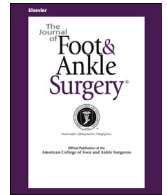




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Original Research

Comparison of Complications for Internal and External Fixation for Charcot Reconstruction: A Systematic Review

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ABSTRACT

The surgical reconstruction of Charcot deformity can be a challenge for foot and ankle surgeons. Consensus is lacking among surgeons regarding the best method of surgical fixation to be used in reconstruction, and clear strong evidence is also lacking in published studies. We undertook a systematic review of electronic databases and other relevant sources in an attempt to better understand the complications and outcomes associated with internal and external fixation for Charcot foot and ankle reconstruction. A total of 23 level 4 studies with 616 procedures were identified. Of these, 12 studies with 275 procedures used internal fixation, and 11 studies with 341 procedures used external fixation. The odds of a successful outcome with internal fixation was 6.86. The odds of a successful outcome with external fixation was 13.20 (odds ratio 0.52, 95% confidence interval 0.30 to 0.90). The odds of success for internal fixation was 0.52 times as likely as the odds of success with external fixation. Because the odds ratio did not include 1, this difference was statistically significant at the $p < .05$ level. An identified trend was that external fixation was used more often in cases deemed to be difficult by the surgeon preoperatively. These findings could prove helpful to foot and ankle surgeons when making decisions regarding fixation for Charcot reconstruction.

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Charcot foot deformity is a challenging condition most commonly seen in diabetic patients with lower extremity sensory neuropathy. Difficulty results from both the loss of stability and bone and joint destruction (1). Surgeons must consider the onset and severity of the deformity, with the goals of restoring stability and plantigrade positioning of the foot for normal ambulation (2). Surgical stabilization is often necessary when severe deformity has developed or when conservative measures have failed.

The options for stabilization of Charcot foot and ankle deformity after correction include internal fixation and external fixation. Controversy exists in the foot and ankle surgery community regarding which of these techniques is most efficacious and most appropriate. Although the scientific evidence is sparse and opinions vary among physicians regarding the choice of internal versus

external fixation, our clinical experience has revealed some general trends. First, internal fixation techniques have the advantage of patient and surgeon acceptance, because they use fixation techniques we are comfortable with in everyday practice for a variety of conditions. Furthermore, internal techniques are preferred by some because they are perceived as being more straightforward and might not require multiple or staged procedures. However, some surgeons prefer external techniques because they provide a wider range of stability and adjustability and can provide a platform for soft tissue preservation through minimally invasive surgical techniques. External fixation can also provide a platform for progressive correction in complicated and severe deformities, which is not possible with internal techniques. Some surgeons combine these techniques to capitalize on the strengths of both.

To better understand the outcomes for each technique we undertook a systematic review of the published data regarding internal and external fixation for Charcot reconstruction. It is useful to understand these outcomes from both techniques to provide the safest and most efficacious methods for reconstruction in our patients.

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Materials and Methods

We undertook a systematic review of electronic databases, including PubMed (available at <http://www.ncbi.nlm.nih.gov/pubmed>), OvidSP (available at <http://ovidsp.ovid.com/>), Google Scholar (available at <http://scholar.google.com>), and the websites for the Journal of Foot and Ankle Surgery (available at <http://www.jfas.org/>) and Foot and Ankle International (available at <http://www.aofas.org>). An inclusive search using “internal fixation,” “internal reconstruction,” “external fixation,” and “external reconstruction,” with the Boolean operators “AND” and “OR” to include “Charcot” and “diabetic deformity,” was performed. A manual bibliographic search of the chosen reports was also completed to identify any additional pertinent references. The inclusion criteria were as follows: reports published in English or translated into English in peer-reviewed medical journals between 1960 and 2014, human clinical studies with patients >18 years old, a study population of ≥10 procedures per fixation method, defined outcomes and data with complication rates reported, a mean follow-up period of ≥12 months, and a specific description of the fixation methods used.

