CHAPTER 4

Accurate Computer-Assisted Gradual Correction of Charcot Foot Deformity: A Stage I Realignment in Preparation for Stage II Fixation

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INTRODUCTION

Charcot neuroarthropathy is a destructive disease that can lead to great disability and often leads to lower extremity amputation. This disease affects patients with neuropathy of the lower extremity and causes progressive destruction and collapse of the joints of the foot and ankle, ultimately resulting in debilitating deformity. Patients with a Charcot-related foot wound have an increased risk of lower extremity amputation by a factor of 6 (1). This has been a very challenging disease to manage for the medical community. Numerous conservative and surgical treatments have been attempted, and controversy exists concerning when to proceed with surgery, the acuity of correction, and the fixation constructs.

Previous authors have postulated that an acute deformity correction of the Charcot foot places stress on the neurovascular structures and may lead to local ischemia and soft tissue failure (2-4). Classically, it was believed that the Charcot foot has "bounding pulses" and more than adequate blood flow, however, recently it has been shown that there is a 40% prevalence of peripheral arterial disease in diabetic Charcot neuroarthropathy (5,6). Acute deformity correction entails the removal of truncated wedges usually through large open incisions. It can be challenging to preoperatively plan for acute correction as Charcot collapse is a triplanar deformity often with associated shortening of the foot due to subluxation of the forefoot on the rearfoot. Correcting for a shortened foot requires either lengthening the foot or removal of bone to reduce the subluxation. It is extremely complex to calculate the amount of bone to remove to safely achieve an acute correction without placing tension on the soft tissue and neurovascular structures. Because of the great challenge in accurately planning preoperatively for a safe triplanar wedge, many surgeons resort to estimations and intra-operative judgement for achieving correction. To prevent soft tissue compromise and neurovascular stress to the Charcot limb, there have been descriptions of a two-staged approach to Charcot reconstruction using gradual correction of the deformity followed by internal fixation (2). Gradual correction has been long used in deformity correction of long bones for these reasons and is applied to the Charcot foot in a similar manner.

The authors believe that gradual correction allows for adequate deformity correction, provides less risk to neurovascular structures, preserves bone, and allows access for local wound care. The present case series is the largest to date focusing on deformity correction of Charcot neuroarthropathy using external fixation. The goal of this study is to achieve accurate and safe correction using computer assisted programming to safely correct large deformities in Charcot foot. The outcomes of interest of the present study is achieving deformity correction in the sagittal plane as well as ulcer healing, this is the first stage of a two-stage treatment. It is the author's experience that once this has been achieved, the patient is then prepared for the second stage of implanting internal fixation. The Meary's angle correction is especially of interest as it measures the deformity within the medial column. Correction of the Meary's angle is thought to be the most significant reconstruction principle producing the best long term survivability (7-9). The medial column drives the deformity in midfoot Charcot. When there is insufficiency within the medial column, this contributes to lateral column failure and often plantar dislocation of the cuboid or fifth metatarsal base (10).

PATIENTS AND METHODS

The present review consisted of fourteen patients (14 feet) who underwent two-staged Charcot reconstruction with gradual correction using external fixation (stage I) followed by internal fixation (stage II) during the period of November 2011 to January 2017. The patients were from the senior author's (PW) private practice. The primary aim of the investigation was to evaluate the ability to correct the Meary's and calcaneal inclination angles radiographically with gradual correction using external fixation (stage I). The secondary goal was to evaluate ulcer healing in those patients that had an ulcer prior to surgical intervention.

Patient age was determined at the time of the initial surgery. The presence of ulceration was determined by clinical examination by the senior author (PW) and was to include any full-thickness ulcerations with neuropathic etiology as well as surgical dehiscence from previous surgeries. History of osteomyelitis was determined by chart review and included any diagnosis of osteomyelitis of the operative foot at any time prior to surgical intervention. The type of deformity was determined by both clinical and radiographic examination, and the presence and type of equinus was measured using the Silfverskiöld test (11). Charcot stage and location were defined by the Eichenholz and Sanders/Freiberg classifications, respectively (12).

