Introduction

Limb reconstruction surgery, developed on the science of tissue regeneration through distraction [1–4], has become invaluable in the treatment of limb length discrepancies, angular limb deformities, recalcitrant bone infections, fracture non-unions and complex limb deformities. Practitioners of the technique range from dedicated, tertiary-level limb reconstruction specialists to ‘occasional’ users in general hospitals and the demand for places on limb reconstruction training courses is testimony to its increasing popularity. However, as with any surgical technique, it has problems and these issues can be technically difficult, time-consuming or expensive to treat, but are relatively easy to prevent. The aim of this article is to help clinicians and allied professionals understand problems that may arise with the use of external fixators in limb reconstruction and trauma, and in particular describe how preventative strategies can be implemented.

A keystone in the implementation of the classic Ilizarov technique over some conventional techniques of fracture fixation is early functional loading of the limb as distinct to early functional use. A considerable body of literature attests to the importance of functional loading (weight bearing) in promoting fracture healing; by minimising the size of the fracture gap and reducing torsional and sheer stresses while allowing small amounts of axial strain, physiological loading of the bone in the immediate post-operative period can significantly reduce the time taken for healing to occur and reduce the incidence of delayed or non-union [5–13]. Early loading also preserves muscle tone, proprioceptive sensation and gait, thereby optimising rehabilitation. Follow-up studies of patients who have had leg-lengthening procedures show that the recovery of knee range of movement is excellent in the long term, although patients with congenital leg length discrepancies tend to do slightly worse [14, 15].

The indications for splinting and orthotic use with external fixators can be broadly subdivided into those that facilitate functional loading and those that maintain joint integrity and function. Specific techniques to accompany use of external fixators in fracture management and limb reconstruction are described. In particular, problems concerning knee, ankle and foot support together with leg length issues are covered and proposals for dealing with joint subluxation, forefoot deformity and toe clawing, regenerate deformity after fixator removal and oedema control are discussed. The solutions described and illustrated are intended to assist those who use external fixators but do not have regular therapist input for support in the after-care of their patients.

Abstract The aim of this article is to help clinicians and allied professionals understand problems that may arise with use of external fixators in limb reconstruction and trauma, and in particular describe how preventative strategies can be implemented. The indications for splinting and orthotic use with external fixators can be broadly subdivided into those that facilitate functional loading and those that maintain joint integrity and function. Specific techniques to accompany use of external fixators in fracture management and limb reconstruction are described. In particular, problems concerning knee, ankle and foot support together with leg length issues are covered and proposals for dealing with joint subluxation, forefoot deformity and toe clawing, regenerate deformity after fixator removal and oedema control are discussed. The solutions described and illustrated are intended to assist those who use external fixators but do not have regular therapist input for support in the after-care of their patients.

Key words Ilizarov • External fixator • Splint • Orthotic • Fracture • Deformity

M. Mooney
Occupational Therapy, Orthopaedic Trauma
Royal Liverpool and Broadgreen University Hospital NHS Trust
Prescot Street
Liverpool L7 8XP, UK
e-mail: madeleine.mooney@rlbuht.nhs.co.uk

J. Gilbody
Trauma and Orthopaedics
University Hospitals Coventry and Warwickshire NHS Trust
Clifford Bridge Road, Coventry, UK
facilitate functional loading and those that maintain joint integrity and function. Specific techniques to accompany use of external fixators in fracture management and limb reconstruction will be described.

**Referral and assessment**

In preferred circumstances, all patients who undergo fracture management or limb reconstruction with external fixation are referred to a therapist for appropriate splintage and footwear. Communication ahead of surgery facilitates preparation for and anticipation of problems; an accurate assessment ensures that splintage, footwear and any other support are appropriate to the patient’s needs. This process details the planned operative procedure, anticipates post-operative requests and considers the patient’s medical history prior to action; as with any intervention, an explanation for the assessment and treatment is given and verbal consent is obtained.

The following areas need to be considered:

1. The type of fixator used (circular or monolateral type) and number of joints crossed; joint-spanning fixation may obviate the need of splintage in some cases
2. Presence of oedema
3. Pain – the patient’s response to surgery and type of analgesia used
4. Sensation – a check for sensory loss will avert problems from splinting an insensate sole
5. Circulation – a check for ulcers or necrotic areas before splinting. Some guidance can be obtained from skin temperature and colour
6. Range of movement of joints, both active and passive
7. Resting position of the joints
8. Liaison with other medical and paramedical staff with regard to possible problems with pin sites, skin grafts (if present), wounds and pain relief.

