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Altered joint moment strategy during stair walking in diabetes patients with and without peripheral neuropathy

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ABSTRACT

Aim: To investigate lower limb biomechanical strategy during stair walking in patients with diabetes and patients with diabetic peripheral neuropathy, a population known to exhibit lower limb muscular weakness.

Methods: The peak lower limb joint moments of twenty-two patients with diabetic peripheral neuropathy and thirty-nine patients with diabetes and no neuropathy were compared during ascent and descent of a staircase to thirty-two healthy controls. Fifty-nine of the ninety-four participants also performed assessment of their maximum isokinetic ankle and knee joint moment (muscle strength) to assess the level of peak joint moments during the stair task relative to their maximal joint moment-generating capabilities (operating strengths).

Results: Both patient groups ascended and descended stairs slower than controls ($p < 0.05$). Peak joint moments in patients with diabetic peripheral neuropathy were lower ($p < 0.05$) at the ankle and knee during stair ascent, and knee only during stair descent compared to controls. Ankle and knee muscle strength values were lower ($p < 0.05$) in patients with diabetic peripheral neuropathy compared to controls, and lower at knee only in patients without neuropathy. Operating strengths were higher ($p < 0.05$) at the ankle and knee in patients with neuropathy during stair descent compared to the controls, but not during stair ascent.

Conclusion: Patients with diabetic peripheral neuropathy walk slower to alter gait strategy during stair walking and account for lower-limb muscular weakness, but still exhibit heightened operating strengths during stair descent, which may impact upon fatigue and the ability to recover a safe stance following postural instability.

1. Introduction

Diabetes and associated comorbidities have been shown to negatively impact upon locomotion: affecting both gait and balance [1,2]. Diabetic peripheral neuropathy is one of the most common comorbidities known to influence gait [3–5], with diminished foot sensation and progressive muscle weakness placing individuals at a higher risk of falls than their non-neuropathic counterparts [6–8].

Previous studies have investigated the kinetics and kinematics of walking on level ground in patients with diabetes, demonstrating alterations such as smaller step lengths, lower gait speeds [9,10] and lower peak joint moments [11,12] than non-diabetic controls. These gait alterations have been shown to be modulated by the difficulty of the task, with greater effects when walking on uneven surfaces [13]. Our understanding of how people with diabetes negotiate stairs is currently very sparse, despite the higher muscular demands of this task compared to level walking [14,15] and high risk of falling during stair negotiation [16,17]. Picon et al. [18] reported lower ankle and knee joint moments when stepping from stairs to floor, however this transitional step whilst more challenging than level walking, requires lower joint ranges of motion than a step both preceded and followed by an additional step down, which may result in

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lower joint moment requirements for this final step. Therefore, the joint moment strategy of negotiating continuous stairs in patients with diabetes remains unknown. Rate of joint moment production during stair ascent and descent, has been investigated and patients with diabetic peripheral neuropathy were shown to generate joint moments upon initial contact slower, in both stair ascent and descent [19]. Whilst a slower rate of joint moment production has been associated with impaired balance [20], it tells us little of the magnitude of lower limb joint moments developed during these activities.

Elderly populations have been more thoroughly investigated already during stair walking, and have shown similarities to diabetic populations in level walking studies, including slower walking speeds and shorter step lengths [21] as well as decreased muscle joint strengths [22]. Elderly people have been shown to ascend and descent stairs with lower joint moments, but at higher levels of their maximal joint moment-generating capabilities [23,24]. It has been hypothesised that operating at a higher level of their maximal capabilities may explain why the elderly have difficulties completing daily activities [25,26]. If these findings translate to a population with diabetes during stair walking, as indications of such a trend have already been seen during level walking [27], it may highlight the potential utility of exercise interventions for redressing this detrimental effect of diabetes and peripheral neuropathy and improve patients ability to perform daily activities. Therefore, whilst strides toward assessing the musculoskeletal alterations of patients with diabetes during stair walking have begun to be addressed within the past few years, there is still a large knowledge gap presented by the limited number of variables reported and potential ambiguity of the actual activities reported. This study aimed to investigate biomechanical alterations to joint moments during stair ascent and stair descent, as a result of the muscular joint weakness known to occur in populations with diabetes. It was hypothesised that patients with diabetes would adopt a strategy that reduced peak joint moments to maintain magnitudes further within their maximal capabilities.