Radiographic measurements of the Meary's and calcaneal inclination angles were measured by the senior author (PW) using a modification of previously described standard techniques (13). The preoperative radiographs were taken weightbearing in angle and base of gait on digital radiography and all measurements were taken digitally. The postoperative radiographs were taken with external fixation devices holding the foot in a static position without the ability to take a standard weightbearing radiograph.

Complications were defined as additional surgery during stage I, pin tract infection, and deep infections. Superficial pin tract infections that did not cause true bone infections were defined as a problem. A pin tract infection was considered a complication if it caused a true bone infection (14).

SURGICAL TECHNIQUE

The senior author performed a planned two-stage reconstruction for Charcot as previously described by Lamm et al (1). Stage I was the application of an external fixation device used for gradual correction. After sufficient correction was achieved, the stage II procedure was performed to remove the external fixation device. At the same time of external fixation removal, rigid internal fixation was implanted with necessary beaming and arthrodesing procedures.

The patients underwent general anesthesia in the supine position for each procedure. Prophylactic antibiosis was administered. The author did not use a tourniquet for these cases. Posterior lengthening was achieved by either a Strayer procedure or a percutaneous triple hemi-section Achilles tendon lengthening prior to the application of external fixation as described by Hatt and Lamphier (15). Resection of osteomyelitis was performed as needed as well as packing with antibiotic impregnated calcium sulfate beads to provide local antibiosis. The application of the external fixation device was created either in a miter or a butt configuration depending on the deformity (16) (Figure 1). Miter frames were applied in cases where there was only forefoot deformity. Butt frames were applied in combination of forefoot and hindfoot deformities, where the surgeon felt gradual correction of the hindfoot was necessary. The patients with a severely coalesced deformity required a midfoot osteotomy to allow distraction osteogenesis to occur. The patients that did not require a midfoot osteotomy were incompletely coalesced, which allowed for deformity correction through ligamentotaxis.

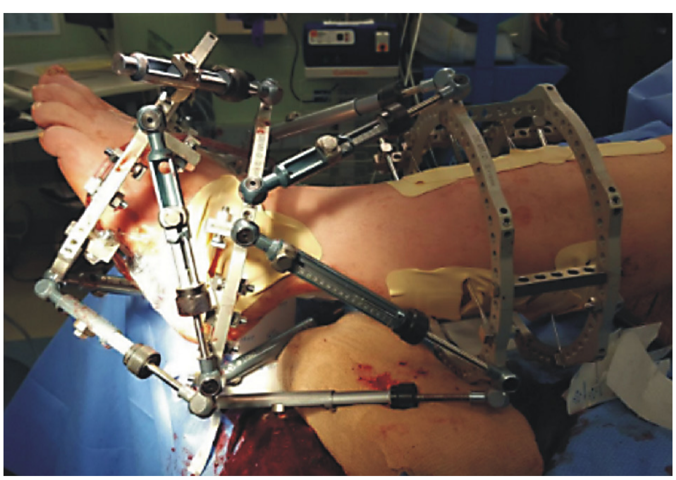

Figure 1. An example of a Miter frame construction.

Osteotomies were done percutaneously using a Gigli saw. The Gigli saw was placed percutaneously through 4 1-centimeter incisions around the midfoot prior to application of the external fixator, and the osteotomy was performed after stabilization of the leg was achieved with the external fixator in place (17). Deformity and mounting parameters were measured by the senior author (PW) using digital measurements on digital radiography and were later entered into an internet-based software that was used to calculate the strut adjustments required for deformity correction using external fixation. The patient and family members were relied on to adjust the struts daily, provide pin tract care, and perform wound care as needed. Patients were allowed to be partial weightbearing on the external fixator as tolerated. Weekly follow-up with our senior author (PW) included radiographic and clinical evaluation.

After deformity correction was achieved, stage II required the removal of the external fixation device and immediate internal fixation with various combinations of medial and lateral column beaming, plating techniques, and subtalar joint fusion. Statistical analysis was performed using the Wilcoxon matched-pairs signed rank test to evaluate the median and range of the Meary's and calcaneal inclination angles both preoperatively and postoperatively. Statistical significance was defined as $P \leq 0.05$. The mean and range of the remaining parameters were taken preoperatively and postoperatively (Figure 2).

