or amputation. *J Bone Joint Surg [Am]* 1987;69-A:799-800.
4. **Georgiadis GM, Behrens FF, Joyce MJ, Earle S, Simmons AL.** Open tibial fractures with severe soft-tissue loss: limb salvage compared with below-the-knee amputation. *J Bone Joint Surg [Am]* 1993;75-A:1431-41.

5. **Fairhurst MJ.** The function of below-knee amputee versus the patient with salvaged grade-III tibial fracture. *Clin Orthop* 1994;301:227-32.

6. **Edwards CC, Simmons SC, Browner BD, Oreck SL, Weigel MC.** 203 open tibial fractures treated with Hoffmann external fixation. *Orthop Trans* 1984;8:383-4.

7. **Chan KM, Leung YK, Cheng JCY, et al.** The management of type III open tibial fractures. *Injury* 1984;16:157-65.

8. **Caudle RJ, Stern PJ.** Severe open fractures of the tibia. *J Bone Joint Surg [Am]* 1987;69-A:801-5.

9. **Blick SS, Brumback RJ, Lakatos R, Poka A, Burgess AR.** Early prophylactic bone grafting of high-energy tibial fractures. *Clin Orthop 1989;240:21-41.*

10. **Court-Brown CM, Wheelwright EF, Christie J, McQueen MM.** External fixation for type III open tibial fractures. *J Bone Joint Surg [Br]* 1990;72-B:801-4.

11. **Edwards CC, Simmons SC, Browner BD, Weigel MC.** Severe open tibial fractures. *Clin Orthop* 1988;230:98-115.

12. **Dellinger EP, Miller SD, Wertz MJ, et al.** Risk of infection after open fracture of the arm or leg. *Arch Surg* 1988;123:1320-7.

13. **Gustilo RB, Merkow RL, Templeman D.** Current concepts review: the management of open fractures. *J Bone Joint Surg [Am]* 1990;72-A:299-304.

14. **Byrd HB, Cierney G III, Tebbetts JB.** The management of open tibial fractures with associated soft-tissue loss: external pin fixation with early flap coverage. *Plast Reconstr Surg* 1981;68:73-9.

15. **Yaremchuk MJ, Brumback RJ, Manson PN, et al.** Acute and definitive management of traumatic osteocutaneous defects of the lower extremity. *Plast Reconstr Surg* 1987;80:1-14.

16. **Francel TJ, Vander Kolk CA, Hoopes JE, Manson PN, Yaremchuk MJ.** Microvascular soft tissue transplantation for reconstruction of acute open tibial fractures: timing of coverage and long-term functional results. *Plast Reconstr Surg* 1992;89:478-87.

17. **Kaye JC.** Management protocols in high-energy tibial fracture. *Ann R Coll Surg Engl* 1994;76:363-64.

18. **Green AR.** The courage to co-operate: the team approach to open fractures of the lower limb. *Ann R Coll Surg Engl* 1994;76:365-6.

19. **British Orthopaedic Association and British Association of Plastic Surgeons.** *A working party report.* The early management of severe tibial fractures: the need for combined plastic and orthopaedic management. September, 1997.

20. **Sinclair JS, McNally MA, Small JO, Yeates HA.** Primary free flap cover of open tibial fractures. *Injury* 1997;28:581-7.

21. **Hertel R, Lambert SM, Muller S, Ballmer FT, Ganz R.** On the timing of soft-tissue reconstruction for open fractures of the lower leg. *Arch Orthop Trauma Surg* 1999;119:7-12.

22. **Byrd HS, Spicer TE, Cierny G III.** Management of open tibial fractures. *Plast Reconstr Surg* 1985;76:719-28.

23. **Court-Brown CM, McQueen MM, Quaba AA, Christie J.** Locked intramedullary nailing of open tibial fractures. *J Bone Joint Surg [Br]* 1991;73-B:959-64.

24. **Tornetta P III, Bergman M, Watnik N, Berkowitz G, Steuer J.** Treatment of grade IIIB open tibial fractures: a prospective randomised comparison of external fixation and non-reamed locked nailing. *J Bone Joint Surg [Br]* 1994;76-B:13-9.

25. **Tu Y-K, Lin C-H, Su J-I, Hsu D-T, Chen R-J.** Unreamed interlocking nail versus external fixator for open type-III tibia fractures. *J Trauma* 1995;39:361-7.

26. **Keating JF, O'Brien PJ, Blachut PA, Meek RN, Broekhuyse HM.** Locking intramedullary nailing with and without reaming for open fractures of the tibial shaft: a prospective, randomised study. *J Bone Joint Surg [Am]* 1997;79-A:334-41.

27. **Godina M.** Early microsurgical reconstruction of complex trauma of the extremities. *Plast Reconstr Surg* 1986;78:285-92.

28. **Cierney G III, Byrd HS, Jones RE.** Primary *versus* delayed soft tissue coverage for severe open tibial fractures: a comparison of results. *Clin Orthop* 1983;178:54-63.

29. **Russell GG, Henderson R, Arnett G.** Primary or delayed closure for open tibial fractures. *J Bone Joint Surg [Br]* 1990;72-B:125-8.

30. **Hansen ST Jr.** *Open fractures in orthopaedic trauma protocols.* Hansen & Swinotowski, ed. New York: Raven Press, 1993.

31. **Rhinelander FW.** Tibial blood supply in relation to fracture healing. *Clin Orthop* 1974;105:34-81.

32. **Keating JF, O'Brien PJ, Blachut PA, Meek RN, Broekhuyse HM.** Reamed interlocking intramedullary nailing of open fractures of the tibia. *Clin Orthop* 1997;338:182-91.

33. **Worlock P, Slack R, Harvey L, Mawhinney R.** The prevention of infection in open fractures: an experimental study of the effect of fracture stability. *Injury* 1994;25:31-8.

34. **Holden CEA.** The role of blood supply to soft tissue in the healing of diaphyseal fractures: an experimental study. *J Bone Joint Surg [Am]* 1972;54-A:993-1000.

35. **MacNab I, de Haas WG.** The role of periosteal blood supply in the healing of fractures of the tibia. *Clin Orthop* 1974;105:27-33.