Correction of Foot Deformities from Charcot Arthropathy with the Taylor Spatial Frame: A 7–14-year Follow-up

Om Lahoti¹, Naveen Abhisetty², Sandesh Shetty³

ABSTRACT
Charcot arthropathy related foot and ankle deformities are a serious challenge. Surgical treatment of these deformities is now well established. Conventional surgical treatment includes extensive surgical exposure, excision of bone, acute correction and internal fixation, which is not always appropriate in presence of active ulceration, infection and poor bone quality. A minimally invasive approach to osteotomies and gradual correction of deformities using a circular frame are proving helpful in minimizing the complications. Taylor Spatial Frame (TSF) hexapod with its various modules is well suited for a range of foot and ankle deformities. We have advocated minimally invasive targeted hind and mid foot osteotomies and gradual correction with Taylor Spatial Frame (TSF) in 10 patients with recurrent ulceration and deformity. There are 2 female and 8 male patients in this cohort. Appropriate TSF module was chosen for each patient – a long bone module for ankle and hindfoot deformities (4 patients) and a forefoot 6x6 butt frame (6 patients) for foot deformities. An osteotomy through the midfoot was performed in all chronic stable foot deformity cases. In the ankle and hindfoot deformities, a combination of soft tissue distraction correction of equinus and acute correction of hindfoot deformity through a calcaneal osteotomy, were used. Our outcome measures are complete healing of the ulcers and resolution of infection, clinically plantigrade foot and ability to wear regular or diabetic footwear. Complications included eight episodes of pin infection that responded to oral antibiotics only and two pin breakages. We achieved ulcer and infection free plantigrade feet that fit in to regular or diabetic footwear in 9 out of 10 patients. 9 patients remain ulcer and infection free at a minimum of 7 years and maximum of 14 years follow up. Taylor Spatial Frame treatment provides an alternative to conventional surgery in high-risk complex Charcot neuroarthropathy foot and ankle deformities.

Keywords: Charcot neuroarthropathy, Circular frame, Cohort study, Diabetic foot ulcers, Forefoot butt 6 × 6, Long bone TSF module, Rocker-bottom foot deformity, Taylor spatial frame.

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INTRODUCTION
Foot problems related to diabetes are a serious surgical challenge. In the United Kingdom, there are an estimated 4.5 million people with diabetes and around 10% are likely to develop a foot ulcer in their lifetime.¹ With a 5-year mortality rate of 50% in those with ulcers and 80% amongst diabetes-related amputees, it is stated that diabetic foot ulcer mortality rates are similar or even worse than many types of common cancers.² Well-established foot care pathways have shown a reduction in the first presentation of diabetic foot ulceration but failed to reduce recurrent ulceration.³ Charcot neuroarthropathy is progressive, and microtrauma potentiates it, resulting in the steady destruction of bone, subluxation of joints and a resultant deformity. Thus, in the acute phase, immobilisation and unloading of the foot are essential to prevent deformities from developing. However, orthotics and braces do not always support unstable joints fully and patients may develop a range of foot deformities which promote ulceration.⁴ The traditional surgical approach is to excise wedges or segments of bone through large incisions and often through compromised skin. Internal fixation is almost always used after such procedures which further increases the risk of wound breakdown and infection.⁵ Metal implant failure is also common. Circular external fixators have several advantages in being minimally invasive, can be applied in the presence of infection and allow gradual correction of the deformity. In the acute Eichenholz stage 1, frames are often used as a static device to prevent the collapse of the tarsal bones or to treat displaced fractures and active ulcers in patients who are not suitable for total contact casting, as might be the case with obese patients or those with amputation on the other side.⁶ ⁷ ⁸ In a foot with established deformity (Eichenholtz stage 2 and 3), a circular frame is used either as a holding device after open wedge excision and the acute correction of deformity⁹ or to gradually correct the deformity⁹ ¹⁰ ¹¹ ¹² ¹³ without excising bone.

The aim of this study is to report the results of a strategy comprising of a minimally invasive targeted osteotomy, an acute correction of hindfoot deformity where possible and a gradual correction of midfoot deformity using a Taylor spatial frame (TSF) hexapod in patients with recurrent active ulceration due to deformity and with an active or past history of deep infection in the foot, all of which increase the risk of complications following open surgery and internal fixation. The successful outcome measures are complete healing of ulcer, clearance of infection without recurrence, a clinically plantigrade foot and the ability to use regular shoes.

References:

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or diabetic footwear. There were successful outcomes in 9 out of 10 patients. One patient did not complete the treatment for psychosocial reasons. We included this case as a failure even though the likely contributing factor was poor patient selection. The other nine patients remain ulcer- and infection-free at a minimum of 7 years and maximum of 14 years follow-up.

