16 Charcot foot

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16.1 Introduction

In spite of the massive amount of health system resource consumption directly attributed to diabetic foot morbidity, a 1999 Diabetic Medicine editorial noted that only 3% of 6,661 clinical trials on diabetes-related issues were concerned with diabetic foot morbidity.<1,2> The goal of this review is to provide the reader a summary of our current understanding of the disease process named after the famous French neurologist, Jean Martin Charcot, and provide evidence-supported guidance for clinical management.

In 1868, Jean-Martin Charcot provided the first in-depth description of a destructive hypertrophic osteoarthropathy that affected joints of patients with tertiary syphilis.<3,4,5> Penicillin has virtually eradicated tertiary syphilis, while insulin has allowed patients with diabetes to survive and develop the longstanding peripheral neuropathy that appears to be the precursor for the development of a neuropathic (Charcot) osteoarthropathy.

Our modern understanding of neuropathic (Charcot) arthropathy is based on a benchmark monograph published by Eichenholtz in 1966. He summarized the available literature and cataloged clinical, radiographic, and pathologic data in 68 consecutive patients. His light microscopy photographs demonstrate the pronounced osteoclastic activity that provides the basis of recent bone turnover and electron microscopy investigations.<6> Based on his clinical and pathologic observations, Eichenholtz proposed a timeline of the disease that was divided into three stages:

- **Stage I (Stage of Development)**, initiation of the process
- **Stage II (Stage of Coalescence)**, the active period of the disease process when bony destruction and deformity occur
- **Stage III (Stage of Reconstruction)**, commencing when the destructive process "burns out" and the bone consolidates (heals) with the resulting deformity, making the patient prone for the development of tissue failure, deep infection and the frequent necessity for lower extremity amputation
16.2 Pathophysiology

The development of peripheral neuropathy in individuals with diabetes is attributed to a complex interaction of glycosylated hemoglobin with arterioles of both central and peripheral nerves. The resultant progressive loss of function is first appreciated in the smallest nerve fibers, leading to conduction defects in sensory, motor, and autonomic nerves. Precipitation of glycosylated hemoglobin at the arteriolar level is likely responsible for many of the co-morbidities associated with diabetes.<7,8>

While there are more sensitive methods for detecting the presence of peripheral neuropathy, the accepted clinical tool is the Semmes-Weinstein 5.07 monofilament (Figure 1). The lack of perception of 10 grams of pressure (pressure applied by 5.07 monofilament) is considered the clinical threshold to support a diagnosis of diabetic peripheral neuropathy.<9,10,11,12> This level of sensory neuropathy is present in approximately 25% of adults with diabetes, as determined by population screening.<13> While not universally true, most patients who develop Charcot foot arthropathy have this threshold level of peripheral neuropathy.<9,14>

Figure 1. Semmes-Weinstein 5.07 monofilament

Acute or sub-acute repetitive trauma is likely a key initiating event of the pathologic process that leads to Charcot foot arthropathy. The *neurotraumatic theory* suggests that the inciting event is trauma. Without the presence of protective sensation, the patient continues to bear weight, eventually leading to a clinical scenario that mimics a hypertrophic non-union.<15> The *neurovascular theory* is predicated on an autonomic peripheral neuropathy that creates a high-flow vascular state in affected patients. This increased blood flow simplistically “washes out” structural calcium from the bone, leading to localized osteopenia and mechanically induced deformity associated with continued weight-bearing.<16,17> The truth is likely a combination of both theories.

