Early or delayed limb lengthening after acute shortening in the treatment of traumatic below-knee amputations and Gustilo and Anderson type IIIC open tibial fractures

THE RESULTS OF A CASE SERIES

F. Parmaksizoglu,
A. S. Koprulu,
M. B. Unal,
E. Cansu

From Yeni Yuzyil
University, Istanbul,
Turkey

We present the results of 13 patients who suffered severe injuries to the lower leg. Five sustained a traumatic amputation and eight a Gustilo-Anderson type IIIC open fracture. All were treated with debridement, acute shortening and stabilisation of the fracture and vascular reconstruction. Further treatment involved restoration of tibial length by callus distraction through the distal or proximal metaphysis, which was commenced soon after the soft tissues had healed (n = 8) or delayed until union of the fracture (n = 5).

All patients were male with a mean age of 28.4 years (17 to 44), and had sustained injury to the leg only. Chen grade II functional status was achieved in all patients. Although the number of patients treated with each strategy was limited, there was no obvious disadvantage in the early lengthening programme, which was completed more quickly.

High-energy motor vehicle accidents may result in extensive trauma to bone and soft tissue, for which radical debridement is necessary.¹⁻⁸ In order to enable provision of tension-free soft-tissue cover, substantial shortening of bone may be needed.^{3,9,10} These injuries occasionally result in traumatic amputation. In order to improve functional outcome after significant shortening, subsequent lengthening is required.^{3,5} Generally the achievement of union of the fracture and a lengthening procedure at the metaphysis, either distally or proximally, are undertaken consecutively, resulting in a long period of treatment. Employing both treatments concurrently offers a shorter duration of treatment. A few reports have described acute shortening and early lengthening in patients with a bone and soft-tissue defect, but these have been in patients without impaired distal circulation.^{3,10,11} However, acute shortening and delayed lengthening has been the preferred approach when tibial shortening has been undertaken to provide soft-tissue cover for re-implantation of traumatic amputations and in Gustilo-Anderson type IIIC¹² injuries when limb salvage is attempted.^{3,9-11}

Previously we had followed the approach of delayed lengthening for these severe injuries, in order to ensure that union of the fracture had occurred, and had measured the difference in leg length before performing lengthening at the metaphysis in a second-stage. Later we

adopted a method of acute shortening and early lengthening in an attempt to shorten the duration of treatment and restore function more quickly.

We present the results of our patients who sustained traumatic below-knee amputation with subsequent limb re-attachment or a Gustilo-Anderson type IIIC open fracture, treated with either early or delayed lengthening following initial acute shortening. All patients had complete loss of distal perfusion and underwent emergency treatment. As early lengthening represented a change in our established practice for this group of patients, we chose to review the results and compare them with our previous approach.

Patients and Methods

We retrospectively studied five patients with a traumatic below-knee amputation and eight with a Gustilo-Anderson type IIIC open fracture, who presented between 1991 and 2007, for whom replantation and/or revascularisation with acute shortening was performed. Lengthening was either deferred until union of the fracture (n = 5), or performed just after stabilisation of the patient and wound healing while union of the fracture progressed. The mean age of the patients was 28.4 years (17 to 44) and all were male (Table I).

In order to be eligible for a salvage operation the general condition of the patient had to be suitable for replantation/revascularisation

■ F. Parmaksizoglu, MD,
Associate Professor,
Orthopaedic Surgeon
■ M. B. Unal, MD, Orthopaedic
Surgeon
■ E. Cansu, MD, Orthopaedic
Surgeon
Medical Park Goztepe Hospital,
E5 Karayolu, Goztepe Kavşagi,
Goztepe, Istanbul, Turkey.

■ A. S. Koprulu, MD,
Anaesthesiologist
Department of
Anaesthesiology
Yeni Yuzyil University, Kisikli
Mah. Yunus Emre Sok. No. 18
Uskudar, Istanbul, Turkey.

Correspondence should be sent
to Dr F. Parmaksizoglu; e-mail:
drfatihpar@gmail.com

©2010 British Editorial Society
of Bone and Joint Surgery
doi:10.1302/0301-620X.92B11.
23500 \$2.00

J Bone Joint Surg [Br]

2010;92-B:1563-7.