**Materials and Methods**

A range of treatments are provided at our institute for the Charcot foot deformities, including the total contact casting, open surgical correction and internal fixation and circular frame treatment (with the TSF). Our indication for the treatment with TSF is recurrent or intractable ulceration with or without active bone infection or a history of recurrent ulceration and deep infection in a deformed foot. Case selection is important for all reconstructive procedures in the diabetic neuroarthropathic population and our prerequisites were as follows:

- Confirmation of good arterial perfusion to the limb
- Being medically stable and having good cognitive function
- Being independently mobile before the Charcot process became established

Patients who did not meet these prerequisites were excluded and offered other alternative, often non-surgical, treatment.

The TSF was used in 10 patients (10 feet) to correct the Charcot arthropathy-related foot deformities between 2005 and 2013. Table 1 shows patient data and Figure 1, duration in frame. Figure 2 illustrates a case of rocker-bottom foot deformity with an ulcer (case 5) and forefoot 6 × 6 butt frame. The average age was 51 years (range 32–68). There were two female and eight male patients in this cohort. A long bone TSF module (Fig. 3, for ankle and hindfoot deformities) was used in four patients and a forefoot 6 × 6 butt frame in six patients with midfoot deformities.

**Preoperative Counselling and Preparation**

A full physical examination was conducted at the first consultation. At least two outpatient consultations were arranged to ensure that patients understood the need for a frame treatment clearly and that they were capable of compliance and had a good family and social support. A range of available treatment modalities were also discussed, including non-frame treatment options. The patients were also shown a model of a frame and offered an opportunity to meet other patients undergoing such treatment. The patients were also shown a model of a frame and offered other alternative, often non-surgical, treatment.

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Weight-bearing anteroposterior (AP) and lateral (LAT) radiographs of the foot and ankle with hindfoot views were obtained routinely. Our experience has shown advanced imaging modalities, such as magnetic resonance imaging and nuclear medicine scans, are not helpful in decision-making because the absence of infection was not a prerequisite for frame treatment. In fact, the frame treatment is the preferred option in the presence of infection. The apex of the deformity was identified on the AP and LAT foot X-rays according to deformity analysis planning methods and was correlated with the clinical deformity.

**Operative Technique**

Surgery was performed under general anaesthesia or spinal block. The patient was positioned supine with a sandbag under the ipsilateral buttock. Appropriate antibiotics were given at induction of anaesthesia unless bone sampling was planned for suspected osteomyelitis. Deformity correction was through an osteotomy in all cases. The osteotomy was planned at the apex of the deformity or as close to it as possible, depending on the location of the ulcer, any previous surgery and the condition of soft tissues. The osteotomy was often either through cuboid and navicular or through the cuboid and cuneiform bones. Osteotomies through the bases of the metatarsals were avoided because of the potential risk to neurovascular structures and the interosseous muscles in the intermetatarsal spaces. Midfoot osteotomies were made through two small incisions, one on the lateral and another on the medial border of the foot. The path of the osteotomy was marked with two K-wires which helped to constrain the osteotomes or Gigli saw (Fig. 4A). Laminar spreaders were used from the lateral and medial wounds to confirm that the osteotomy was complete and was able to move freely; this was particularly important if the osteotomes were used to perform an osteotomy. One advantage of using a Gigli saw is that the technique itself confirms that the osteotomy is complete. In hindfoot deformity cases, the correction was achieved through a calcaneal osteotomy. A forefoot 6 × 6 butt (Fig. 4B) configuration was used for the midfoot correction, using distal reference and the rotational frame angle set at 180°, as recommended. A hindfoot 2/3rd ring was fixed to the calcaneum (open section facing upwards and proximally) with a combination of Schanz screws and olive wires. A forefoot 2/3rd ring (open section facing plantarwards) was fixed using two olive

