Bone 105 (2017) 237–244

Contents lists available at ScienceDirect

Bone

journal homepage: www.elsevier.com/locate/bone

Full Length Article

Immobilization-induced osteolysis and recovery in neuropathic foot impairments

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ARTICLE INFO

Article history:
Received 18 April 2017
Revised 22 August 2017
Accepted 16 September 2017
Available online 20 September 2017

Keywords:
Quantitative ultrasonometry
Total contact casting
Bone loss
Neuropathic (Charcot) osteoarthropathy
Neuropathic plantar ulcers

ABSTRACT

Background: Neuropathic foot impairments treated with immobilization and off-loading result in osteolysis. In order to prescribe and optimize rehabilitation programs after immobilization we need to understand the magnitude of pedal osteolysis after immobilization and the time course for recovery.
Objective: To determine differences in a) foot skin temperature; b) calcaneal bone mineral density (BMD) after immobilization; c) calcaneal BMD after 33–53 weeks of recovery; and d) percent of feet classified as osteopenic or osteoporotic after recovery in participants with neuropathic plantar ulcers (NPU) compared to Charcot neuroarthropathy (CNA).
Methods: Fifty-five participants with peripheral neuropathy were studied. Twenty-eight participants had NPU and 27 participants had CNA. Bilateral foot skin temperature was assessed before immobilization and bilateral calcaneal BMD was assessed before immobilization, after immobilization and after recovery using quantitative ultrasonometry.
Results: Before immobilization, skin temperature differences in CNA between their index and contralateral foot were markedly higher than NPU feet (3.0 degree C versus 0.7 degree C, respectively, $p < 0.01$); BMD in NPU immobilized feet averaged 486 ± 136 mg/cm^2, and CNA immobilized feet averaged 456 ± 138 mg/cm^2, $p > 0.05$). After immobilization, index NPU feet lost 27 mg/cm^2; CNA feet lost 47 mg/cm^2 of BMD, $p < 0.05$. After recovery, 61% of NPU index feet and 84% of CNA index feet were classified as osteopenic or osteoporotic.
Conclusions: There was a greater osteolysis after immobilization with an attenuated recovery in CNA feet compared to NPU feet. The attenuated recovery of pedal BMD in CNA feet resulted in a greater percentage of feet classified as osteoporotic and osteopenic.

1. Introduction

Neuropathic foot disease is an amalgam of impairments characterized by peripheral neuropathy, vascular disease, skin ulceration, infection, and arthropathy including fracture, joint subluxation and dislocation resulting in non-reducible deformities. Neuropathic foot impairments occur most often in individuals with diabetes mellitus (DM). Two of the most common diabetic neuropathic foot impairments seen either in community clinics or diabetic foot specialty clinics are Charcot neuroarthropathy (CNA) and neuropathic plantar ulcers (NPU) [1,2]. Both NPU and acute CNA occur in the presence of sensory and autonomic peripheral neuropathy [3,4]. NPUs often occur in areas of high stresses (pressures) on the weight bearing surface of the foot, frequently in the forefoot or mid foot with deformities [5]. CNA can occur in any of the small joints or bones in the foot and believed to result from unperceived (even repetitive minor) trauma. Some authors suggest CNA often start in the bones comprising the medial column of the foot [6] resulting in progressive foot deformities [7]. Some studies have implicated that low pedal bone density may be an underlying contributor to both neuropathic foot impairments since neuropathic osteopenia has been associated with diabetic metatarsal fractures [8] ankle fractures [9], progression of acquired foot and ankle deformities [10] which too often culminate in lower extremity amputation [11]. Pedal osteolysis may be accelerated by local and systemic inflammation which accompanies the acute onset of both diabetic foot impairments [12,13].

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https://doi.org/10.1016/j.bone.2017.09.009
8756-3282/

Both CNA and NPU impairments are commonly managed with pressure off-loading and immobilization [14,15]. Total contact casting (TCC) is considered the gold-standard method for off-loading and immobilization because it combines maximal protection to insensitive feet and optimal pressure off-loading in high stress areas to rapidly heal plantar ulcers and acute arthropathies [14–17] yet still allow for protected weight bearing and ambulation. Though TCC is highly effective for ulcer healing and reducing the acute inflammatory stages of CNA, there may be several unavoidable consequences to prolonged immobilization and off-loading including a further acceleration of pedal bone osteolysis [13,18–20]. After healing with immobilization, a program of rehabilitation may be beneficial to restore foot and ankle mobility, regain muscle strength and allow a gradual return to walking and weight bearing activities in therapeutic footwear in order to prevent recurrence or subsequent sequelae. A program of rehabilitation may also help the recovery of pedal bone density [18], however, in order for orthopaedic and rehabilitation specialists to design and prescribe optimal interventions to remedy the immobilization-induced consequences, it is important to know the magnitude and time course of recovery from these impairments.