RESULTS

Of the 14 patients involved in this series, the average age at the time of initial surgery was 63 years (range 39 to 81 years). Seventy-nine percent of the patients were male (11 of 14 patients) and 21% were female (3 of 14), and the laterality was 57% right foot (8 of 14) and 43% left foot (6 of 14). The deformity present was largely midfoot Charcot with a rocker bottom deformity, which made up

Table 1. . Demographics of the 14 patients*

Patient	Age	Sex	Foot	Deformity	Eichenholz	Charcot location	Osteomyelitis	Ulcer location†	Previous foot surgery
1	61	M	L	EQ, RB, FFV	2	midtarsal	Yes	1	-
2	69	M	R	EQ, RB, FFV, D	1	midtarsal	Yes	2	Left: BKA; Right: metatarsal head resections & 2nd digit amputation
3	49	M	L	EQ, RB, FFV, D	1	midtarsal	Yes	1	-
4	71	M	L	EQ, RB, FFV, D	2	midtarsal	No	4	-
5	53	M	L	EQ, RB, FFV, D	1	midtarsal	No	3	I&D for infection misdiagnosis
6	69	M	R	EQ, RB, FFad, D, loss of navicular	2	midtarsal	No	1	-
7	66	F	R	EQ, RB, FFad, D, loss of navicular	2	midtarsal	No	1	-
8	72	M	L	EQ, RB, FFV, D	2	midtarsal	No	1	wound debridement
9	69	M	R	EQ, RB, FFV, first ray amp	2	midtarsal	Yes	3	first ray amp
10	81	M	R	EQ, RB, FFV, first ray amp	2	midtarsal	No	1	wound debridement
11	67	F	R	EQ, RB, RFV	2	midtarsal	No	1	-
12	56	M	L	EQ, RB, FFV	2	midtarsal	No	4	first ray amp
13	39	M	R	EQ, RB, RFV	2	midtarsal	No	4	-
14	60	F	R	EQ, RFV	2	subtalar	No	1	-

*M = male; EQ = equinus; RB = rockerbottom; FFV = forefoot varus; D = diastasis (subluxation); BKA = below knee amputation; I&D = incision and drainage; FFad = forefoot adductus; F = female; amp = amputation.
† Ulcer location 1 = plantar cuboid; 2 = plantar medial; 3 = dorsal; 4 = none.

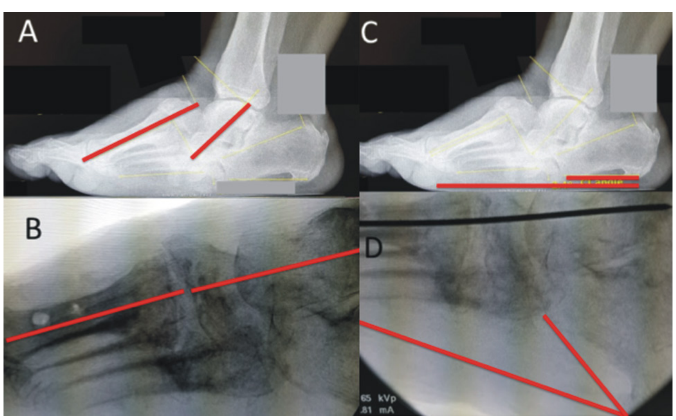

Figure 2. Examples of radiographic demonstration of deformity correction. A. Preoperative Meary's angle measurement. B. Postoperative Meary's angle measurement. C. Preoperative calcaneal inclination angle measurement. D. Postoperative calcaneal inclination angle measurement.

93% of the patients (13 of 14 patients), while 7% of the patients (1 of 14) had a subtalar joint Charcot. Equinus was found in all 14 of the patients, and a diastasis or subluxation of the forefoot on the rearfoot was found in 50% of the patients (7 of 14). These were mostly Eichenholtz stage 2 Charcot, which made up 79% of the patients (11 of 14) and Eichenholtz stage 1 made up 21% (3 of 14). There was a history of osteomyelitis prior to surgical intervention in 28% (4 of 14). There was an ulceration present on the operative foot at the time of surgery in 79% of patients (11 of 14), and 57% (8 of 14) had an ulcer that was plantar to the cuboid bone. Previous foot surgery had been performed in 43% of the patients (6 of 14) (Table 1).

