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Original Research

Prognostic Scoring System for Patients Undergoing Reconstructive Foot and Ankle Surgery for Charcot Neuroarthropathy: The Charcot Reconstruction Preoperative Prognostic Score

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ABSTRACT

Charcot neuroarthropathy is a destructive process that occurs in patients with peripheral neuropathy, often due to poorly controlled diabetes mellitus. Surgical reconstruction can be necessary to provide a plantigrade foot that is wound free. A risk of major amputation exists after a Charcot event and after attempted reconstruction. We retrospectively reviewed the data from 34 patients (36 reconstructions) who had undergone reconstructive surgery for Charcot neuroarthropathy. The mean patient age was 56.44 years. The mean follow-up period was 56 months. We collected patient age, body mass index, presence of wound or osteomyelitis, anatomic location, activity of disease, and hemoglobin A1c. Using these data, each patient was given a score using our novel prognostic scoring system, the Charcot Reconstruction Preoperative Prognostic Score (CRPPS). Our primary outcome measure was no wound and no major amputation at the final follow-up visit. The limb salvage rate was 89% (32 of 36), and 78% (28 of 36) had no wound at the final follow-up examination. For patients without a wound or major amputation at the final follow-up visit, the mean CRPPS was 2.96 ± 1.23. The mean CRPPS for those with a wound or major amputation at the final follow-up visit was 4.33 ± 1.07 ($p = .0024$). Univariate logistic regression revealed 2 statistically significant predictors of wound and/or amputation: anatomic location (odds ratio [OR] 5.0, 95% confidence interval [CI] 1.051 to 23.789; $p = .043$) and CRPPS (OR 2.724, 95% CI 1.274 to 5.823, $p = .01$). A CRPPS of ≥4 was also predictive of a negative outcome (OR 7.286, 95% CI 1.508 to 35.211; $p = .013$). This scoring system, with a sensitivity of 75%, specificity of 71%, and negative predictive value of 85%, is a potential starting point when educating patients and making treatment decisions in this exceptionally challenging group.

The Charcot foot and ankle continue to present challenges for the foot and ankle surgeon. Nonsurgical versus surgical intervention continues to be debated in published studies, and no clear consensus has been reached on patient selection when considering reconstruction. The aim of reconstruction is to reduce the risk of ulceration by creating a stable plantigrade foot that will allow the patient to bear weight and remain ambulatory in commercially available shoe gear, decreasing morbidity and the risk of amputation (1). However, the risk of ulceration and reulceration after reconstruction has been high (33%) (2). Patients' cases are often complicated by longstanding diabetes mellitus, increasing the risk of total perioperative complications.

Although limb salvage rates after Charcot reconstructive foot and ankle surgery have been reportedly high (~90%) (3), it is difficult to determine which patients will be likely to progress to a functional limb amenable to shoe gear without ulceration. In 2007, Pinzur (4) reported criteria conveying a high risk of complications after Charcot reconstruction, including a large bone deformity, longstanding ulceration with underlying bone infection, regional osteopenia, obesity, and immunocompromised health status. Eschler et al (6) subsequently investigated the outcomes of patients with ≥2 of the 5 of Pinzur's

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Table 1
System for determining the Charcot Reconstruction Preoperative Prognostic Score

Factor	Score
Age (y)	
<50 y	0
>50 y	1
BMI (kg/m^2)	
<30	0
30 to 35	1
35 to 40	2
>40	3
Presence of wound	
No	0
Yes	1
Presence of osteomyelitis	
No	0
Yes	1
Anatomic location	
Excluding ankle	0
Including ankle	1
Active clinical disease	
No	0
Yes	1
Hemoglobin A1c (%)	
<8	0
8 to 10	1
>10	2
Total CRPPS possible	10

Abbreviations: BMI, body mass index; CRPPS, Charcot Reconstruction Preoperative Prognostic Score.

high-risk criteria and found that a PEDIS score (5) of <7 was associated with successful limb salvage. No other investigations have directly attempted to determine which patient factors affect the reconstruction outcome. Most available studies have focused on technique description rather than patient selection factors.

The purpose of the present study was to retrospectively review the data from patients at a single foot and ankle center with a diagnosis of Charcot foot or ankle who had undergone reconstruction by a single surgeon (P.R.B.) in hopes of identifying how age, body mass index (BMI), hemoglobin A1c (HbA1c), clinical activity of Charcot disease, anatomic location, and the presence of a wound and/or osteomyelitis are associated with the outcomes. A novel prognostic scoring system is presented.