Received 25 September 2009;

Accepted after revision 12 July
2010

Table I. Demographic and clinical characteristics of 13 male patients

Patient number	Treatment group	Age (yrs)	Side/type of injury*	Circumstances of accident	Method of initial fixation	Delay in lengthening (days)	Amount of limb lengthening (cm)
1	Delayed	20	R/traumatic amputation	Road traffic accident	Plated	240	6.5
2	Delayed	23	R/traumatic amputation	Road traffic accident	Plated	260	6.0
3	Delayed	20	R/Type IIIC	Road traffic accident	Plated	300	5.5
4	Delayed	40	L/Type IIIC	Train accident	Plated	412	6.0
5	Delayed	28	L/traumatic amputation	Industrial accident	External fixation	240	8.0
6	Early	32	L/traumatic amputation	Road traffic accident	External fixation	45	4.0
7	Early	17	R/Type IIIC	Train accident	External fixation	30	12.5
8	Early	20	L/Type IIIC	Train accident	External fixation	25	8.0
9	Early	17	R/traumatic amputation	Road traffic accident	External fixation	30	7.5
10	Early	48	L/Type IIIC	Occupational	External fixation	10	5.0
11	Early	44	L/Type IIIC	Occupational	Plated	15	5.0
12	Early	39	R/Type IIIC	Occupational	External fixation	10	5.0
13	Early	21	L/Type IIIC	Road traffic accident	External fixation	45	6.5

* R, right-sided; L, left-sided; type IIIC, Gustilo-Anderson type IIIC open fracture

without any other life-threatening injury. Patients had to be < 50 years of age without any signs of shock, or to have been fully resuscitated by the administration of fluid and blood. The injured leg had to meet the following criteria: the skin of the foot had to be intact; the knee joint had to be stable to allow actively controlled movements; the elimination of any length discrepancy that might result would have to be attainable and a successful direct repair of a transected nerve would be feasible.

Surgical procedure. All patients were operated on under general anaesthesia with full monitoring during the perioperative period to ensure maintenance of the fluid-electrolyte balance, normal body temperature, an adequate diuresis and tissue perfusion.

Initial emergency operation and acute shortening. The replantation/revascularisation procedure for all patients was completed within six hours of trauma by one author (FP). Microsurgical techniques were used for vascular and neurological repairs. Kessler suturing was used for tendon repair. Muscles were sutured by separated stitches. Initially an extensive debridement was undertaken, leaving only viable tissue. The ends of the fracture were shortened to ensure sufficient debridement of bone and adequate soft-tissue cover. The fracture was then approximated and stabilised either by a unilateral external fixator when the quality of the circulation to the overlying soft tissues was low ($n = 8$) or by a plate and screws ($n = 5$). Lengthening of the tibia was not initiated at the emergency operation.

Following the initial surgery all patients were transferred to the intensive care unit with respiratory, haemodynamic, metabolic and nutritional support provided as required. The systemic effects of reperfusion were closely monitored. In the event of a patient developing acute renal failure, haemofiltration was commenced.

Early versus delayed lengthening of the bone. Delayed lengthening was used in five patients between 1991 and 2003, being postponed until union of the fracture had occurred. After 2004 we initiated lengthening once the soft tissues had healed and the patient was clinically stable. The proximal metaphysis was used for the lengthening procedure if the fracture was located distally ($n = 7$) or in the middle ($n = 5$) of the diaphysis, whereas the distal metaphysis was used when the fracture was located proximally ($n = 1$). Osteotomy was created subperiosteally with an oscillating saw at least 2 cm away from the Schanz screws.

During the initial surgery, when an articulated dynamic axial external fixator (Orthofix, Verona, Italy) was used it was maintained until lengthening commenced. At this stage the Orthofix device was removed and replaced with a non-articulated external fixator (New Adult Railing System, EBI, LLC, Biomet Trauma, Parsippany, New Jersey) (Figs 1 and 2). The rate of lengthening was 1 mm/day. In unilateral cases, crutches were used for mobilisation. In bilateral cases, a wheelchair was used.

During the extensive soft-tissue debridement important muscular groups were sacrificed and stability of the ankle was obtained by arthrodesis or tenodesis.