There have been few reports of immobilization-induced pedal osteolysis in individuals with diabetic, neuropathic foot impairments [13,19,20–22] and no previous reports comparing the impact of pedal osteolysis or recovery in individuals with NPU to individuals with CNA. Therefore, we aimed to determine the magnitude of pedal osteolysis in both neuropathic impairments after immobilization and the time course of recovery. The purposes of our study were to determine if there were differences in a) foot skin temperature; b) calcaneal bone mineral density (BMD) loss after immobilization; c) calcaneal BMD loss after recovery; and d) percent of feet classified as osteopenic and osteoporotic after recovery in participants with NPU compared to CNA. We tested the hypotheses that foot skin temperature difference, calcaneal BMD and percent of feet classified as osteopenic and osteoporotic would be similar (i.e., no differences) in diabetic neuropathic participants with CNA and NPU before cast immobilization, after immobilization and after recovery.

2. Materials and methods

Twenty-eight participants with PN and a unilateral NPU were compared to 27 participants with PN and stage 1 or 2 CNA. Both groups of participants were seeking treatment and followed in our weekly diabetic foot clinic or referred to our physical therapy service for TCC immobilization and off-loading. Inclusion criteria for CNA participants included a radiograph-confirmed overt fracture or arthropathy (subluxation or dislocation) consistent with CNA without evidence of deep or local infection, osteomyelitis or cellulitis. Participants with plantar ulcers and physical signs consistent with infection (cellulitis, osteomyelitis) were excluded from our analysis.

2.1. Peripheral neuropathy & skin temperature

The presence or absence of PN in each participant was assessed using light touch (pressure) at 6 locations on non-callused plantar surfaces of each foot using multiple thicknesses of Semmes Weinstein monofilaments at participant's initial clinical presentation [23]. Participants unable to accurately feel the 5.07/10-gram filament at any single location were graded as absent protective sensation and were considered to have PN [24]. Local inflammation was confirmed by assessing skin temperature (degrees Fahrenheit) at the same locations for sensation on each foot using an Exergen Model DT1001™ infrared dermal thermometer [a] [13,25–27]. We performed three trials of temperature assessment at each of 6 locations in each foot in the NPU group (8 locations in the CNA group, adding the medial and lateral plantar mid foot), in a standardized sequence [26]. Three trials were averaged to obtain a single skin temperature for each location. The average skin temperature difference at each site in the index (immobilized) foot was subtracted from the corresponding skin temperature in the non-immobilized foot and expressed as an average skin temperature difference from all locations in each foot. The maximal skin temperature difference at the site of the ulcer or arthropathy was also recorded. Core body temperature was assessed at the mouth using Tempa-Dot™ [b] and room temperature was recorded prior to the foot skin temperature assessment [26].

2.2. Calcaneal bone mineral density

During the same baseline visit, we estimated calcaneal bone density of both feet using quantitative ultrasonometry (QUS)[c]. Bone mineral density (in mg/cm^2) and T-score (standard deviation units above or below young adult female population 20–29 years of age) were recorded [28]. The sonometer was calibrated according to the manufacturer instructions before each participant's visit. A research assistant (KLB) who performed all skin temperature assessments is a certified clinical bone densitometry technologist and performed all QUS assessments. Two trials of each foot were averaged and expressed as a single value for each foot. T scores were classified as normal or low bone mass (formerly osteopenia) and osteoporotic (combined) based on World Health Organization (WHO) criteria [29,30]. Calcaneal BMD highly correlates with dual-energy x-ray absorptiometry-derived BMD and relative fracture risk of the hip and spine [29]. The precision of BMD in the heel is excellent using sonometry [30]. Coefficient of variation of BMD from eight measures over a 4-week period on a cadaver foot-phantom was 2.2% [19]. Intra-class correlation coefficients (ICC model 3,1) calculated from test and retest measures at a 1-week interval in twenty healthy subjects was 0.97 for BMD [19]. Calcaneal bone sonometry was performed by the same research assistant after immobilization and after recovery.

2.3. Immobilization & offloading

All participants with CNA were immobilized and off-loaded using TCC [14,31,32]. TCC immobilization was discontinued after an average of 16 weeks (SD, 9 weeks) when the physician judged the arthropathy to be healed [31] and the skin temperature difference between index and contralateral non-immobilized feet at the arthropathy site did not exceed 1 to 2 degree C [26]. The majority of participants with NPU were immobilized in a TCC, though 9 participants (36%) were immobilized in a commercially-available removable cast walker boot (RCWB) for off-loading [33]. The TCC or RCWB was discontinued after ulcer healing which was defined as complete epithelialization of the skin without evidence of drainage or sinus formation [17]. Whether immobilized in either the TCC or RCWB, participants were allowed full weight bearing on their index foot but were instructed to reduce their weight bearing activities to one third of their normal daily activity level. All participants were encouraged to use assistive devices such as crutches, walkers or canes for balance and to assist with off-loading and to aid healing [31].

2.4. Exercise & therapeutic footwear

After immobilization, all participants were instructed in a home exercise program that included ankle joint range of motion exercises to restore ankle joint motion, sitting progressing to standing heel raises to restore plantar flexor muscle strength and a graded increase in weight-bearing activity including progressive walking. Most individuals were encouraged to exercise on a cycle ergometer gradually increasing their duration to 30 min of daily activity. Thirteen participants (6 with NPU, 7 with CNA) had Charcot-restraint orthotic walkers [34] fabricated prior to or after TCC immobilization to transition into therapeutic footwear. In general, each participant was prescribed therapeutic footwear or modifications to existing footwear. Therapeutic shoe prescriptions included extra-depth shoes with sole modifications that consisted of