FOOT AND ANKLE

Outcome of one-stage correction of deformities of the ankle and hindfoot and fusion in Charcot neuroarthropathy using a retrograde intramedullary hindfoot arthrodesis nail

We report the outcomes of 20 patients (12 men, 8 women, 21 feet) with Charcot neuroarthropathy who underwent correction of deformities of the ankle and hindfoot using retrograde intramedullary nail arthrodesis. The mean age of the patients was 62.6 years (46 to 83); their mean BMI was 32.7 (15 to 47) and their median American Society of Anaesthetists score was 3 (2 to 4). All presented with severe deformities and 15 had chronic ulceration. All were treated with reconstructive surgery and seven underwent simultaneous midfoot fusion using a bolt, locking plate or a combination of both. At a mean follow-up of 26 months (8 to 54), limb salvage was achieved in all patients and 12 patients (80%) with ulceration achieved healing and all but one patient regained independent mobilisation. There was failure of fixation with a broken nail requiring revision surgery in one patient. Migration of distal locking screws occurred only when standard screws had been used but not with hydroxyapatite-coated screws. The mean American Academy of Orthopaedic Surgeons Foot and Ankle (AAOS-FAO) score improved from 50.7 (17 to 88) to 65.2 (22 to 88), (p = 0.015). The mean Short Form (SF)-36 Health Survey Physical Component Score improved from 25.2 (16.4 to 42.8) to 29.8 (17.7 to 44.2), (p = 0.003) and the mean Euroqol EQ-5D-5L score improved from 0.63 (0.51 to 0.78) to 0.67 (0.57 to 0.84), (p = 0.012). Single-stage correction of deformity using an intramedullary hindfoot arthrodesis nail is a good form of treatment for patients with severe Charcot hindfoot deformity, ulceration and instability provided a multidisciplinary care plan is delivered.

Cite this article: Bone Joint J 2015;97-B:76–82.

Charcot neuroarthropathy (CN) of the foot is a debilitating condition characterised by pathological fractures, subluxations or dislocations leading to disruption of the bony architecture of the foot and ankle. Although diabetes mellitus (DM) is the most common cause, CN may also be seen in syringomyelia, multiple sclerosis and hereditary neuropathy.1 The exact pathophysiology is still a matter of debate; however, sensory and motor neuropathy with loss of protective sensation and muscular atrophy lead to repetitive micro-trauma in the weight-bearing joints of the foot and ankle.1 Autonomic neuropathy can increase bone perfusion and resorption, leading to osteopenia, fracture and deformity.2 The deformities are often associated with chronic ulceration and osteomyelitis, which may eventually require amputation.3

Reconstruction may be undertaken with the aim of reducing the risk of ulceration by creating a stable plantigrade foot allowing the patient to bear weight and mobilise, thereby decreasing the morbidity and the risk of amputation. Midfoot and forefoot reconstruction has been attempted with screws,4 bolts5 or external fixators6 with varying clinical outcomes.7 Surgical strategies for deformities of the hindfoot and ankle have included the use of intramedullary nails,8-12 ring fixators13 or a combination of both10 with or without simultaneous lengthening of the tendo-Achillis or gastrocnemius muscle.14

The intramedullary (IM) hindfoot fusion nail offers stable fixation and weight-bearing, allowing fusion and correction of the deformity. Although rates of fusion of > 70% have been described using this technique, there is a high rate of complications including nonunion, failure of fixation, infection and amputation.8-12 Patients often have long standing DM with a high prevalence of associated cardiac, renal and vascular co-morbidities, increasing the risk of anaesthetic and surgical complications.15
Reconstructive treatment for patients with CN has therefore been offered in few specialist centres. Only three centres reported series with > 20 patients treated with a hindfoot nail fusion.\textsuperscript{8,10,12} Moreover the patient self-reported outcome measures (PROMs) in this population have not been described in the literature.\textsuperscript{14,16}

We have a diabetic foot referral clinic in our university hospital with a multidisciplinary team that treats > 600 patients a year. The aim of this study was to report the outcome of treatment of patients with CN who underwent correction of deformities of the ankle and hindfoot and fusion using a retrograde IM nail.