Follow-up. All patients were evaluated both radiologically and clinically on a monthly basis until the completion of treatment. This point was defined as when the patient no longer required physiotherapy or any additional procedure and could walk unaided. Union of the fracture and consolidation of the lengthened segment were evaluated radiologically. Sufficient consolidation was defined as complete union of the cortexes with sufficient callus support and continuity of the medullary canal on both anteroposterior and lateral radiographs. The re-establishment of sensation in the foot was monitored in all patients, testing with a 6.5 g monofilament. This was defined as evidence for

Fig. 1a

Fig. 1b

Fig. 1c

Radiographs of patient 9, managed by acute shortening and early lengthening, showing a) immediately after reattachment with a temporary axial external fixator, b) new external fixator placed for compression at the level of amputation and distraction from the proximal metaphysis, c) union of the fracture and consolidation at the site of lengthening has been obtained, and the external fixator has been removed.

Fig. 2a

Fig. 2b

Fig. 2c

Radiographs of patient 1, managed by acute shortening and delayed lengthening, showing a) immediately after reattachment with a plate and screws, b) full bony union is obtained between four and six months at the level of the traumatic amputation and the plate is replaced by an axial external fixator and lengthening commenced (note Kirschner wires at a supramalleolar osteotomy performed to reconstruct the ankle), c) full fracture union and bony consolidation at the site of lengthening has been obtained, and the external fixator has been removed.

protective sensation. The patients were instructed on how to prevent the development of sores in the foot.

Evaluation of functional capacity. At the end of treatment, all patients were evaluated for function by the operating orthopaedic surgeon (FP) and a physiotherapist using the following Chen criteria,¹² grade I: can return to previous work, walking with a normal gait, possessing an almost normal range of movement in the knee and ankle joints; grade II: can perform light work, walks with a slight limp, has good sensation and a range of movement which is at

least 40% of normal; grade III: the replanted limb is useful in daily life, walking is possible with a raised shoe, reduced sensation is present in the sole but without trophic ulcers; grade IV: cannot walk without crutches, has no sensation in the sole and trophic ulcers on the sole.^{11,13,14}

Results

In four patients acute renal failure occurred in the immediate post-operative period. This involved two patients from each group. They underwent haemofiltration and

Table II. Surgical treatment, complications and additional procedures for each patient

Patient number	Treatment group	Type of injury	Type of vascular repair	Type of repair of tibial nerve	Complications	Additional procedures*	Total duration of treatment (mths)
1	Delayed	Traumatic amputation	Arterial and venous end-to-end anastomosis	End-to-end anastomosis	Valgus deformity of the ankle	Tenodesis for ankle stability, supramalleolar osteotomy for valgus deformity†	15
2	Delayed	Traumatic amputation	Arterial and venous end-to-end anastomosis	End-to-end anastomosis		Arthrodesis for ankle stability	15
3	Delayed	IIIC‡	Vein interposition for arterial repair, venous end-to-end anastomosis	No repair required		Arthrodesis for ankle stability	20
4	Delayed	IIIC	Arterial and venous end-to-end anastomosis	No repair required	Equinus deformity of the ankle	Arthrodesis for ankle stability, supramalleolar osteotomy for equinus deformity†	25
5	Delayed	Traumatic amputation	Vein interposition for arterial and venous repair	End-to-end anastomosis	Skin necrosis, nonunion at lengthening site, nonunion of ankle arthrodesis	Arthrodesis for ankle stability, free latissimus dorsi musculocutaneous flap for skin necrosis (on the 14th post-operative day), bone grafting for nonunion at lengthening site (ten months after injury), orthopaedic brace for permanent ankle stability	18
6	Early	Traumatic amputation	Arterial and venous end-to-end anastomosis	End-to-end anastomosis		Radial forearm flap to cover the skin defect, tenodesis for ankle stability	14
7	Early	IIIC	Vein interposition for arterial repair, venous end-to-end anastomosis	End-to-end anastomosis		Tenodesis for ankle stability	11
8	Early	IIIC	Arterial and venous end-to-end anastomosis	End-to-end anastomosis		Tenodesis for ankle stability	14
9	Early	Traumatic amputation	Arterial and venous end-to-end anastomosis	End-to-end anastomosis	Valgus deformity of the ankle	Arthrodesis for ankle stability, supramalleolar osteotomy for valgus deformity†	15
10	Early	IIIC	Arterial and venous end-to-end anastomosis	No repair required	Toe flexion deformity	Tenodesis for ankle stability, flexor tenotomy for flexion deformity six months after injury	6
11	Early	IIIC	Arterial and venous end-to-end anastomosis	No repair required		Tenodesis for ankle stability	8
12	Early	IIIC	Arterial and venous end-to-end anastomosis	No repair required	Infection	Tenodesis for ankle stability, debridement of infected nonunion followed by grafting at the level of traumatic amputation and local fasciocutaneous flap (on the 12th post-operative day)	11
13	Early	IIIC	Arterial and venous end-to-end anastomosis	End-to-end anastomosis	Non-union at the lengthening site eight months after injury	Tenodesis for ankle stability, bone grafting eight months after injury	11

