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Comparison of *in vivo* segmental foot motion during walking and step descent in patients with midfoot arthritis and matched asymptomatic control subjects

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ABSTRACT

The purpose of this study was to compare *in vivo* segmental foot motion during walking and step descent in patients with midfoot arthritis and asymptomatic control subjects. Segmental foot motion during walking and step descent was assessed using a multi-segment foot model in 30 patients with midfoot arthritis and 20 age, gender and BMI matched controls. Peak and total range of motion (ROM), referenced to subtalar neutral, were examined for each of the following dependent variables: 1st metatarso-phalangeal (MTP1) dorsiflexion, 1st metatarsal (MT1) plantarflexion, ankle dorsiflexion, calcaneal eversion and forefoot abduction. The results showed that, compared to level walking, step descent required greater MTP1 dorsiflexion ($p<0.01$), MPT1 plantarflexion ($p<0.01$), ankle dorsiflexion ($p<0.01$), calcaneus eversion ($p=0.03$) and forefoot abduction ($p=0.01$), in all subjects. In addition, step descent also necessitated greater MTP1 dorsiflexion ($p<0.01$), ankle dorsiflexion ($p<0.01$) and forefoot abduction ($p=0.02$) excursion compared to walking. Patients with midfoot arthritis responded differently to the step task compared to control subjects in terms of MT1 and calcaneus eversion excursion. During walking, patients with midfoot arthritis showed significantly less MT1 plantarflexion excursion compared to control subjects ($p=0.03$). However, during step descent, both groups showed similar MT1 plantarflexion excursion. During walking, patients with midfoot arthritis showed similar calcaneus eversion excursion compared to control subjects. However, during step descent, patients with midfoot arthritis showed significantly greater calcaneus eversion excursion compared to control subjects ($p=0.03$). Independently or in combination, these motions may contribute to articular stress and consequently to symptoms in patients with midfoot arthritis.

1. Introduction

Patients with midfoot arthritis present with persistent midfoot pain that limits weight bearing and physical activity (Teng et al., 2002). The etiology of midfoot arthritis includes primary, inflammatory and post-traumatic causes; post-traumatic arthritis is the most common (Hardcastle et al., 1982). Previous reports have estimated that the incidence of midfoot injuries is 55,000 per year (Hardcastle et al., 1982). More recently, a retrospective review of restrained front seat occupants noted that the relative incidence of foot and ankle injuries, particularly midfoot disruptions, has increased (Richter et al., 2001). Due to the multiple articulations that comprise the midfoot, even minimal disruption of the tarsometatarsal complex is indicative of significant injury (Myerson et al., 1986). In addition, as our population ages, the long-term effects of chronic increased loads sustained with high-heeled footwear may also contribute to the development of degenerative midfoot arthritis (Yu et al., 2007). Irrespective of the etiology, midfoot arthritis has been reported to be the inevitable sequelae of tarsometatarsal disease (Arntz and Hansen, 1987).

The high prevalence of pain in patients with midfoot arthritis has been linked to purported loss of midfoot stability and consequent abnormal patterns of foot motion during functional activities (Teng et al., 2002). In particular, patients report stair descent as being particularly painful. Stair descent is acknowledged to be a more challenging functional activity compared to walking because of the greater magnitudes of motion as well as loading sustained during stair descent (Andriacchi et al., 1980; Costigan et al., 2002). Evidence in support of the contention that stair descent is considerably more demanding than walking comes from studies demonstrating increased sagittal plane

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motion at the hip, knee and ankle joints during stair descent compared to level walking in healthy subjects (Andriacchi et al., 1980). The increase in motion has been accompanied by increased net joint moments (Andriacchi et al., 1980) and consequent increases in joint contact forces (Costigan et al., 2002) during stair descent compared to walking. However, investigations examining the effect of stair descent on segmental foot motion are lacking.

Multi-segment foot models have been used to successfully identify differences in foot function in patients with foot pathology compared to control subjects. Compared with healthy control subjects, patients with rheumatoid arthritis showed excessive subtalar eversion (Woodburn et al., 2003; Turner et al., 2008) and reduced forefoot range of motion (Khazzam et al., 2007). In patients with posterior tibial tendon dysfunction, increased calcaneal eversion and forefoot abduction was found compared to a matched controls (Tome et al., 2006). Patients with hallux rigidus demonstrated reduced hallux dorsiflexion as well as reduced metatarsal plantarflexion compared to control subjects (Canseco et al., 2008; Nawoczenski et al., 2008). In patients with diabetes, reductions in calcaneal eversion and forefoot abduction have been noted (Rao et al., 2007). These recent reports support the contention that impairments in foot function during walking can be effectively delineated in patients with foot pathology. However, these previous studies assessed foot function during level walking and not in more demanding functional activities that provoke patients' symptoms.