The initial abstract review was completed by all of us (P.D., M.F., M.T., P.W.), with agreement by all required for final inclusion. The lead author (P.D.) acted as the moderator. The selected studies were reviewed in detail by 2 senior authors (P.D., M.F.), and final inclusion according to the criteria was agreed on. After review of the included reports, the following data were extracted: number of procedures in each report; mean patient age, number of male and female patients, anatomic site (foot or ankle, or both), fixation type, number of successful procedures (union, stable nonunion, successful return to ambulation), number of unsuccessful procedures (recurrence, infection causing abandonment of reconstructive procedure, unsuccessful revision, amputation), and amputation rate reported as a separate outcome measure. The reports were graded using the American College of Foot and Ankle Surgeons levels of clinical evidence guidelines as referenced in the Journal of Foot and Ankle Surgery Guide for Authors. Those reports determined to be a level 1, 2, 3, or 4 were included. Level 5 clinical evidence reports were excluded.

We did not undertake a rigorous meta-analysis in the present systematic review because the reported methods and results were, we believe, too heterogeneous. Although it has been established that a meta-analysis can be performed on observational studies (3), such as those selected for use in our review, the differences in study design, inconsistencies in data collection, and the lack of reported variance data (e.g., standard deviation) in the selected reports made the use of Cochran's Q test or the I^2 statistic inappropriate, because the published reports were unsuitable for meta-analysis (3).

The proportion of successful outcomes for each study was calculated by dividing the number of successful outcomes by the total number of procedures. The proportion of successful outcomes was then used to calculate the probability of success for each group (internal versus external fixation). Using the formula $odds = P/(1 - P)$, the odds of success for each group was calculated (Table 1). The odds of a successful outcome with internal fixation was 6.86. The odds of a successful outcome with external fixation was 13.20. The odds of success for internal fixation was 0.52 as likely as the odds of success with external fixation (odds ratio 0.52, 95% confidence interval 0.30 to 0.90).

Results

A total of 65 reports were recovered using our systematic search terms as defined in the “Materials and Methods” section. After the initial abstract review, 27 studies were eliminated, leaving 38 for the full review, of which 23 fit our selection criteria. All 23 studies had a level of evidence of 4 as determined using the Journal of Foot and Ankle Surgery Guide for Authors. A total of 616 procedures were reported in these studies, with 275 specific to Charcot deformity correction using internal fixation (12 studies) and 341 attempting correction with external fixation (11 studies).

The 12 studies using internal fixation as a method for Charcot deformity correction are summarized in Table 2. A total of 275 procedures in 274 patients (124 females and 150 males) included a mean follow-up period of 33.7 months and an average patient age of 57.8 years. Of the 275 procedures, 240 (87.3%) achieved successful salvage, and 35 (12.7%) were reported as unsuccessful. Amputation was performed 18 times in these studies, for an amputation rate of 6.5%. The

procedures involving the ankle joint totaled 175 and led to successful salvage in 147 (84%), with amputation performed 15 times (8.6%). When surgery was performed in the foot only, successful outcomes were obtained in 93 of 100 cases (93%), with 3 amputations (3%) required.

The 11 studies reporting on the results of external fixation in Charcot foot reconstruction are summarized in Table 3. A total of 341 procedures were performed among 319 patients (139 females and 180 males), with a mean follow-up period of 26.9 months and an average patient age of 55.1 years. Of the 341 total procedures, 317 (92.9%) resulted in successful salvage and 24 (7.04%) in unfavorable outcomes. The amputation rate for external fixation was 3.5% (12 amputations). Of the external fixation procedures used to treat both the foot and ankle, 203 (94.9%) resulted in successful salvage, 5 (2.3%) in amputation, and 11 (5.1%) in unsuccessful salvage. External fixation with just foot involvement yielded 84 (90.3%) with successful salvage, 5 (5.4%) with amputation, and 9 (9.7%) with unsuccessful salvage. Finally, when only considering the ankle with external fixation, 30 (88.2%) resulted in successful salvage, 2 (5.9%) in amputation, and 4 (11.7%) in unsuccessful salvage.