**Patients and Methods**

The multidisciplinary team comprises orthopaedic surgeons, endocrinologists, vascular surgeons, podiatrists, wound-care specialist nurses, orthotists, physiotherapists and occupational therapists. A treatment algorithm for the management of new referrals was established (Fig. 1).

The initial assessment involves taking a thorough history and performing an examination including recording temperature difference, redness, tenderness, sensation, ulceration, deformities, tightness of the tendo-Achillis and the vascular status. Inflammatory markers such as C-reactive protein and white cell count as well as the diabetic status and glycaemic control are recorded. Dorsoplantar and lateral standing radiographs of both feet are obtained and further imaging is performed to investigate suspected deep tissue or bone infection. CT imaging is performed routinely for all complex deformities. Swabs are sent for microbiological analysis for all patients with ulcers.

A red, hot and swollen foot in the absence of infection is diagnosed as acute CN and is treated with a total contact cast\textsuperscript{17} until the swelling and temperature difference has returned to normal. Patients with an unstable deformity of the foot and ankle, which is not amenable to bracing, are offered surgical treatment. Those patients with a CN and an active infected ulcer are treated with debridement, intravenous antibiotics and negative pressure wound therapy prior to definitive fusion. Feet with signs of peripheral vascular disease are re-vascularised prior to fusion.

We identified 20 consecutive patients (12 men and 8 women) with CN who underwent reconstruction of the ankle and hindfoot between January 2008 and April 2013. Their mean age was 62.6 years (46 to 83). (Table I). One female patient underwent reconstruction of both feet. The mean weight of patients was 102.3 kg (36 to 158) and the mean BMI was 32.7 kg/m\textsuperscript{2} (15 to 47); four patients were morbidly obese with a BMI > 40. In all, 13 patients had type-2 and six had type-1 DM whereas one was not diabetic. The mean duration of DM at the time of surgery was 19.2 years (6 to 38). Glycaemic control was suboptimal in some patients, with a mean HbA1c of 7.7% (5.2% to 11.3%; target HbA1c: < 6.5%). All patients had evidence
of peripheral neuropathy and six had a diabetic retinopathy. A total of 18 patients had chronic renal disease; 14 with stage 2, three had stage 3 and one had stage 4 renal disease. All patients were considered of increased risk for general anaesthesia: 18 patients were American Society of Anesthesiology (ASA) grade III; one was grade II and one was grade IV. Chronic or recurrent ulceration was noted in 15 feet with some patients having undergone up to four years of conservative management. Of these, 11 had residual ulceration at the time of surgery around the hindfoot, in spite of an offloading regime and standard wound care including debridement and negative pressure therapy. Four patients had instability of the ankle and/or subtalar joint. Two were referred for revascularisation procedures prior to reconstruction; one underwent peroneal angioplasty and one femoral endarterectomy and a patch angioplasty.

All were treated using a hindfoot arthrodesis nail (TRIGEN Hindfoot Fusion Nail, Smith & Nephew, Memphis, Tennessee). Surgery was undertaken by a single surgeon (VK) using a standard technique (Figs 2 and 3). During the course of the study the standard distal locking screws were replaced by hydroxyapatite-(HA) coated screws as standard screws had migrated in two patients during the early part of the study. Patients with additional midfoot deformities were treated with simultaneous midfoot fusion using a bolt and/or a locking plate.

Correction of the deformity was achieved by resecting a wedge of bone through a single incision on the convex side of the deformity where possible and stabilised with the hindfoot fusion nail. An extended lateral approach, including a proximal translateral malleolar approach to the ankle and more distally directly over the subtalar joint was used for a varus ankle and hindfoot deformity. A two-incision approach was used for valgus deformities, involving an anteromedial approach to the ankle and a separate lateral approach to the subtalar joint. The residual midfoot deformity was corrected using a separate incision over the apex of the deformity, with the principles of wedge resection and plate and/or intramedullary stabilisation. The concept of a ‘super construct’ was used for stabilisation of the deformity. This required fixation to be extended beyond the zone of Charcot involvement of the midfoot into the unaffected first tarso-metatarsal joint to provide a long segment of fixation. Deep tissue samples were sent for microbiological assessment. Minor tightness of the tendo-Achillis often improved following wedge resection. Percutaneous lengthening of the tendo-Achillis was performed using multiple stab wounds if there was a severe contracture. Bone graft substitutes were used as required before closure over a drain. Post-operative wound management was supervised by the multi-disciplinary team. Non weight-bearing was continued for at least three months followed by partial weight-bearing for three more months, guided by the radiological and clinical progression of healing. Full weight-bearing in a removable brace was allowed thereafter, once union was shown on radiographs or CT scans.