Recent reports have examined foot function in tasks other than straight-ahead walking, such as walking on an incline (Huang et al., 2006). The latter tasks are more challenging than level walking and therefore, may be more effective in unmasking underlying impairments in foot function. However these data are absent in patients with midfoot arthritis. Further no studies have examined foot function during stair descent. In order to design the most effective intervention and minimize the secondary loss of function associated with pain, potentially detrimental changes in segmental foot motion during functional activities that exacerbate symptoms must be identified. Based on these data, corrective intervention may be designed and instituted to optimize functional outcomes. The purpose of this study is to compare *in vivo* segmental foot motion during walking and step descent tasks in patients with midfoot arthritis and asymptomatic matched control subjects. Based on previous studies in patients with rheumatoid arthritis (Woodburn et al., 1999; Turner et al., 2008), and ankle arthritis (Huang et al., 2006; Khazzam et al., 2006), we expect to see increased calcaneal eversion and forefoot abduction, and decreased segmental foot ROM in patients with midfoot arthritis compared to control subjects. Based on recent reports highlighting the importance of ambulatory mechanics in the evolution of knee osteoarthritis (Andriacchi and Mundermann, 2006) and the increased demands associated with step descent, we hypothesize that patients with midfoot arthritis will show increased peak motion as well as ROM during the step task compared to walking.

2. Methods

2.1. Subjects

50 subjects participated in this study, 30 with midfoot arthritis and 20 control subjects, matched in age, gender and BMI. All procedures were approved by the review boards of the University of Rochester and Ithaca College; informed consent was sought prior to initiating study procedures.

2.2. Inclusion criteria

All patients sought care at the University of Rochester Medical Center, USA. All patients presented with unilateral symptoms, comprising pain on the dorsum of the foot, localized to the tarsometatarsal region and aggravated by weight bearing. The diagnosis of isolated midfoot arthritis was confirmed by radiographic evidence of degenerative changes at one or more tarsometatarsal joints on antero-posterior and lateral weight-bearing X-rays. All patients with midfoot arthritis were invited to participate in this study with the following exclusion criteria: (1) concomitant injury or previous surgery of the lower extremity, (2) conditions such as stroke, inflammatory arthritis, diabetes, or (3) use an assistive device. A single Fellowship-trained foot and ankle orthopedic surgeon (JB) screened all subjects. None of the patients recollected a traumatic event preceding their symptoms. Control subjects were recruited from the community using fliers, screened by a single trained physical therapist (SR) for lower extremity pain and/or dysfunction and were matched for age, gender and BMI to patients with midfoot arthritis (Table 1).

2.3. Data acquisition

All data were collected at the Movement Analysis Lab at the Department of Physical Therapy, Ithaca College–Rochester Center, Rochester, NY, USA.

2.3.1. Patients' self-reported foot function

The foot function index-revised (FFI-R), a region-specific health-related quality-of-life instrument was used to assess patients' foot function. The FFI-R consists of 34 questions organized into the following subscales: pain, stiffness, disability, activity limitation and psychosocial issues. The reliability and validity of the foot function index has been established in patients with chronic foot disorders (Budiman-Mak et al., 1991; SooHoo et al., 2006). In 2006, the foot function index was revised to include a more rigorous theoretical model. The construct validity and reliability of FFI-R was established in field testing on a sample of 92 patients,

Table 1
Summary of demographic characteristics, expressed in mean (SD).

Variable	Midfoot arthritis	Control
Age (years)	62 (7) range: 47–78	58 (8) range: 48–78
BMI (kg/m^2)	30 (6) range: 20–46	29 (5) range: 22–41
M:F	2:28	1:19
Radiographic measures of foot architecture, compared to normative data from the literature		
Calcaneal inclination	17 (5) range: 9–30	22 (6)[a]
Calcaneal 1st metatarsal angle	145 (9) range: 163–129	132 (10)[b]
Radiographic measures of arthritis severity, using Kellegren Lawrence grades[c]		
1st and 2nd Tarso-metatarsal joints	2.3 range: 0–4	
Naviculo-cuneiform joint	1.2 range: 0–2	
Talo-navicular joint	0.40 range: 0–1	
Calcaneo-cuboid joint	0	
Subtalar joint	0.20 range: 0–1	

[a] Data from Cavanagh et al. (1997).
[b] Data from Saltzman et al. (1995).
[c] Rating scale based on Greisberg et al. (2003) and Menz et al. (2007), higher scores indicate greater radiographic severity. Range values have been obtained from the current study cohort.