Discussion

The decision to use external or internal fixation in reconstruction of Charcot deformity is based on many factors. In many cases, surgeon comfort, experience, and traditions are at the forefront of the decision. A thorough understanding of the risks and benefits of each technique provides the surgeon with important information to determine the best option for fixation in each individual case. Clearly, in the case of Charcot, which involves complex and varied deformity and high-risk patients, a detailed understanding of the options will help guide the decisions that will lead to the best possible patient outcomes.

Our systematic review has helped to clarify the available evidence regarding the choice of reconstruction procedure, and our results highlight several trends in the usage of each fixation technique. Internal fixation tended to be the method chosen when the deformity did not include complicated wounds or osteomyelitis. In the internal fixation population, screws were the preferred hardware of choice for surgeons correcting foot deformities (5 of 6 studies). In contrast, those correcting ankle deformities were more likely to use intramedullary nails (6 of 7 studies). Amputation also occurred at a greater prevalence (8.6%) in the patients undergoing only ankle procedures compared with those undergoing operation in the foot only (3.0%). The treating physician must also consider the necessary extended time in non-weightbearing status for patients undergoing correction using internal fixation alone.

A retrospective study of 22 patients undergoing reconstruction with midfoot arthrodesis using axially placed intramedullary screws was performed by Sammarco et al (4) in 2009. Their data showed a stable foot in 21 of 22 cases, with complete union in 16 and nonunion in 5. One patient showed no radiographic progress and eventually developed a collapsed longitudinal arch due to hardware failure. The investigators also reported on complications involving hardware, which led to screw removal (8 of 22), breakage (7 of 22), and replacement (1 of 22) (4).

Dalla et al (5) in 2007 completed a retrospective review of 18 patients with Charcot neuroarthropathy. In these patients, pantalar arthrodesis using an intramedullary retrograde transcalcaneal nail was performed. Of the 18 cases, 14 resulted in stable union; the remaining 4 patients achieved a fibrous union. Limb salvage was accomplished in all 18 patients, along with satisfactory plantigrade positioning of the foot. Three patients were noted to have developed ulcers at the site of the proximal screws in the tibia; however, this did not compromise nail fixation.

Placement of a plantar plate for reconstruction of Charcot foot was performed on 24 patients (25 feet) by Garchar et al (6) in 2013. The

Table 1
Odds ratio calculations for internal versus external fixation

Fixation Type	Success (n)	Failure (n)	Total (n)
Internal	240	35	275
External	317	24	341

Odds ratio: $(240/35)/(317/24) = 0.52$; 95% confidence interval = odds ratio \pm 1.96 \times standard error log normal(odds ratio) = 0.3 to 0.90.

Table 2

Summary of internal fixation (n = 275 feet in 274 patients)

Investigator	Procedures (n)	Anatomic Site	Fixation	Mean Age (y)	Gender (F/M)	Follow-Up (mo)	Successful Salvage (n)	Unsuccessful Salvage (n)	Amputation (n)
Papa et al (14), 1993	25	Ankle	Screws	56	22/7	42	23	2	0
Early et al (15), 1996	21	Foot	Screws	58	9/9	28	18	3	2
Pinzur et al (16), 1997	21	Ankle	IM nail	56.3	11/9	20	19	2	1
Simon et al (17), 2000	14	Foot	Screws	48.2	4/10	41	14	0	0
Stone et al (18), 2000	10	Foot and ankle	IM nail and screws	63	5/5	24	9	1	1
Caravaggi et al (19), 2006	14	Ankle	IM nail	58	1/13	18	10	4	1
Dalla et al (5), 2007	18	Ankle	IM nail	65	5/13	14	18	0	0
Assal et al (20), 2010	15	Foot	Screws	55	6/9	42	13	2	1
Sammarco et al (4), 2009	22	Foot	Screws	59.4	16/6	52	21	1	0
Caravaggi et al (21), 2012	45	Ankle	IM nail	56	18/27	60	39	6	2
DeVries et al (7), 2012	45	Ankle	IM nail	59.4	17/28	25	32	13	10
Garchar et al (6), 2013	25	Foot	Plate	58.8	10/14	38	24	1	0
Total procedures	275			57.758333		33.66666667	240	35	18

Abbreviations: F, female; IM, intramedullary; M, male.

results showed stable fusion in all but 1 case, which was problematic owing to recurring ulceration and infection. These patients had late-stage Charcot deconstruction, with complications including recurrent ulceration. The investigators suggested that the additional plantar plate was useful in maintaining stability in these difficult cases. Minor complications among these patients did not lead to loss of salvage and included infection in 4, ulceration in 2, and wound dehiscence in 1 patient.