<table>
<thead>
<tr>
<th>Patients</th>
<th>Gender</th>
<th>Age (yrs)</th>
<th>ASA grade</th>
<th>Fusion: Hindfoot (H), Midfoot (M)</th>
<th>Time to fusion (mths)</th>
<th>Minor revision†</th>
<th>Major revision†</th>
<th>Post-operative mobility status</th>
<th>Chronic/recurrent ulceration</th>
<th>Post-operative ulcer healing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>57</td>
<td>3</td>
<td>H</td>
<td>3.6</td>
<td>Screw dislodgement†</td>
<td>FWB</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>65</td>
<td>3</td>
<td>H</td>
<td>6.5</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>46</td>
<td>4</td>
<td>H</td>
<td>16.6</td>
<td>Screw dislodgement†</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>70</td>
<td>3</td>
<td>H</td>
<td>Fibrous</td>
<td>Nail removal†</td>
<td>FWB</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>60</td>
<td>3</td>
<td>H</td>
<td>3.8</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>72</td>
<td>3</td>
<td>H</td>
<td>37.9</td>
<td>Nail breakage + revision†</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>83</td>
<td>3</td>
<td>H + M</td>
<td>11</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>62</td>
<td>3</td>
<td>H</td>
<td>4.6</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>78</td>
<td>3</td>
<td>H</td>
<td>5.7</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>59</td>
<td>3</td>
<td>H + M</td>
<td>Non-union</td>
<td>Nail dynamisation†</td>
<td>FWB in CFO</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>77</td>
<td>3</td>
<td>H + M</td>
<td>4.4</td>
<td>Midfoot revision†</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>61</td>
<td>3</td>
<td>H</td>
<td>3.6</td>
<td>Metal work removal†</td>
<td>Chair bound</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>13†</td>
<td>F</td>
<td>50</td>
<td>3</td>
<td>H + M</td>
<td>3.8</td>
<td>Metal work removal†</td>
<td>FWB in CFO</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>14†</td>
<td>F</td>
<td>50</td>
<td>3</td>
<td>H + M</td>
<td>9.8</td>
<td>Midfoot revision†</td>
<td>FWB in CFO</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>M</td>
<td>76</td>
<td>3</td>
<td>H</td>
<td>2.9</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>M</td>
<td>53</td>
<td>3</td>
<td>H</td>
<td>2.9</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>M</td>
<td>52</td>
<td>3</td>
<td>H</td>
<td>6.2</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>M</td>
<td>69</td>
<td>3</td>
<td>H</td>
<td>3.5</td>
<td>FWB in OSO</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>F</td>
<td>61</td>
<td>3</td>
<td>H + M</td>
<td>4.5</td>
<td>FWB</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>F</td>
<td>50</td>
<td>3</td>
<td>H + M</td>
<td>2.2</td>
<td>FWB in CFO</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>M</td>
<td>56</td>
<td>2</td>
<td>H</td>
<td>4.6</td>
<td>FWB in OSO</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FWB, fully weight bearing; CFO, Custom Foot Orthoses (patient is FWB); OSO, off-shelf orthoses (patient is FWB) ASA American Society of Anesthesiologists grade
† 13 and 14 are right and left feet of the same patient
patients were then allowed to progress to full weight-bearing using well-fitting lace-up shoes or custom-made foot wear.

The migration of distal locking screws was measured six months post-operatively in comparison with the immediate post-operative appearance. In order to eliminate the effect of rotation and magnification of two different radiographs, the ratio of the proximal part of the screw to its total length was calculated to enable estimation of the amount of migration as a percentage of the total length of the screw. Migration of > 2.0% of the length of the screw was considered to be significant as in control measurements, it was observed that the average error using this method was between 0% and 2% and that a dislodgement of < 2% could therefore not reliably be detected.