Patients and Methods

Formal institutional review board approval was obtained. We reviewed the electronic medical records of the senior author (P.R.B.) from March 2006 to October 2013. We included consecutive patients who had undergone arthrodesis reconstructive surgery for Charcot neuroarthropathy (CN). Patients with ICD-9 code 713.5 (Charcot/neuropathic arthropathy) who underwent any combination of the following CPT codes were searched and included: pantalar arthrodesis (28705), ankle arthrodesis (27870), subtalar arthrodesis (28725), midtarsal arthrodesis (28730), midtarsal arthrodesis with osteotomy (28735), talonavicular arthrodesis (28740). Some reconstructions were staged procedures with external fixation if deemed necessary because of an active Charcot disease process, wounds, and/or compromised soft tissue. All definitive reconstructions were arthrodeses using the superconstruct principles (7). We collected each patient's age, BMI, presence of wound or osteomyelitis, anatomic location of Charcot, activity of Charcot at reconstruction, and HbA1c.

The osteomyelitis diagnosis was determined using a probe-to-bone test, complete blood count, erythrocyte sedimentation rate, C-reactive protein, and microbiologic analysis results of bone biopsy. In cases of osteomyelitis, aggressive debridement of the infected bone was performed with organism-specific antibiotic therapy given. It is our treatment protocol to treat such patients in a staged fashion. Active versus nonactive CN was determined by the clinical presence of a red, hot, swollen foot or ankle with radiographic evidence of effusion, subluxation, and periarticular debris. For the anatomic location, we evaluated whether the ankle was involved. Those patients without diabetes were assigned an HbA1c of 5%.

We excluded patients missing any single piece of required information or lacking postoperative follow-up data. Each patient was assigned a Charcot Reconstruction Preoperative Prognostic Score (CRPPS) using our novel scoring system (Table 1). Items were selected for inclusion in the scoring system according to the authors' opinion on easily quantifiable, readily available information that could influence surgical outcome (see discussion). The score range is from 0 to 10.

The primary outcome measure was defined as no major amputation and no wound at the final follow-up visit. Two groups were formed according to the primary outcome (group 1, those without a wound or major amputation at the final follow-up

Table 2
Group 1 (no wound or major amputation at final follow-up visit) characteristics

Pt. No.	Age (y)	BMI (kg/m^2)	Wound	Osteomyelitis	Location	Active	HbA1c	CRPPS
1	48.11	38.72	No	No	Ankle	Yes	9.6	5
2	44.71	35.62	No	No	Midfoot	Yes	6.2	3
2 (Bilateral)	44.71	35.62	No	No	Midfoot	Yes	6.2	3
3	55.61	24.9	Yes	Yes	Midfoot	No	9.4	4
4	71.3	38.2	No	No	Midfoot	No	6.4	3
4 (Bilateral)	71.3	38.2	No	No	STJ	No	6.4	3
5	44.61	46.1	Yes	No	Chopart	No	7.0	4
6	52.64	27.3	No	No	Midfoot	No	7.5	1
7	72.7	28.7	No	No	Midfoot	No	6.6	1
8	37.86	30.6	No	No	Ankle	No	5.8	2
9	50.28	23.1	Yes	Yes	Midfoot	No	9.1	4
10	56.82	29.12	No	No	Midfoot	No	9.6	2
11	50.09	31.56	Yes	No	Ankle	Yes	8.8	6
12	76.03	29.6	Yes	No	Midfoot	No	7.0	2
13	47.67	30.11	Yes	Yes	Chopart	No	7.5	3
14	65.05	33.84	Yes	No	Midfoot	No	7.0	3
15	61.26	33.38	No	No	Midfoot	No	5.0	2
16	59.59	33.75	No	No	Midfoot	No	8.3	3
17	65.48	37.07	Yes	No	Chopart	No	7.0	4
18	58.57	36.4	No	No	STJ	No	5.0	3
19	52.77	25.85	No	No	TNJ	No	5.0	1
20	57.27	41.99	No	No	Midfoot	No	6.2	4
21	54.98	23.23	No	No	Ankle	No	8.6	3
22	67.56	24.37	Yes	No	Midfoot	No	7.6	2
Average (mean)	56.96	32.39	9/24 37.5), yes	3/24 (12.5), yes	4/24 (16.7), ankle	4/24 (16.7), yes	7.2	2.96

Data in parentheses are percentages.
Abbreviations: BMI, body mass index; CRPPS, Charcot Reconstruction Preoperative Prognostic Score; HbA1c, hemoglobin A1c; Pt. No., patient number; STJ, subtalar joint; TNJ, talonavicular joint.