In 2012, DeVries et al (7) reported a comprehensive review of 45 patients treated with an intramedullary nail for Charcot ankle deformity correction. Their results corresponded to limb salvage in 35 patients, with 10 others undergoing amputation. Hardware failure was reported in 23 of 31 patients who had undergone radiographic evaluation. That retrospective review also considered 7 patients, who had undergone placement of a circular external fixator and an intramedullary nail. These patients were not included in our study because of our inclusion criteria; however, it is worth noting that 5 of the 7 patients had limb salvage and 2 undergoing amputation. Hardware failure occurred in 4 of 7 cases in the patient group treated with an intramedullary nail combined with external fixation. The outcome variables were similar among the groups and included the use of incision and drainage (22 in the internal fixation group and 3 in the external fixation group), stress fractures (4 in the internal fixation group and 1 in the external fixation group), and the use of intravenous antibiotics (25 in the internal fixation group and 4 in the external fixation group).

Our review of the published data revealed that external fixation was used most often in patients with more complicated cases, such as those with osteomyelitis or those presenting with open wounds. The most common type of external fixator seen in our research was the Ilizarov-type ring fixator, which was used in 9 of the 11 studies. Also,

an even split was noted between external fixation used independently and external fixation combined with internal fixation. The deformity correction process with external fixation was often staged in multiple adjustments, leading to a salvaged foot and/or ankle. Many of the external fixation studies reported earlier weightbearing than with internal fixation.

In 2011, Grant et al (8) reviewed the records of 71 Charcot foot reconstructions. The surgical technique used medial and lateral column beams and Ilizarov or hybrid external fixators for compression and to stabilize the reconstructed foot. We categorized the study under external fixation techniques for our review. Grant et al (8) reported that beaming surgical intervention plus external fixation yielded only successful results for Charcot reconstruction with no reported amputations.

In 2012, Pinzur et al (9) reviewed 73 cases of patients who had undergone Charcot foot reconstruction with external fixation. These were all complicated cases because all the patients had reported osteomyelitis. Osteomyelitis had been diagnosed before surgery and histologically confirmed. Postoperatively, the patients with deformity of the foot were allowed to bear weight after 8 weeks in the external fixator. When the Charcot deformity was in the ankle, weightbearing was allowed at a minimum of 12 weeks postoperatively. At the end of the follow-up period, 71 patients were evaluated, and 68 (95.7%) had had successful salvage with ambulatory ability and only 3 (4.2%) had required amputation. Osteomyelitis was combated most commonly through multiple antibiotics during these procedures for the most efficient healing.

Lamm et al (10) in 2010 reported on external fixation in patients in whom the Charcot deformity involved only the foot. Rings and gradual multistaged correction was the implemented technique. The

Table 3

Summary of external fixation (n = 341 feet in 319 patients)