The outcome measures which were used included the American Academy of Orthopaedic Surgeons Foot and
Ankle Outcomes (AAOS-FAO),\textsuperscript{21} Short Form (SF)-36 Health Survey\textsuperscript{22} and the Euroqol EQ-5D-5L\textsuperscript{23} which were recorded pre- and post-operatively. The following were also recorded: limb salvage, the achievement of full weight-bearing, the healing of ulcers, bony fusion and revision surgery.

**Statistical analysis.** The Wilcoxon signed-rank test was used to examine differences for statistical significance, which was defined as a p-value < 0.05

**Results**

All patients (21 feet) underwent hind foot deformity correction and tibiocalcaneal fusion using the IM hindfoot fusion nail. A total of seven patients (seven feet) underwent simultaneous midfoot fusion which was achieved using a medial column bolt alone in four patients, a bolt augmented by a locking plate in two and a dorsal locking plate alone in one patient. Two patients underwent simultaneous first metatarsophalangeal joint fusion. Two required percutaneous lengthening of the tendo-Achillis. One had a split skin graft at the time of initial surgery. The mean follow-up was 26 months (8 to 54).

Limb salvage was achieved in all patients (Table II). Patient satisfaction and function improved as reflected by all three PROMs (Table III). One patient died due to a cerebrovascular accident, four years after surgery. Healing of the ulcer was achieved in 12 of 15 patients (12 of 15 feet) who had ulceration pre-operatively at a median of 8 months (6 to 13) post-operatively. All but one patient achieved full weight-bearing, with patients wearing well-fitting shoes. Three (four feet) required a custom-made ankle-foot orthosis and two needed a pneumatic walking brace. One patient remained wheel-chair bound. Fusion was achieved radiologically in 19 of 21 feet (90%); one had a stable painless pseudoarthrosis. One fusion failed to unite.

Two patients underwent nail removal due to complications. In one patient, the fixation failed and the nail broke, requiring removal of the nail and revision fixation. The nail was removed in another patient due to a non-healing ulcer over the sole at the site of insertion of the nail. Three reconstructions required dynamisation of the nail by removal of proximal locking screws to enhance fusion. In three of the four feet in which simultaneous midfoot fusion using a bolt alone was undertaken, the bolt migrated, requiring revision using a locking plate. Four of 22 standard distal locking screws (18%), in two patients, migrated by approximately one third of the length of the screw. None of the 34 HA coated locking screws migrated.

**Discussion**

These results show that single-stage reconstruction and internal fixation in patients with severe Charcot ankle and hindfoot deformity can achieve healing of chronic ulcers and independent mobilisation with appropriate
supplementary orthoses in most patients. These improvements in outcome were associated with significantly better quality of life as reflected by PROMs after surgery.

The rate of major complications following hindfoot nail arthrodesis is significantly higher in patients with diabetic neuroarthopathy. Consequently, reconstruction has been limited to a few centres with few reports involving large series. In Charcot feet without chronic ulceration, Dalla Paola et al. achieved 100% limb salvage and a 77.8% rate of fusion (n = 18). Similarly, a 100% limb salvage and rate of fusion using a longer IM femoral nail was reported in a smaller study including nine patients with Charcot feet without ulcers. However, the results of hindfoot nail arthrodesis in Charcot feet with ulcers have been poorer. Caravaggi et al. reported 45 patients, seven with chronic ulcers, with a rate of limb salvage of 86.7%. Pinzur and Kelikian reported a cohort of 21 patients, eight with chronic ulcers, with a rate of limb salvage of 95.2% and a rate of fusion of 90.5%. With 12 feet (26%) having pre-operative ulceration, DeVries et al. showed a higher rate of amputation (22%) in their cohort of 45 Charcot feet. In contrast, we achieved 100% limb salvage in our patients with 71% of feet having chronic ulceration and 52% feet having ulcers at the time of surgery. Improvement in PROMs in our patients suggests that the salvaged limbs had satisfactory function. With our approach, the presence of a pre-operative ulcer does not seem to be a contraindication for using an internal fixation device such as an IM nail for fusion in these patients.