The decision to splint is made according to the above information. A patient who has full range of movement at the ankle joint, who is allowed to weight bear fully and is not lengthening should not really require splinting. Active physiotherapy and mobility should avert problems. If there is reluctance on the part of the patient to weight bear or difficulty with active exercise of the joint, contractures may ensue and prompt splinting is needed. Any patient not provided with a splint is closely monitored and reviewed to ensure that deterioration does not occur.

**Tibial fractures**

**Ankle and foot support**

Fractures around joints can pose particular problems if the fixator assembly physically restricts full movement of the joint, e.g., if a ring or bar just above the ankle restricts maximum dorsiflexion and prompts the patient to adopt a plantarflexed posture (Fig. 1). In this case it is important that the foot is kept plantigrade to discourage equinus. This is done with Thera-Band (the Hygenic Corporation, Ohio, USA) attached between the fixator and footwear (Fig. 2). Such splintage also allows the patient to mobilise the ankle through plantarflexion against the resistance of the Thera-Band, which then returns it to plantigrade upon relaxation (Fig. 3a, b).
If the fixator is extended across the ankle by use of a calcaneal ring or similar adaptation, it ensures the hindfoot is kept plantigrade but interferes with the normal gait pattern. The locked hindfoot position abolishes the normal foot progression through the stance phase of walking and even blocks subtalar inversion and eversion. This problem can be resolved with a rocker sole.

Knee support

Similar problems are encountered near the knee. The most proximal ring can restrict knee flexion through posterior impingement of hamstring muscles. Full extension can also be lost either from a poor resting position or by instruction to non-weight bear, prompting a flexed knee posture when walking. Although extending the fixator across the knee can maintain extension, it is uncomfortable. A knee extension brace attached to the most proximal tibial ring is a more practical solution (Fig. 4). Whilst not routinely used, they are indicated if a significant degree of collateral knee ligament insufficiency is associated with a tibial plateau fracture. In these cases the hinges are locked in knee extension for mobilisation and weight bearing but unlocked during physiotherapy. The brace is made of a thermoplastic femoral cuff to which the hinges, constructed from fixator components, are attached (Fig. 5). This has proved to be extremely successful and is more comfortable than extending the fixator, which invariably involves transfixation half-pins or wires in the distal femur. The same general considerations are necessary when using circular fixators for the treatment of delayed or non-unions in this area.

Assisted ambulation

Another aspect of limb support for patients with Ilizarov fixators is wheelchair modification. This may seem contradictory given the beneficial effects of functional loading, but for many patients (especially children) where prolonged periods in a fixator for limb lengthening or deformity correction are unavoidable, the wheelchair provides ready transportation to enable the child to maintain family-centred activities outside the home. In certain circumstances children are also able to attend school.

The size and circumferential nature of fixator rings or even bulky monolateral fixators create difficulties for comfortable sitting in a wheelchair, even with the knee flexed. A leg extension fitted to the chair overcomes the problem and has the added advantage of maintaining the knee in extension. In most instances, obtaining a wheelchair for modification is only possible with forward planning and communication between the surgical team and therapists; a standard leg rest has to be adapted to accommodate the rings of the fixator because an unmodified elevated leg rest is inadequate. The usual procedure is for rehabilitation engineers from the local Wheelchair Service to modify a Kings Stump Board (as used with amputees) to accommodate the circumference of the fixator rings and full length of the leg. It is important when issuing a wheelchair that all relevant Health and Safety standards and legislation are met.

Tibial reconstruction

This usually refers to bone lengthening, deformity correction (both bony deformities and joint contractures) and the technique of bone transport. The resistance of soft tissues to the distraction process underpins many of the problems...
seen during reconstruction. These problems are greater in congenital deformities where an entirely new limb length or alignment is being created, as compared to post-traumatic cases where the issue is one of restoration to a previous state. The prophylaxis of such problems is a priority. The techniques of splinting outlined below have either been developed independently or modified from initial reports by others [16].

Lengthening in cases of congenital deficiency arguably places the greatest demand on the soft tissues. Distraction of the muscles produces tension, which in turn pulls joints into characteristic postures. In the case of the tibia there are the gastrocnemius and soleus muscles which tend to flex the knee and plantar flex the ankle, creating contractures if left unattended. The splint is applied on either the first or second day post-surgery; this may be delayed if the patient has a problem with swelling which is being addressed with an arterial-venous impulse (A VI, Orthofix SRL, Verona, Italy) foot pump [17], but even in this instance the use of the splint and pump may alternate – close liaison with the physiotherapist is important to discuss the relative priorities (Fig. 6).