Looking at the surgical procedures performed, 86% (12 of 14) had a percutaneous Achilles release, while 14% (2 of 14) had a Strayer procedure performed. The external

Table 2. Surgical procedures 14 patients*

Patient	Gastric or Achilles	Frame configuration	Time in external fixation (days)	Internal fixation procedure (Stage II)	Internal fixation used
1	Perc Achilles	Mitre	48	Medial/lateral column (perc); 2nd procedure was open medial column fusion	Synthes Bolt x2; then replaced with 4.0 crossing screw at TN joint and plantar locking plate
2	Perc Achilles	Mitre	60	Medial/lateral column (open)	Arthrex medial locking plate; 4.0 screws x2 laterally
3	Perc Achilles	Mitre	58	Medial/lateral column (perc)	6.5 bolt x2
4	Perc Achilles	Mitre	50	Medial column (open)	Plantar/medial plating
5	Perc Achilles	Mitre	86	Medial/lateral column (open)	Arthrex medial locking plate; plantar plating; dorsal locking plate; lateral locking plate
6	Perc Achilles	Butt	85	Medial/lateral column (open)	Wright medial locking plate
7	Perc Achilles	Butt	90	Medial/lateral column (perc)	Wright bolting system
8	Perc Achilles	Mitre	82	Medial/lateral column (perc)	Bolt Wright
9	Strayer	Mitre	79	Medial/lateral column (perc)	Bolt Wright
10	Strayer	Mitre	98	Medial/lateral column (perc)	Wright bolting system
11	Perc Achilles	Mitre	79	Medial column (perc)	Wright bolting system
12	Perc Achilles	Mitre	50	none	-
13	Perc Achilles	Mitre	88	ankle fusion open	Smith-Nephew ankle locking plate
14	Perc Achilles	Mitre	67	STJ fusion	Arthrex cannulated screws

*Perc = percutaneous.

Table 3. Preoperative and postoperative results

Patient	Meary's Angle (degrees)		Calcaneal Inclination Angle (degrees)		Presence of ulcer at time of fram placement and removal	
	Preoperatively	Postoperatively	Preoperatively	Postoperatively	Preoperatively	Postoperatively
1	-44	0	10	15	Yes	No
2	-31	7	2	5.5	Yes	No
3	-9	0	-1	10	Yes	No
4	-43	5	11	18	No	No
5	-35	2	4	26	Yes	No
6	-22	4	12.9	27	No	No
7	31	3	14.6	28	No	No
8	-21	4	2.4	31	Yes	No
9	-28	0	7	27	Yes	No
10	-55	2	-10	28	Yes	No
11	-15	4	7.7	25	No	No
12	-26	3	5	25	No	No
13	15	0	14	25	No	No
14	0	0	-19	24	Yes	No

*Perc = percutaneous.

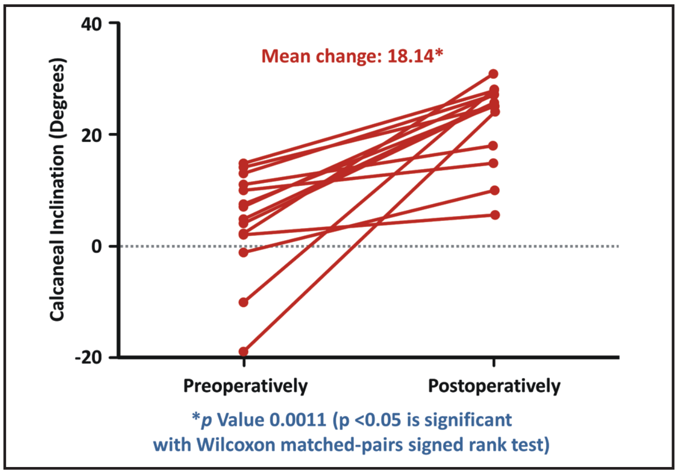

Figure 3. Change in preoperative and postoperative calcaneal inclination angle.