Our current understanding of the effect of glycosylated hemoglobin on arterioles within central and peripheral nerves, leading to neuropathy, creates an excellent foundation for explaining the pathologic process. Some inciting event, likely trauma, initiates the production of the bioactive cytokines IL-1, beta IL-6, and TNF-alpha, which, in turn, activate osteoclastic recruitment, proliferation, and differentiation, thus initiating the destructive process described by Eichenholtz. Baumhauer identified the specific cytokines and demonstrated the presence of both an increased number of osteoclasts in affected tissue and increased destructive osteoclastic activity.<18> This concept is well supported by Gough, who demonstrated similar findings of increased unbalanced osteoclastic bone turnover based on measurement of serum and urine markers.<19>
The motor neuropathy, which initially affects smaller nerves and muscles, leads to a motor imbalance in which the larger and stronger foot and ankle plantar-flexor muscles overpower the smaller dorsiflexors. Recent evidence from several authors has clearly demonstrated increased static stiffness within the Achilles tendon and the posterior ankle ligamentous tissues. This creates an intuitive pathomechanism to explain the initiation of the destructive process. The motor imbalance created by the motor neuropathy applies an increased bending moment during terminal stance phase of gait that apparently overloads the structures at the midfoot level. The resultant forces appear to be responsible for upregulating the cytokines that “turn on” the osteoclastic activity demonstrated pathologically and clinically.<20-28>

16.3 Impact on Health Related Quality of Life

The incidence of Charcot foot appears to be approximately 0.3% per year, based on a longitudinal observational study of 3,000 Scandinavian patients with diabetes.<29> Major complications related to the deformity occur in 4% of patients.<29,30> One hundred patients with Charcot foot arthropathy were followed for 3 years as the target population used in validation of the AOFAS Diabetic Foot questionnaire. This investigation demonstrated a significant negative health related quality of life impact on affected patients. This negative impact was sustained, and not resolved following even successful treatment.<31> Similar observations were made from a small cohort of patients being treated in a specialty diabetic foot clinic, using the Short Musculoskeletal Assessment questionnaire (SMFA).<32>

16.4 Clinical Presentation

Patients typically present in the sixth or seventh decade. The vast majority were diagnosed with diabetes (both Types I and II) many years earlier. Most have clinical evidence of peripheral neuropathy, as measured by insensitivity to the Semmes-Weinstein 5.07 (10 gm) monofilament. Occasionally, patients with neuropathy of other etiologies, such as alcohol, chemotherapy, and heavy metal, will present for treatment. Most patients are morbidly obese. Better than half of patients can cite a specific traumatic episode, often trivial, that initiated the process.

Patients classically were thought to present with painless swelling of affected joints. In fact, many patients have pain associated with the swelling and deformity. While the involved foot is warm, swollen, and erythematous, the patient has an absence of clinical signs of sepsis, such as fever, leucocytosis, elevated blood sugar, or increased insulin requirement. A further clinical differentiation from infection can be made by limb elevation. The erythema will decrease with elevation associated with arthropathy, as opposed to infection. Patients with infection generally have some element of purulent drainage. Patients with Charcot arthropathy have drainage only if there is secondary infection of a pressure ulcer.<6,7,8,9,14,29,30,33>

16.5 Diagnosis
While multiple imaging techniques have been studied, the diagnosis is generally made clinically, and supported with plain radiographs. The initial presentation is often confused with deep infection because affected patients are generally poor hosts.<sup>34</sup> While several diagnostic imaging techniques have shown promise in differentiating acute neuropathic arthropathy from infection, none has been sufficiently specific to warrant routine use.<sup>35</sup> Most patients are morbidly obese, have had diabetes for more than 10 years, and have evidence of peripheral neuropathy as measured by insensitivity to the Semmes-Weinstein 5.07 (10 gm) monofilament.<sup>14</sup> Several radiographic classifications have been developed based on anatomic location and deformity; however, most experts use the original time-line advocated by Eichenholtz.<sup>6,37-40</sup>

### 16.6 Treatment

Based on the notion that increased osteoclastic/bone turnover is the root cause of the disease process, the parenteral bisphosphonate pamidronate has been demonstrated to decrease bone turnover and clinical symptoms for a limited study period.<sup>36</sup> While many clinicians have used oral bisphosphonates with unpublished anecdotal success, this form of treatment has not been approved for use by the US Food and Drug Administration.