* unless otherwise stated, procedures were performed during the initial operation

† after bone healing. Early limb lengthening is initiated just after wound healing; delayed limb lengthening is initiated after fracture union

‡ IIIC, Gustilo-Anderson type IIIC open fracture

recovered without permanent organ damage. The details of the surgical treatment, complications and further procedures for each patient are shown in Table II. The total duration of treatment for each patient is also given.

No patient had a problem with the restoration of arterial flow, but venous difficulties were experienced in six patients including self-limiting venous stasis, impaired lymphatic drainage characterised by distal oedema and lymphatic leakage from sites where skin integrity was interrupted. For these latter problems compression stockings were used. In every patient who required the repair of a nerve, satisfactory protective sensation was restored. All patients recovered to Chen grade II functional status. The

bone defect was fully restored, equalising the leg lengths in every patient. No limping due to such a discrepancy developed in any patient.

Discussion

Although Gustilo-Anderson type IIIC open fractures were largely treated with amputation in the past, currently success rates of up to 93% are possible with adequate management of selected cases.¹⁵ A characteristic feature of this type of injury is the extent of soft-tissue damage, which is more extensive than initially appears.⁵⁻⁷ Debridement of all injured tissues is of the utmost importance in preventing early and late local or systemic complications.^{6,13} Failure to

adhere to this principle in the presence of widespread impairment of soft tissue and the osseous circulation, and muscle necrosis in particular, may lead to complications and amputation.^{2,7,8} The problem of providing soft-tissue cover after extensive debridement can be satisfactorily addressed by shortening the bone. Initial shortening followed by lengthening to equalise the legs has been described in Gustilo-Anderson type IIIB injuries, with successful results.³ In contrast to our patients, Gustilo-Anderson type IIIB injuries are associated with normal distal circulation, where usually tissue reconstruction with microsurgical methods is not required. Shortening of bone and soft-tissue debridement may occasionally necessitate the use of free tissue transplants or pedunculated flaps to ensure sufficient cover.^{2,5,6} Acute shortening and subsequent re-lengthening has also been described for Gustilo-Anderson grade I and II tibial fractures.¹⁰

In Gustilo-Anderson type IIIB open tibial fractures treated with acute shortening, the leg-length discrepancy is usually treated with a second-stage procedure performed after union of the fracture.⁹ The main disadvantage of this approach is the prolonged duration of treatment. In traumatic amputation or Gustilo-Anderson type IIIC open fractures, lengthening is delayed in order to prevent traction on vascular anastomoses as they heal, which may potentially risk the revascularisation/replantation procedure. In this study, we performed early lengthening in a group of patients without causing any harm to the vascular repair. The lengthening was performed at the metaphysis most distal to the injury in all cases. Animal experiments have demonstrated that side branches emerging from the artery towards the soft tissue help prevent the retraction of the main artery, which may allow safe early lengthening.¹⁶

Primary shortening at the initial replantation/revascularisation followed by subsequent lengthening at the distal or proximal metaphysis after bony union at the amputation level was associated with considerably prolonged treatment. In an attempt to reduce this we performed the lengthening after stabilisation of the patient and healing of the skin, thereby providing simultaneous fracture healing and leg lengthening. None of these patients developed problems related to the initial vascularisation, and all had protective sensation on the sole of the foot at long-term follow-up.