The combination of DM, peripheral neuropathy, obesity, impaired renal function and other cardio-vascular co-morbidities raises the peri-operative morbidity and mortality. These patients characteristically have wounds which heal poorly due to loss of protective sensation and to long-standing DM that increases the risk of peripheral arterial disease and microvascular dysfunction with impaired tissue oxygenation. Correction of deformity, meticulous wound management and a pressure offloading regime resulted in a rate of ulcer healing of 80%. All wounds healed initially but ulcers developed later due to prominent metal work in two feet; the wounds healed after removal of metal work.

Complications were mostly noted in relation to midfoot fusion using a medial column bolt in patients who underwent simultaneous midfoot reconstruction. However, no further complications occurred following revision to fusion using a locking plate. Although medial column fusion alone has been shown to be successful in a small study (n = 5), performing this as a procedure in addition to hindfoot nail fusion in feet with severe deformities at many sites resulted in a high rate of revision in our study.

More recently, the use of external ring fixators in patients with CN has become popular as an alternative to IM fixation. Pinzur et al. reported the largest cohort (n = 178), with a rate of limb salvage of 95.7%. In their study, 45 of 73 patients (62%) who had an ulcer achieved healing after surgery. Fragomon et al. reported a rate of limb salvage of 95% and a rate of union of 73% using an Ilizarov frame, with one frame revision and four tibial stress fractures in a series of 19 patients. Dalla Paola et al. and El-Gafary et al. achieved rates of limb salvage of 89% (n = 45) and 100% (n = 20), respectively. One study compared the use of an IM nail alone to nailing combined with the use of a circular external fixator and concluded the latter may add extra stability to the construct. No study has directly compared the results of different surgical techniques, or of reconstruction versus amputation. Our study showed that similar or better results can be obtained in these patients with reconstruction using a hindfoot nail, thereby avoiding the problems associated with external fixation, such as poor compliance, the need for several operations, meticulous long-term pin tract care, and a negative psychological impact.

The durability of fixation following Charcot hindfoot fusion is paramount, as the time to fusion is often > three months and the bone is usually osteopenic. The arthrodesis nail used in this study has threaded distal screw holes to improve engagement and thereby reduce the risk of migration of the screw. Nevertheless, non-HA coated locking screws showed significant migration six months post-operatively. This effect is well known in mechanical engineering as rotational loosening in bolted joints due to cyclic transverse loads. Factors increasing the threshold of loosening are an increased frictional coefficient, steeper thread lead angle, finer threads, increased preload and the use of adjuncts such as fasteners. In biological tissue, HA coating increases the torque of screws during insertion and extraction compared to standard screws. In addition, the potential for bony on-growth on the screws may further increase the self-loosening threshold of distal locking screws. These factors probably contributed to the superior fixation of HA coated screws as there was no migration or osteolysis around these screws.

Following reconstruction of a foot in patients with CN, close monitoring and care in a multi-disciplinary team is required to avoid complications in these complex patients. This extensive care is time consuming and expensive and this may serve as an argument for proponents of amputation. However, a cost comparison study of limb salvage (n = 76) versus amputation (n = 17) in patients with CN could not find any difference within the first year. A total of nine of our patients were offered amputation elsewhere and were referred to our centre for a further opinion. We acknowledge that there are limitations to this study. The outcome of treatment was not compared with a control group, but a randomised controlled trial in such a diverse and complex group of patients is practically challenging. Although our series involves a small number of patients, with few centres undertaking this approach, the numbers of patients available is limited. A multicentre, prospective, randomised controlled trial would be the best way to shed more light on this approach.
In summary, we report satisfactory outcome following corrective fusion of severe deformities of the ankle and hindfoot in patients with CN treated with a hindfoot intramedullary nail. Most patients achieved healing of an ulcer and independent mobilisation. Complications occurred mostly in patients who underwent simultaneous midfoot fusion using a bolt. Initial results also suggest that HA coating of distal locking screws may achieve better fixation.

M. Siebachmeyer: Data collection, Writing and editing the manuscript, Checking the proof.
K. Boddu: Writing and editing the manuscript, Data collection.
T. W. Hester: Co-author, Data collection.
T. Hardwick: Data collection.
T. Fox: Data collection.
M. Edmonds: Writing and editing the manuscript, Checking the proof.
V. Kavarthapu: Writing and editing the manuscript, Checking the proof.
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