2. Methods

2.1. Participants

Power analysis identified minimum group sizes of $n = 18$, for an effect size 0.657 ($\beta = 0.1$, $\alpha = 1\%$). Power analysis was based upon one of the key variables, ankle joint moment, conservative population standard deviations (0.18 Nm kg^{-1}) and a between group difference to be considered significant (0.29 Nm kg^{-1}) based upon previous work on stair negotiation in older adults [23,24].

After receiving ethical approval from the National Health Service (NHS) ethics committee, as well as the relevant Hospital and University bodies; ninety-four participants gave informed written consent: sixty-one patients with diabetes and thirty-two non-diabetic controls (CTRL group). Participants were assessed to confirm absence of: musculoskeletal disorders, serious foot deformity (e.g. Charcot), open foot ulcers, lower-limb amputation, history of cerebral injury, an inability to walk unaided, or poor visual acuity (less than 6/18 of any aetiology). Absence of diabetes in non-diabetic controls was confirmed by a random blood glucose test (all readings were between 4 and 7 mmol l^{-1}).

Presence of diabetic peripheral neuropathy was assessed for using the modified Neuropathy Disability Score (mNDS) and Vibration Perception Threshold (VPT). Patients were sub sequentially assigned to either the DM group ($n = 39$; mNDS <6 and a VPT <25 for both feet) or DPN group ($n = 22$; mNDS score ≥6, and/or a VPT ≥25 V on either or both feet) group.

2.2. Gait analysis

Participant's gait was assessed during ascent and descent of a 7-step staircase (Fig. 1) in a step-over-step manner (one foot per step) at their self-selected speed. Participants were provided with tight-fitting shorts and t-shirts for the gait analysis, and standardised footwear with a neutral foot bed (MedSurg, Darco, Raisting, Germany) to ensure standardisation of footwear, whilst maintaining a suitable shoe for the high-risk (ulceration) feet of the diabetic participants. For safety, all participants wore a full-body harness during gait analysis.

Kinematics were measured using a ten-camera Vicon (Vicon, Oxford, UK) system, and a fifty-six retroreflective marker modified Helen-Hayes whole-body marker set. Modifications to the marker set included two additional tracking markers on each foot and shank, and three additional tracking markers on the pelvis, to provide redundancy for any marker dropout due to occlusion by the staircase structure. Medial ankle and knee markers were also added to improve joint centre definition for those joints. Joint centres were defined using medial and lateral joint markers for the ankle and knee, and hip joint centres were calculated based upon the Bell, Pederson and Brand hip joint regression equations [28]. Kinetics were recorded from four Kistler force platforms (Kistler, Winterthur, Switzerland) mounted in steps 2–5 of the seven-step staircase.

Participants were asked to ascend and descend the staircase at their self-selected speed until a minimum of 3 trials were collected for both ascent and descent. Adequate rest was provided between trials to minimise the impact of fatigue. Gait velocity was calculated for each trial and lower-limb joint moments were calculated using inverse dynamics. Peak joint moments were defined as the peak during the stance phase.

2.3. Maximum isokinetic joint moment

Maximum effort concentric (muscle shortening) and eccentric (muscle lengthening) ankle plantarflexion and knee extension moments were measured using an isokinetic dynamometer (Cybex Norm, USA) as previously described and performed by the same cohort [27]. Due to patient availability, maximum isokinetic joint moment were recorded for fifty-nine (CTRL: $n = 18$, DM: $n = 27$ and DPN: $n = 14$) of the original ninety-four participants. These muscle groups were chosen as the predominant muscle groups active

Fig. 1. Experimental seven-step staircase with four Kistler force plates built into steps 2–5. A moveable dolly mounted on the ceiling above the staircase allowed a safety harness to be used whilst participants walked along the staircase.