Investigator	Procedures (n)	Anatomic Site	Fixation	Mean Age (y)	Gender (F/M)	Follow-up (mo)	Successful Salvage (n)	Unsuccessful Salvage (n)	Amputation (n)
Farber et al (22), 2002	11	Foot	NR	55	NR	24	10	1	0
Zarutsky et al (23), 2005	11	Ankle	Ring	57.4	4/7	27	9	2	1
Fabrin et al (24), 2007	12	Ankle	Ring	61	7/4	48	11	1	1
Pinzur (25), 2007	26	Foot	Ring	56.6	12/14	12	24	2	1
Dalla Paola et al (26), 2009	45	Foot	Pin to bar	65.3	15/30	12	39	6	4
El-Gafary et al (27), 2009	20	Foot/ankle	Ring	30	9/11	20	20	0	0
Grant et al (28), 2009	50	Foot/ankle	Ring	55.1	24/20	30	44	6	2
Karapinar et al (11), 2009	11	Ankle	Ring	51	4/7	58.3	10	1	0
Lamm et al (10), 2010	11	Foot	Ring	61	5/3	22	11	0	0
Grant et al (8), 2011	71	Foot/ankle	Ring	56.1	27/43	31	71	0	0
Pinzur et al (9), 2012	73	Foot/ankle	Ring	57.9	32/41	12	68	5	3
Total procedures	341			55.127273		26.93636364	317	24	12

Abbreviations: F, female; M, male; NR, not reported.

study consisted of 11 procedures on 8 patients. The successful salvage rate was 100% in all 11 feet, with no amputations reported. The patients were able to begin progression to weightbearing at around 2 to 3 months, with treatment completion at 5 months. These results showed that multistage corrections with external fixation could also be a viable treatment method for Charcot foot reconstruction.

In 2009, Karapinar et al (11) reported on 11 patients who had undergone Charcot ankle reconstruction using Ilizarov external fixators. Weightbearing in their study began the day after surgery if the patient was willing and able to do so. Of the 11 patients, 10 had successful salvage in which they were able to walk freely. One patient's procedure was unsuccessful, with fibrous nonunion resulting. The patient only had the ability to walk short distances with the help of a brace. These results support the notion that not only will external fixation with an Ilizarov-style fixator help the foot but could also be helpful in ankle arthrodesis cases.

In 2008, Conway (12) completed a published data review on external fixation correction for Charcot foot. Their report considered 5 studies, comparing the results to determine the efficacy of external fixation. Conway (12) found that the salvage rate was quite encouraging when external fixation was used, citing a success rate of 80% to 96%. Coinciding with many of the studies included in our review, Conway reported that the most common complication with external fixation was pin tract infection, requiring oral antibiotics for treatment. Conway indicated that more reviews of published studies on external fixation are needed to explore this method of treating Charcot foot but concluded that it appears to be quite effective thus far.

Wang et al (13) in 2002 reviewed 28 cases of external fixation for Charcot foot reconstruction. All 28 patients experienced a discontinuation of breakdown in their affected foot. Compared with other studies, they reported a lower occurrence of pin tract infection, with only 11% (3 patients) developing pin tract infections. Although their study provided great support for the use of external fixation in treating Charcot foot deformity, that external fixation was used as an early intervention to slow the progression of the disease did not warrant inclusion in our systematic review.

We are aware of the limitations of our systematic review. First, we only considered studies with a minimum of 10 procedures, thereby omitting some available data on Charcot foot reconstruction fixation. Although we consider this a limitation, we believe that including studies with ≥ 10 patients, an indication of a minimum level of surgeon experience, was necessary to draw meaningful conclusions. It is also important to note that many of our included reports had a small patient population size, which can lead to skewing of the data. Another limitation of our systematic review was that we only included studies published in English, omitting foreign language data that might be pertinent to our systematic review. Additionally, the level of evidence was 4 for each of the studies, as determined by the Journal of Foot and Ankle Surgery Guide for Authors. At this level of evidence, selection bias and the definitions of terms, such as complications and success, varies greatly among studies. Finally, as noted in the "Materials and Methods" section, we did not perform a meta-analysis of the pooled data after determining the homogeneity ("poolability") of the results described in each of the reports we selected for inclusion in our review. Instead, we focused on qualitative descriptive factors and believe that surgeons interested in further investigating reconstruction of the Charcot foot can use the information.

The sample size for both groups was similar, allowing a clinical comparison of the outcomes and complications (internal fixation in 12 studies and external fixation in 11 studies). An important consideration is that external fixation had greater odds of success, although used in much more complicated cases than were the internal fixators.

These data could be helpful to surgeons involved in the treatment of Charcot foot deformity when faced with decisions involving the varying fixation options.

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