A few studies have reported the results of acute shortening and early lengthening in lower limb trauma. In grade III type A and B open tibial fractures with bone and soft-tissue defects, Sen et al¹¹ commenced simultaneous lengthening in the metaphysis distal to the level of amputation while undertaking initial shortening of the primary defect, and obtained good results. However, unlike our patients, all of these patients had adequate distal circulation. Similarly, El-Rosasy¹⁰ obtained good results in chronic cases with bone and soft-tissue defects, when acute shortening and simultaneous lengthening was undertaken in the distal metaphysis

under elective conditions. However, all these patients also had unimpaired distal circulation.

Although it would be relatively easy for a young amputee to adapt to a prosthesis, all our patients achieved Chen grade II functional status and avoided the psychological trauma of amputation. In addition, limb salvage has been found to be more cost-effective than amputation and the use of a prosthesis.^{17,18}

Our results have shown that acute shortening and early lengthening is as safe and effective as acute shortening and delayed lengthening, but offers accelerated rehabilitation. Although the number of our patients is limited, our results suggest that early lengthening is acceptable in traumatic amputations and type IIIC open tibial fractures.

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.

Listen live

Listen to the abstract of this article at
www.jbjs.org.uk/interactive/audio

References

1. Bondurant FJ, Cotler HB, Buckle R, Miller-Crotchett P, Browner BD. The medical and economic impact of severely injured lower extremities. *J Trauma* 1988;28:1270-3.
2. Byrd HS, Spicer TE, Cierney G 3rd. Management of open tibial fractures. *Plast Reconstr Surg* 1985;76:719-30.
3. Lerner A, Fodor L, Soudry M, et al. Acute shortening: modular treatment modality for severe combined bone and soft tissue loss of the extremities. *J Trauma* 2004;57:603-8.
4. 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.
5. Francel TJ. Salvage of the massively traumatized lower extremity. *Clin Plast Surg* 1992;19:871-80.
6. Godina M. Early microsurgical reconstruction of complex trauma of the extremities. *Plast Reconstr Surg* 1986;78:285-92.
7. Walton RL, Rothkopf DM. Judgment and approach for management of severe lower extremity injuries. *Clin Plast Surg* 1991;18:525-43.
8. Lin CH, Wei FC, Levin LS, Su JI, Yeh WL. The functional outcome of lower-extremity fractures with vascular injury. *J Trauma* 1997;43:480-5.
9. Yokoyama K, Itoman M, Nakamura K, et al. Primary shortening with secondary limb lengthening for Gustilo IIIB open tibial fractures: a report of six cases. *J Trauma* 2006;61:172-80.
10. El-Rosasy MA. Acute shortening and re-lengthening in the management of bone and soft-tissue loss in complicated fractures of the tibia. *J Bone Joint Surg [Br]* 2007;89-B:80-8.
11. Sen C, Kocaoglu M, Eralp L, Gulsen M, Cinar M. Bifocal compression-distraction in the acute treatment of grade III open tibia fractures with bone and soft-tissue loss: a report of 24 cases. *J Orthop Trauma* 2004;18:150-7.
12. Wood GW 2nd. General principles of fracture treatment. In: Canale ST, ed. *Campbell's operative orthopaedics*, tenth edition. Philadelphia: Mosby, 2002:3017-84.
13. Chen Z-W, Chen L-E. Lower limb replantation. In: Brunelli G, ed. *Textbook of microsurgery*. Milano: Masson, 1988:503-8.
14. Cavadas PC, Landín L, Ibáñez J, Roger I, Nthumba P. Infrapopliteal lower extremity replantation. *Plast Reconstr Surg* 2009;124:532-9.
15. Quirke TE, Sharma PK, Boss WK Jr, Oppenheim WC, Rauscher GE. Are type IIIC lower extremity injuries an indication for primary amputation. *J Trauma* 1996;40:992-6.
16. Parmaksizoglu F, Beyzadeoglu T. Role of side branches in determining suitable arterial segmental for anastomosis in avulsion injuries: experimental studies. *J Reconstr Microsurg* 2003;19:279-84.
17. Hertel R, Strebel N, Ganz R. Amputation versus reconstruction in traumatic defects of the leg: outcome and costs. *J Orthop Trauma* 1996;10:223-9.
18. Williams MO. Long-term cost comparison of major limb salvage using the Ilizarov method versus amputation. *Clin Orthop* 1994;301:156-8.