Table 3
Comparison of variables and Charcot Reconstruction Preoperative Prognostic Scores between groups (N = 34 patients [36 reconstructions])*

Variable	Group 1 (n = 22 patients [24 reconstructions])	Group 2 (n = 12 patients [12 reconstructions])	*p* Value
Age (y)	56.96 ± 10.25	55.66 ± 11.42	.73
BMI (kg/m²)	32.39 ± 6.09	36.45 ± 8.67	.11
HbA1c (%)	7.2 ± 1.43	7.5 ± 1.59	.60
Wound			.30
Yes	9 (37.5)	7 (58.3)	
No	15 (62.5)	5 (41.7)	
Osteomyelitis			.38
Yes	3 (12.5)	3 (25.0)	
No	21 (87.5)	9 (75.0)	
Location			.05
Ankle	4 (16.7)	6 (50.0)	
No ankle	20 (83.3)	6 (50.0)	
Active			.40
Yes	4 (16.7)	4 (33.3)	
No	20 (83.3)	8 (66.7)	
CRPPS	2.96 ± 1.2)	4.33 ± 1.07	.0024†

Data presented as mean ± standard deviation or number of patients.
Abbreviations: BMI, body mass index; CRPPS, Charcot Reconstruction Preoperative Prognostic Score; HbA1c, hemoglobin A1c.
* Group 1, no wound or major amputation at the final follow-up visit; group 2, the presence of a wound or major amputation at the final follow-up visit.
† Statistically significant.

visit; Table 2; and group 2, those with a wound or major amputation at the final follow-up visit).

Statistical Analysis

All statistical analyses were performed using SPSS software, version 23 (IBM® Corp., Armonk, NY). Statistical significance was defined at the 5% ($p \leq .05$) level. All continuous variables were assessed for normality, and the appropriate statistical tests were used for independent sample comparisons (Tables 3 and 4). A novel scoring system was then used that incorporates these variables. The CRPPSs were compared between groups using the Student *t* test (Table 4). Receiver operating characteristic (ROC) curve analysis was then performed to determine an appropriate cutoff value and analyze the CRPPS. The ROC analysis also provided test accuracy, specificity, and sensitivity. Univariate logistic regression analyses were performed to obtain the odds ratios (ORs) for each variable as they related to the presence or absence of postoperative complications (wound or amputation) at the final follow-up visit.

Results

Forty-six patients were identified. Of these patients, 10 (21.7%) were excluded because of a lack of data. Forty-six reconstructions in 44 patients were identified met our inclusion criteria. Of the 34 patients, 21 were males (62%) and 13 were females (38%). Their mean age was 56.4 (56.5 ± 10.51) years. The mean follow-up period was 56 (5 to 116) months. The limb salvage rate at the final follow-up visit was 89% (32 of 36; 4 below-the-knee amputations). At the final follow-up examination, 78% (28 of 36) had no wound.

The mean CRPPS for all patients was 3.42 ± 1.34. The mean CRPPS in group 1 was 2.96 ± 1.23 compared with 4.33 ± 1.07 in group 2 ($p = .0024$). None of the individual variables was significantly different statistically between the 2 groups, although the BMI and location were closest to significance (Table 3). ROC curve analysis indicated test optimization at a cutoff value of 3.5. Using this cutoff, the scoring system had a sensitivity of 75% and specificity of 71%. Test accuracy was determined to be “good” using ROC curve area analysis (0.8, 95% confidence interval [CI] 0.652 to 0.945). A CRPPS of ≥4 had a positive predictive value of 56% but negative predictive value of 85%. The logistic regression model revealed 3 statistically significant predictors for the development of a wound or amputation: anatomic location (OR 5.0, 95% CI 1.051 to 23.789; $p = .043$), total CRPPS (OR 2.724, 95% CI 1.274 to 5.823; $p = .01$), and CRPPS ≥4 (OR 7.286, 95% CI 1.508 to 35.211; $p = .013$; Table 4).

Discussion

As shown by Stuck et al (8), increased BMI, increased age, and elevated HbA1c are associated with the initial development of Charcot foot and ankle. However, it remains to be determined whether these are associated with the outcomes after surgical correction. In 2005, Pinzur et al (9) found that an increased BMI in patients with diabetes led to the development of diabetic foot disorders. However, they did not examine the association of BMI to Charcot or to the outcomes after Charcot reconstruction (9). Finkler et al (10) found that higher HbA1c levels in patients undergoing Charcot reconstruction with ringed external fixation were associated with superficial pin site infections. However, their study did not investigate the effects of HbA1c level on final surgical outcome or limb salvage (10). Wukich et al (11), in 2010, reported an increased risk of infection and mechanical failure after foot and ankle surgery when the HbA1c level was >8%.