| Patient | Age/sex | Deformity/brodsky type | Eichenholtz stage | TSF module |
|---------|---------|------------------------|------------------|------------|
| 1 HP    | M/62    | Varus ankle (3A)       | 2                | Long bone  |
| 2 GA    | M/59    | Midfoot cavovarus (1)  | 3                | Forefoot butt 6 × 6 |
| 3 CC    | M/40    | Midfoot cavovarus (1)  | 3                | Forefoot butt 6 × 6 |
| 4 MD    | M/58    | Rocker bottom (1)      | 3                | Forefoot butt 6 × 6 |
| 5 TT (Fig. 2) | F/41 | Rocker bottom (1) | 3 | Forefoot butt 6 × 6 |
| 6 PD    | M/48    | Varus deformity (3A)   | 3                | Long bone  |
| 7 HH    | F/36    | Rocker bottom (1)      | 3                | Forefoot butt 6 × 6 |
| 8 CA    | M/63    | Calcaneovalgus (3A)    | 2                | Long bone  |
| 9 PS (Fig. 3) | M/48 | Hindfoot varus, collapsed talus (4) | 3 | Long bone and calcaneal osteotomy |
| 10 AR   | M/68    | Rocker bottom (1)      | 3                | Forefoot butt 6 × 6 |
wires through the metatarsals—a medial olive wire capturing the 1st and 2nd, with or without the 3rd metatarsal and a lateral olive wire capturing the 5th and 4th, with or without the 3rd metatarsals. Stirrup wires (crossed olive wires entering at the distal face of the osteotomy in Fig. 4C) were extended distally and fixed to the distal 2/3rd ring without tensioning them. A similar arrangement was used on the proximal side of the osteotomy in severe deformities. These components enabled the distraction to occur at the osteotomy site mainly and not be dissipated across the joints during the gradual correction. In hindfoot and ankle deformities (cases 1, 6, 8 and 9 in Table 1), the varus or valgus of the heel was corrected acutely through a calcaneal osteotomy but the equinus deformity through the ankle gradually by using a long bone module. With the forefoot butt construct, the hindfoot 2/3rd ring was applied first by placing it as far back as possible to create room for the short and medium struts between the forefoot and hindfoot rings. The forefoot 2/3rd ring was fixed using opposing olive wires across the metatarsal neck or heads, and the stirrup wires were brought to this ring as far forward as possible to create good space between the rings. After achieving good fixation of the two rings, about 5° to 10° of the deformity was corrected acutely by pulling on them. This step further increased the room between the two rings to accommodate short to medium struts. This step also reduced the overall time in the frame by acutely correcting a part of the deformity without incurring a delay in bone healing. Care was taken not to correct more than 5°-10° to avoid neurovascular compromise. Frame mounting parameters were obtained using an image intensifier with threaded rods as markers. Pressure dressings were applied to the osteotomy wounds and pin sites, and the leg was elevated for 12–24 hours.

Gradual correction commenced between 7 and 10 days later. Postoperative monitoring included wound checks, pin-site status and strut checks at weekly intervals. Once the foot deformity was corrected, X-rays focussed on the osteotomy site were obtained to assess the healing. The stability at the osteotomy was also assessed by conducting a stress examination after disconnecting all the struts. If the osteotomy site was found to be stable, the frame with wires and half-pins were removed in the clinic without anaesthesia. Full weight-bearing in an Aircast boot was permitted thereafter for up to 6 months before moving on to regular shoes. Patients were followed up at 3, 6 and 12 months and then annually. Any recurrence of deformity and ulceration was noted.

Fig. 1: Frame duration in days and average of 115 days. X-axis patient details are in Table 1. Eight CA had the frame for 47 days and treatment had to be abandoned as the patient was not coping with the frame treatment.
Figs 3A to C: (A) Hindfoot varus deformity and recurrent ulceration from total contact casting and bracing. Preoperative X-rays show destruction of talus and varus deformity. Managed with calcaneal osteotomy and lateral shift and gradual correction of ankle varus with TSF; (B) Long bone TSF module. Foot frame and two rings tibial block. Gradual correction of varus through collapsed talus; (C) Postcorrection clinical picture and X-rays. Hindfoot neutral and plantigrade foot. Normal off the shelf shoes. Post of X-ray shows good correction of varus and spontaneous fusion of ankle.

Figs 4A to C: (A) Technique of midfoot osteotomy; (B) Forefoot butt 6 × 6 frame configuration; (C) Olive stirrup wires

Results
Pragmatic criteria as suggested by Pinzur\textsuperscript{10} were adopted as there are no specific outcome scores or measures for Charcot neuroarthropathy-related foot deformities. A foot and ankle that was plantigrade, infection-free and able to fit into regular or diabetic therapeutic footwear was considered a successful outcome. This was achieved in 9 out of 10 patients (10 feet). In one patient, the frame treatment had to be abandoned before completion.
The TSF is also showing promising results in the management of diabetic foot deformities.

Addendum:

The strength of this study is that it reports medium-term results (minimum 7 and maximum 14 years) in complex foot deformities after Charcot neuroarthropathy using the very versatile TSF modules. We recognise the shortcomings of this study. The results apply to a carefully selected group of patients who fulfilled certain prerequisites, and the surgery was performed at a tertiary level.
limb reconstruction referral centre with good team support and experience with frame treatment. This was not a uniform group of deformities. We used a pragmatic outcome measure which applies to all Charcot-related foot deformities rather than deformity-specific outcomes but the technique and results described will add to the range of options available for the treatment of difficult foot deformities with recurrent ulcerations.

**CONCLUSION**

Treatment based on the TSF is a good option in carefully selected complex foot and ankle deformities from Charcot neuroarthropathy. Ulcer-free and infection-free plantigrade feet that were able to don the standard diabetic footwear were obtained after treatment in 9 out of 10 feet, with these good outcomes maintained at the 7- to 14-year follow-up review.

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**ADDITIONAL INFORMATION**

The Taylor Spatial Frame.

Manufactured by: Smith and Nephew, 1450 Brooks Road Memphis, Tennessee 38116, USA

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