#### 16.6.1 Eichenholtz Stage I Disease

**Total Contact Cast vs. Early Arthrodesis**

Up until the mid 1990s, Charcot arthropathy was thought to be a rare condition associated with any loss of protective sensation. Experts recognized it as a destructive process, and advised immobilization and the avoidance of further trauma by avoiding weight-bearing until the acute process resolved.<sup>41,42</sup>

The non-weight-bearing total contact cast, which had become popular as a treatment for diabetic foot ulcers, was the accepted treatment standard for acute Charcot foot arthropathy. This approach was supported by several uncontrolled retrospective case series.<sup>9,42</sup> There is approximately a 3% risk for the development of iatrogenic cast-associated ulcers, which generally resolve with local wound care and cast change.<sup>44,45</sup>

The “gold standard” treatment of immobilization of the foot with a non-weight-bearing total contact cast until the foot was sufficiently “stable” to afford longitudinal management with accommodative bracing, was based on expert opinion and confirmed by retrospective case series that had no historical or benchmark standards or a recognized description of a favorable outcome. Two retrospective case series demonstrated similar results when patients were treated with a weight-bearing total contact cast, changed at 2-week intervals.<sup>46,47</sup> Several retrospective case series supported the role of surgery for deep infection with sepsis, osteomyelitis, or when the resultant deformities subjectively could not be managed with accommodative bracing.<sup>14,48-51</sup>

Based on clinical observations that agreed with the more recently reported health-related quality of life outcomes questionnaires, several investigators began to advise early surgical stabilization/arthrodesis with rigid internal fixation to avoid late deformity and/or the need for cumbersome accommodative bracing. Successful results were based on successful arthrodesis and limb salvage. No mention was made of health-related quality of life or functional impact of disease.<sup>23,37,48,52-59</sup>
A retrospective review of patients managed in a Diabetic Foot clinic revealed that patients with a non-linear lateral talar--first metatarsal axis, as determined from weight bearing AP radiographs, were more likely to develop late foot ulcers than those patients with a co-linear hindfoot-forefoot axis.\textsuperscript{60} When this radiographic measure was combined with a clinical assessment of plantigrade vs. non-plantigrade weight bearing, it was retrospectively demonstrated that patients who were clinically plantigrade and possessed a colinear hindfoot-forefoot axis on weight bearing radiographs, could achieve the specific outcome of maintaining walking independence with longitudinal management with commercially-available depth-inlay shoes and custom accommodative foot orthoses.\textsuperscript{61}

### 16.6.2 Eichenholtz Stage II and III Disease

#### Accommodative Bracing vs. Correction of Deformity

Currently, we do not have universally accepted definition of a "favorable outcome" that would allow comparison between accommodative bracing and correction of deformity.

- **Experts who advocate longitudinal management with accommodative bracing techniques**, such as custom-fabricated therapeutic footwear, accommodative ankle foot orthoses (AFO), or the custom-fabricated Charcot Restraint Orthotic Walker (CROW), define favorable outcomes simply based on limb preservation and the avoidance of new ulcers or infections. As such, the reports are retrospective case series without benchmark controls.\textsuperscript{9,14,43,51,55,62,63,64}

- **Experts who wish to avoid the use of accommodative orthoses** advocate early arthrodesis for acute (Stage I) disease and correction of deformity for later (Stage II and III) disease. They perceive the accommodative orthoses as cumbersome and not well tolerated by their patients. They suggest that correction of deformity and the provision of a stable foot allows the use of commercially available therapeutic footwear. Without benchmark controls, they define their surgical outcomes based on successful arthrodesis or correction of deformity. Their case series also fail to report on the perceived positive impact on health related quality of life.\textsuperscript{48,52,53,55-58,65}

It is well accepted that patients with long-standing diabetes who have peripheral neuropathy, morbid obesity, and, often, severe localized osteoporosis are frequently poor surgical candidates. These characteristics put them at high risk for mechanical loss of fixation with attempted surgical correction, as well as wound infection or failure with extensive dissection. These observations have led many investigators to report on non-controlled case series of patients treated surgically with correction of deformity and the maintenance with fine wire ring external fixation in those patients arbitrarily defined as high risk for infection or mechanical failure.\textsuperscript{53,59,66-68}

Partial foot and Syme’s ankle disarticulation amputations have been discussed in retrospective case series as a functional alternative to other forms of treatment.\textsuperscript{54,69,70}