Equinus deformity

There are several ways to keep the patient’s foot plantigrade. Contractures are avoided if muscles are placed under tension for as many hours as possible but stretching exercises do not necessarily result in prevention of contractures unless maintained for at least six hours a day [16]. Attaching a wooden-soled shoe to the fixator by Velcro to hold the ankle plantigrade has been tried but found limited success at our hospital; problems arose from the constant high pressure to the heel and the forefoot, which patients found difficult to tolerate for any period of time. To overcome this complication, a piece of thermoplastic contoured to the sole of the patient’s foot is attached with soft strapping and Velcro. The splint is supported by either Velcro (for a static splint) or Thera-Band (for a dynamic splint) looped over one of the fixator pins or an extension plate built off a fixator ring (Figs. 2, 3 and 7).

Patients are encouraged to use the splint for an hour initially. It is then checked by the therapist for any problems and adjusted accordingly. The patient is also provided with an advice sheet detailing the use and care of their splint and limb in a regime specific to their needs as determined by the therapist. This takes into account the balance between the aim of splintage and the expected compliance or patient’s ability to care for the splint; due leeway in the regime is required for those who need assistance applying or removing their splint.

A statically applied splint, e.g., to immobilise a joint, is provided with a recommendation for prolonged use but will require checks at least twice each day for hygiene and physiotherapy. This splint regime is then reviewed when active joint movement is started. Even with dynamic splints prolonged use is encouraged, but additional advice is given to use the resistance of the Thera-Band as an aid to exercise. These splints are removed during weight bearing and replaced with a shoe; if necessary the Thera-Band can be placed around the shoe to encourage normal ankle dorsiflexion. Night-time use is also encouraged to avoid contractures. It is important the splints remain in place during the lengthening phase of treatment and for longer if problems persist.

Forefoot deformity/toe clawing

Problems with the forefoot may occur in patients despite adequate hindfoot splinting, whether this is done through
Joint subluxation

This is more common in congenital disorders with an associated joint instability. The imbalance of muscle tension across the joint from lengthening or deformity correction may precipitate the complication and a warning sign is an unyielding contracture in spite of physiotherapy or splinting. The knee is most vulnerable and prevention is accomplished by a check on the resting position (to encourage knee extension), appropriate splints (as described for tibial plateau fractures) and exercises to maintain movement.

Plastic deformation/fracture of lengthened bone (regenerate)

This may follow fixator removal if excessive load is carried through an as yet incomplete or immature regenerate (leng-
tended bone column. Fractures after fixator removal are treated in a cast or by reapplication of the fixator but prevention is simpler. The use of a tibial brace has proved useful in several patients, especially for distal tibial regenerate. The brace is custom made from thermoplastic material, although off-the-shelf devices are available. Partial weight bearing is advised, even though full weight was allowed with the fixator. This is increased to full weight when X-rays confirm the absence of regenerate deformity. Moulding a brace to a patient with significant soft tissue loss or bulky muscle flaps may prove difficult and it may be impossible to obtain adequate compression of the tissues for skeletal support. Such problems may be resolved through use of casting tape and a removable heel cup. In lesser cases it may be possible to pack the area with an elastomer so that the thermoplastic material conforms uniformly to the limb. The thermoplastic brace is convenient as an easy fit under normal clothing and is quick to remove (Fig. 10).

Footwear and leg length discrepancy

In order to facilitate loading of the treated limb it is necessary to provide the patient with appropriate footwear. Footwear modification is also required if the fixator spans the ankle through use of a heel ring and fixation in the calcaneum. This is managed with a simple Shuform slipper (Salts Healthcare, Birmingham, England) to which a layer of foam (which strengthens the sole) and a non-slip rubber sole are added. Velcro fastenings allow ease of adjustment should the foot swell up. The back (counter) is cut away and a Velcro strap is looped over the pin sites and attached to the slipper (Fig. 11). It is necessary to line the Velcro to stop the hooks from catching on the pin site dressings.

For a short limb the amount of shoe raise is adjusted by adding additional layers of foam to the base of the slipper. It is advisable to have the shoe height a little less than the true discrepancy during lengthening; it increases the ‘life-span’ of the shoe and reduces the number of alterations needed (Fig. 12). Shoes are monitored weekly in patients who are lengthening to ensure the raise does not exceed requirements.

On occasions when it has not been possible to fit a shoe, we have used an extension to the fixator (built from Ilizarov fixator components) and bolted on a walking sole. This obviously increases the weight of the entire assembly (Fig. 13).