The influence of a wound or osteomyelitis at reconstruction has also not yet been determined. In 2009, Dalla Paola et al (12) reported healing and successful limb salvage in 87% of Charcot foot and ankle reconstructions with histopathologic confirmation of osteomyelitis. Their patients underwent bone debridement and attempted fusion with external fixation (12). Pinzur et al (13) reported a 95.7% limb salvage rate in patients with CN and osteomyelitis. Their patients were treated with radical resection of the clinically infected bone,

Table 4
Univariate logistic regression analysis using Charcot Reconstruction Preoperative Prognostic Score cutpoint of 4

Variable	Group 1 (n = 22 patients [24 reconstructions])	Group 2 (n = 12 patients [12 reconstructions])	OR	95% CI for OR	*p* Value for OR
Age (y)	56.96 ± 10.25	55.66 ± 11.42	0.99	0.92 to 1.06	.72
BMI (kg/m²)	32.39 ± 6.09	36.45 ± 8.67	1.09	0.98 to 1.21	.13
HbA1c (%)	7.2 ± 1.43	7.5 ± 1.59	1.14	0.71 to 1.84	.59
Presence of wound	9/24 (37.5)	7/12 (58.3)	2.33	0.57 to 9.60	.24
Presence of osteomyelitis	3/24 (12.5)	3/12 (25)	2.33	0.94 to 13.85	.35
Presence of ankle CN (location)	4/24 (16.7)	6/12 (50)	5.0	1.05 to 23.79	.04*
Active CN	4/24 (16.7)	4/12 (33.3)	2.5	0.50 to 12.51	.27
HbA1c dichotomized (>8.0)	7/24 (29.2)	4/12 (33.3)	1.55	0.43 to 5.58	.51
CRPPS	2.96 ± 1.23	4.33 ± 1.07	2.72	1.27 to 5.82	.01*
CRPPS ≥4	7/24 (29.2)	9/12 (75)	7.29	1.51 to 35.21	.01*

Data presented as mean ± standard deviation (continuous data) or as frequency (percentage of presence of variable; nominal data).
Abbreviations: BMI, body mass index; CI, confidence interval; CN, Charcot neuroarthropathy; CRPPS, Charcot Reconstruction Preoperative Prognostic Score; HbA1c, hemoglobin A1c; OR, odds ratio.
* Statistically significant.

combined with acute correction of deformity and application of ring external fixation (13). Their findings suggest that the presence of osteomyelitis might not ultimately adversely affect the outcomes in surgical reconstruction if the appropriate reconstruction techniques are implemented (13). In 2015, Ramanujam et al (14) reviewed the data from 116 patients who had undergone Charcot reconstruction using ringed external fixation. They found a statistically significant association between the presence of a wound preoperatively and below-the-knee amputation. No statistically significant association was found between the patients' HbA1c or BMI and major lower extremity amputation in their patient population (14).

The anatomic location of CN can influence the outcome. Deformities involving the ankle are potentially more unstable, making reconstruction more challenging. The deformities are often multiplanar, and limb shortening often occurs from collapse of the distal tibia or talus (15). Bulk femoral head allograft has been used when significant collapse and bone loss is present. Jeng et al (16) reported on 32 patients who underwent tibiotalocalcaneal fusion with femoral head allograft for a variety of reasons. They reported only a 50% fusion rate, and 19% of their patients subsequently required below-the-knee amputation. All 9 diabetic patients in their study developed nonunion (16).

Increasing age has been associated with peripheral bone loss in both males and females, with postmenopausal women experiencing a greater rate of bone loss (17). This peripheral bone loss due to age could increase the osteopenia already typically seen with CN (18). This could pose issues with fixation and with achieving successful arthrodesis. Furthermore, a literature review from 2010 concluded that increased age is a major risk factor for impaired cutaneous wound healing (19). Age could also be associated with general health and healing potential. For these reasons, we included age in our scoring system.

No clear consensus has been reached on the timing of surgical reconstruction for CN. Currently, the most commonly accepted treatment of active Charcot is immobilization with casting, with surgical intervention more accepted for nonactive disease after bony consolidation has occurred. Potential concerns exist about the soft tissue in the presence of a significant inflammatory process. However, Simon et al (20) reported 14 patients who had undergone surgical reconstruction for midfoot CN during the active phase. They reported 100% limb salvage with no postoperative wound complications (20).