### 16.6.3 Ankle Fracture in Diabetics with Peripheral Neuropathy
Connolly was the first to report on a series of patients with diabetes who developed limb-threatening deformity or infection following failure of internal fixation of seemingly simple ankle fractures.<sup>71</sup> Several authors have reported on high complication rates associated with ankle fracture in the population of patients with diabetes, especially those with evidence of peripheral neuropathy.<sup>34</sup> Several authors have advocated augmented internal fixation combined with prolonged non-weight-bearing until radiographic evidence of bony healing, based on case-controlled series.<sup>13,72,73</sup> Many patients who present with Charcot arthropathy of the ankle initiated their disease process with an ankle fracture, often trivial and non-displaced.

### 16.6.4 Charcot Ankle

Most experts currently agree that when the destructive Charcot process involves the ankle joint, the resultant deformity is so difficult to accommodate with orthotic means that amputation becomes inevitable when stability/joint integrity is lost. Once the joint has been irreversibly damaged, early ankle or tibiocalcaneal arthrodesis are advised. Biomechanical evidence suggests that internal fixation with a retrograde locked intramedullary nail affords the most stable mechanical construct.<sup>74,75</sup> While various applications of blade-plating have been used to achieve ankle fusion in this complex patient population, it appears that ankle fusion with retrograde intramedullary nailing is currently the most popular technique to achieve ankle arthrodesis.<sup>76-80</sup> This technique is complicated by both early and late intramedullary infection that requires creative methods for successful resolution.

Stress fracture of the distal tibial metaphysis is a known complication following successful ankle fusion, regardless of the method of fixation.<sup>13,81,82</sup> This can be avoided by extending the ankle fusion nail to the proximal tibial metaphysis.<sup>75,80</sup>

### 16.7 Conclusions

Charcot foot is becoming a larger clinical problem due to the increased incidence of diabetes and morbid obesity and the improved longevity of affected patients. As the problem has become more apparent, the interest of the orthopaedic device industry has provided improved implants for the surgical treatment of this disorder. Increasing incidence and awareness, combined with increased interest by orthopaedic foot and ankle surgeons and improved implants appears to predict a more favorable future for this very complex patient population.

### 16.8 Other Images
Figure 2a.

Figure 2b.

Figure 2c.
Figures 2a-c. This 58-year-old patient, the owner of a construction firm, presented with a 2-week history of a painful, swollen foot. He is clinically plantigrade, i.e., he is weight-bearing on the normal plantar skin of the foot.

Figure 2d.

Figure 2e.

Figures 2d-e. Weight-bearing radiographs on presentation. The patient is radiographically plantigrade, i.e., the axis of the hindfoot (axis of talus as measured from weight-bearing AP radiograph) is reasonably collinear with the axis of the forefoot (axis of the first metatarsal as measured from weight-bearing AP radiograph). He was treated with a weight-bearing total contact cast, changed every 2 weeks until the foot was clinically stable and the swelling had resolved. The patient was then transitioned to therapeutic footwear.
Figures 2f-g. Weight-bearing radiographs at 1 year. The patient has remained ulcer-free at 3 years.
Figures 3a-c. This 77-year-old female had been treated in a series of non-weight-bearing casts for 9 months prior to presentation. Note that she developed the ulcer from weight-bearing on the head of the talus.
Figures 3g-i. Photographs at 1 year. The patient wears standard therapeutic footwear and custom accommodative foot orthoses.

Figure 3j.

Figure 3k.

Figures 3j-k. The same patient's radiographs at 1 year.

16.9 References

68. Wukich, D, Beilzky, RJ, Burns, PR, Frykberg, RG: Complications Encountered with Circular Ring Fixation in Persons with Diabetes Mellitus. Foot Ank Int. 29: 994-1000, 2008.
83. The Semmes-Weinstein 5.07 monofilament. The 5.07 monofilament applies ten grams of pressure when deformed. This appears to be the clinical threshold of peripheral neuropathy that places diabetic patients at risk for diabetes-associated foot-specific morbidity.