Additional problems in limb reconstruction

Oedema

This might be considered an issue throughout the whole procedure. With the fixator in place, it is managed by positioning the limb in elevation or by use of the foot pressure pumps (AV Impulse, Orthofix SRL, Verona, Italy). Even after fixator removal, swelling and oedema may take sev-
eral months to resolve. This can be greatly assisted by the donning of a pressure garment, which reinforces tissue hydrostatic pressure and in turn improves venous and lymphatic flow. There is an added benefit of reducing scarring as the applied pressure imparts tension which controls vascularity, collagen alignment and accelerates the maturation process within the wound [19]. Pressure garments are made to fit. Patients are generally issued with three garments, which permits continuous use but caters for laundering in between. The garments are removed twice daily for washing the skin; use of an emollient cream and massage are encouraged. Pressure garments have to be monitored on a regular basis because any change in the level of oedema necessitates a new garment. Ill-fitting garments are of no benefit (Fig. 14).

Patients with two tibial fixators
The issues for these patients are essentially the same as for patients with one fixator, except that mobility is disproportionately more difficult as the two fixators tend to obstruct one another. Weight bearing is still encouraged but the impracticalities of extended walking make optimising mobility with a wheelchair an effective solution. Obviously the adaptations have to be made for both limbs.

Summary In this article we have outlined the common soft tissue problems associated with the use of external fixators for fractures and deformities of the tibia, together with the solutions we have adopted for prophylaxis and treatment. Solutions to the problems may vary and individual practitioners may opt to develop their own strategies using locally available resources, both human and material. It is hoped this article will help those who work with this versatile and innovative technique to understand the nature of these problems and assist their efforts to resolve them.

References
1. Ilizarov GA, Ledyaev VI (1992) The replacement of long tubular bone defects by lengthening distraction osteotomy of one of the fragments. 1969. Clin Orthop Relat Res 280:7–10
2. Ilizarov GA (1990) Clinical application of the tension-stress effect for limb lengthening. Clin Orthop Relat Res 250:8–26
3. Ilizarov GA (1989) The tension-stress effect on the genesis and growth of tissues. Part I. The influence of stability of fixation and soft-tissue preservation. Clin Orthop Relat Res 238:249–281
4. Ilizarov GA (1989) The tension-stress effect on the genesis and growth of tissues: Part II. The influence of the rate and frequency of distraction. Clin Orthop Relat Res 239:263–285
5. Kenwright J, Goodship AE (1989) Controlled mechanical stimulation in the treatment of tibial fractures. Clin Orthop Relat Res 241:36–47
6. Kenwright J, Richardson JB, Cunningham JL et al (1991) Axial movement and tibial fractures. A controlled randomised trial of treatment. J Bone Joint Br 73:654–659
7. Richardson JB, Gardner TN, Hardy JR et al (1995) Dynamics of tibial fractures. J Bone Joint Surg Br 77:412–416
8. Noordeen MH, Lavy CB, Shergill NS et al (1995) Cyclic micromovement and fracture healing. J Bone Joint Surg Br 77:645–648
9. Augat P, Merk J, Ignatius A et al (1996) Early, full weight-bearing with flexible fixation delays fracture healing. Clin Orthop Relat Res 328:194–202
10. Gardner TN, Evans M, Simpson AH et al (1997) A method of examining the magnitude and origin of “soft” and “hard” tissue forces resisting limb lengthening. Med Eng Phys 19:405–411
11. Claes L, Augat P, Suger G, Wilke HJ et al (1997) Influence of size and stability of the osteotomy gap on the success of fracture healing. J Orthop Res 15:577–584

Fig. 14 Pressure garments are useful in control of oedema and scarring after fixator removal
12. Augat P, Margevicius K, Simon J et al (1998) Local tissue properties in bone healing: influence of size and stability of the osteotomy gap. J Orthop Res 16:475–481
13. Claes L, Heitemeyer U, Krischak G et al (1999) Fixation technique influences osteogenesis of comminuted fractures. Clin Orthop Relat Res 365:221–229
14. Barker KL, Simpson Ah, Lamb SE et al (2001) Loss of knee range of motion in leg lengthening. J Orthop Sports Phys Ther 31:238–244; discussion 245–246
15. Maffulli N, Nele U, Matarazzo L (2001) Changes in knee motion following femoral and tibial lengthening using the Ilizarov apparatus: a cohort study. J Orthop Sci 6:333–338
16. Paley D (1990) Problems, obstacles and complications of limb lengthening by the Ilizarov technique. Clin Orthop Relat Res 250:81–104
17. Caschman J, Blagg S, Bishay M (2004) The efficacy of the A-V impulse system in the treatment of posttraumatic swelling following ankle fracture: a prospective randomized controlled study. J Orthop Trauma Suppl 18:596–601
18. Kocaoglu M, Eralp L, Atalar AC, Bilen FE (2002) Correction of complex foot deformities using the Ilizarov external fixator. J Foot Ankle Surg 41:30–39
19. Kennedy S, Stone J (1999) Pressure Garment Course Manual. Burns and Plastic Surgery Unit, South Manchester University Hospitals NHS Trust