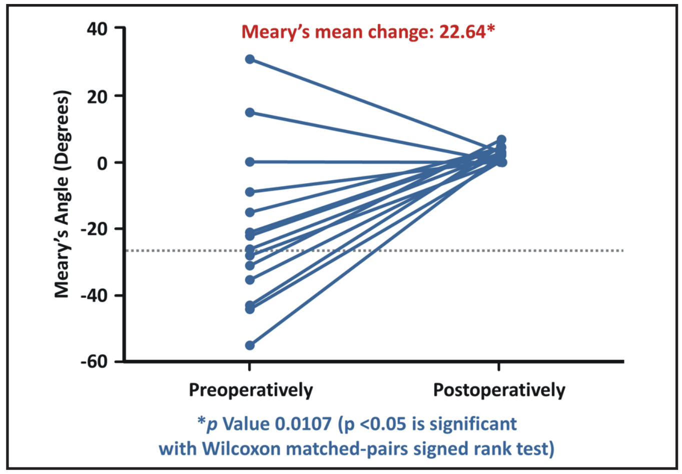

Figure 4. Change in preoperative and postoperative Meary's angle.

fixation device was placed in a miter configuration in 86% (12 of 14) of patients and in a butt configuration in 14% (2 of 14) of patients. The mean time in the external fixation device was 72.86 days (range 48 to 98 days) (Table 2).

The mean preoperative Meary's angle was -20.21 degrees, and the mean postoperative Meary's angle was 2.43 degrees. This was a mean change of 22.64 degrees, which was statistically significant (P = 0.0107) ($P < 0.05$ is significant with Wilcoxon matched-pairs signed rank test) (Figure 4). The mean preoperative calcaneal inclination angle was 4.33 degrees, and the mean postoperative calcaneal inclination angle was 22.46 degrees. This was a mean change of 18.14 degrees, which was statistically significant (P = 0.0011) (Figure 3 and Figure 4). The ulcerations that were present preoperatively in 57% of patients (8 of 14) were 100% healed by the time the external fixation device was removed (Table 3).

DISCUSSION

The first description of a two-staged percutaneous approach to gradually correct the Charcot foot was by Lamm et al (2). In their series of 11 feet in 8 patients, they found a statistically significant correction of deformity postoperatively based on their measurements of the Meary's angle on the anteroposterior and lateral views as well as the calcaneal inclination angle. Our present study successfully demonstrated reproducibility of their ability to accurately correct Charcot deformity using gradual correction as measured by radiographic imaging.

Malay et al also studied a series of patients who underwent a staged surgical management for Charcot foot. In their series of 9 feet in 7 patients, they performed a stage I procedure consisting of application of a static external fixator in order to achieve a quiescent foot, followed by a second stage with beaming of the columns. This differed from both Lamm et al and our present study as the deformity correction was done acutely at the time of the second stage, rather than performing gradual correction during the first stage (2,3).

The authors used plating and beaming techniques when providing internal fixation in the second stage of the reconstruction. When determining which internal fixation technique to choose from, the senior author (PW) would take into account the Meary's angle on both the lateral and anteroposterior view. If the Meary's angle was corrected on both the anteroposterior and lateral views, then a beaming technique was employed. The medial column was plated in those cases where the Meary's angle was only well aligned on the lateral view and not the anteroposterior.

The present study is limited in that we have only examined the ability to correct deformity during the first stage of a 2-stage procedure. Subsequent studies will need to be done to determine how this correction sustains over time and the frequency that limb salvage was achieved. Additionally, this study is limited by the inability to take a true standard weightbearing radiograph postoperatively. The standard for Meary's angle and calcaneal inclination angle measurements is to take weightbearing radiographs in angle and base of gait, however, these lateral radiographs were taken with external fixation devices holding the foot in a static position. It is the author's belief that the foot was held in a "loaded" position with the use of external fixation and this has simulated a weightbearing film in the closest way possible.

The present case series is the largest to date focusing on gradual deformity correction of Charcot neuroarthropathy using external fixation. The results demonstrated reproducibility of previous works to achieve significant correction of the medial column deformity in the sagittal plane and complete ulcer healing. The utilization of external fixation allows for gradual stress on the neurovascular structures and soft tissues, access for wound care, and preserves bone. The focus of this study was on the first stage of a two-staged procedure. It is the experience of the authors that after successful completion of the first stage, the patient is then prepared for the second stage of implanting internal fixation. Future studies are needed to evaluate the first and second stages combined with long-term follow-up.

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