With the global increase in diabetes and obesity, awareness of CN in the foot and ankle has increased. This is fortunate because CN is associated with a reduced self-reported quality of life (21) and should be recognized and treated appropriately. Hastings et al (22) showed the progressive nature of the Charcot foot over 2 years using radiologic measurements. These progressive malalignments can lead to instability, ulceration, and infection. They postulated that the progressive course of the Charcot limb requires more aggressive treatment than historically recognized (22). This acknowledged surgical paradigm shift in recent years has resulted in reconstructive foot and ankle surgeons intervening more frequently to attempt to achieve a stable, plantigrade foot (23). Thus, we believe it is important to identify the factors predictive of a successful outcome in an effort to predict which patients would be optimal candidates for reconstructive limb salvage procedures and which patients could benefit from primary major limb amputation. We have presented the CRPPS scoring system as a method to help provide physicians and patients with more accurate and realistic expectations when faced with potential Charcot surgical reconstruction. The CRPPS could be an instrument to help identify high-risk patients. This would allow for improved patient counseling and better explanations of the treatment options, including amputation. Wukich and Pearson (24) in 2013 demonstrated that patients with CN and chronic osteomyelitis who required major amputation actually had improved self-reported outcomes after the amputation. This gives hope to patients with CN who will require a major amputation (24).

The limb salvage rates after Charcot reconstruction have been high, regardless of the technique or fixation choice, approaching 90% in most studies (3). This rate is consistent with the limb salvage rate found in the present study.

Pinzur (1) in 2004 showed that 40% of patients with midfoot CN required surgical intervention to achieve a plantigrade foot that was amenable to commercially available, therapeutic footwear and custom foot orthoses (1). This is in contrast to ankle Charcot, when varus and valgus malalignments of the ankle often lead to prominent malleoli and ulceration (22). An international CN task force agreed that surgical management could be considered a primary treatment of ankle Charcot. This is because of the poor tolerance of ankle deformity in the coronal plane (25). The results of the present study have confirmed the detrimental effect of ankle CN involvement on the surgical outcomes. Using logistic regression analysis, the anatomic location was strongly predictive of the outcome with an OR of 5.0 ($p = .043$). This is not surprising, given that the axial load through the ankle often results in talar collapse and loss of limb length, which requires a bulk femoral head allograft. It is our experience that Charcot ankle deformities quickly progress and can lead to wound/osteomyelitis.

A high BMI also showed a trend toward significance in our logistic regression model ($p = .13$). Patients with a high BMI and CN often pose a dilemma to surgeons. The outcomes after foot or ankle reconstruction in obese patients have been less favorable; however, these are also the patients who have a difficult time wearing prosthetics after a major amputation (25).

The CRPPS comparison between the 2 groups showed that those with a wound or major amputation had significantly different scores statistically than those without a wound or major amputation at a mean 4.5-year final follow-up examination ($p = .0024$). Although this was significant when we retrospectively analyzed our cohort, future prospective use of the scoring system is required to validate the CRPPS.

Several nonquantifiable factors should be considered when thinking of Charcot foot or ankle reconstruction, such as patients' psychosocial issues and family support. However, we sought to provide prognostic scores that would consider quantifiable or objective patient data easily accessible to the surgeon. We recognize that objective factors certainly exist that can affect the outcomes that were not included in the CRPPS. Peripheral arterial status, renal function, osteoporosis, nutrition status, immunocompetency, and other factors are important and should be considered during the treatment process. In an attempt to keep the CRPPS system quick and useable, we chose to include factors that are readily available, often at the initial visit. A scoring system that is too cumbersome to use would not be practical.

The present study had limitations. We had a relatively small sample size. The retrospective nature of the study was also a weakness. Prospective work is needed to validate our scoring system. We also did not consider the functional outcome as it relates to the scoring system. The outcomes in the present study were based solely on the presence of a wound or major amputation.

Our novel scoring system (CRPPS) demonstrated a significant association between lower preoperative scores and a lower risk of major amputation or wound at 4.5 years of follow-up, with good test accuracy, sensitivity, and specificity. The system also had a high negative predictive value, suggesting that patients with preoperative scores <4 are unlikely to progress to ulceration, repeat ulceration, or major amputation. In our experience, 85% of those with a score of <4 had a positive outcome and had a plantigrade, ulcer-free foot after reconstruction. A score of <4 decreased the pretest probability from 33% to 15%. Although several other important pieces of information should be included when considering reconstruction, the CRPPS could serve as an aid when educating patients and making decisions regarding this exceptionally challenging group of patients.

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