Clinical Biomechanics 25 (2010) 476–482

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Achilles tendon length changes during walking in long-term diabetes patients

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ARTICLE INFO

Article history:
Received 22 October 2009
Accepted 28 January 2010

Keywords:
Diabetes mellitus
Tendon
Stretch reflex
Muscle–tendon interaction
Human walking

ABSTRACT

Background: Diabetes leads to numerous side effects, including an increased density of collagen fibrils and thickening of the Achilles tendon. This may increase tissue stiffness and could affect stretch distribution between muscle and tendinous tissues during walking. The primary aim of this study was to examine stretch distribution between muscle and tendinous tissues in the medial gastrocnemius muscle–tendon unit in long-term diabetes patients and control subjects during walking.
Methods: Achilles tendon length changes were investigated in 13 non-neuropathic diabetes patients and 12 controls, whilst walking at a self selected speed across a 10 m force platform. Electromyographic activity was recorded in the medial gastrocnemius, soleus and tibialis anterior muscles, goniometers were used to detect joint angle changes, and ultrasound was used to estimate tendon length changes.
Findings: Achilles tendon length changes were attenuated in diabetes patients compared to controls, and were inversely correlated with diabetes duration ($r = -0.628$; $P < 0.05$), as was ankle range of motion ($r = -0.693$; $P < 0.01$). Tendon length changes were also independent of walking speed ($r = -0.299$; $P = 0.224$) and age ($r = 0.115$; $P = 0.721$) in the diabetic group.
Interpretation: Stretch distribution between muscle and tendon during walking is altered in diabetic patients, which could decrease walking efficiency, a factor that may be exacerbated with increasing diabetes duration. Diabetes-induced changes in mechanical tendon properties may be at least partly responsible for attenuated tendon length changes during walking in this patient group.

1. Introduction

Diabetes mellitus (DM) can lead to numerous side effects that have functional consequences for movement, such as deterioration in the function of large afferent nerve fibres (e.g. Muller et al., 2008), particularly the type Ia and II afferents originating in the muscle spindles (Nardone and Schieppati, 2007; Nielsen et al., 2004). As afferent receptors from muscle spindles are thought to contribute to the ongoing muscle activity during walking (e.g. af Klint et al., 2008; Sinkjaer et al., 2000), changes in their morphology due to diabetes could affect motor control during walking (e.g. Muller et al., 2008). Furthermore, as DM patients generally exhibit a decreased ability to rapidly produce force (Nielsen et al., 2004), the ability to recover from a balance disturbance during gait may be compromised, thus contributing to the increased fall risk reported in DM patients (e.g. Morley, 2007).

During walking, DM patients exhibit biomechanical deficits compared to age-matched healthy subjects. For example, slower walking speeds, shorter strides and greater co-contraction of agonist and antagonist muscles at the ankle and knee joints have all been reported in DM patients and patients with peripheral neuropathy, a nervous disorder often associated with DM (Kwon et al., 2003; Mueller et al., 1994). Although the kinematics and kinetics of diabetic gait are well documented, very little is known about the mechanical behaviour of muscle and tendinous tissues during gait in DM patients. Structural abnormalities have been observed in the Achilles tendon of DM patients, including an increased density of collagen fibrils, as well as thickening and vascularisation of the Achilles tendon (Giacomozzi et al., 2005; Grant et al., 1997; Ji et al., 2009). This may lead to increased tissue stiffness, and thus contribute to a loss of joint mobility. During the stance phase of human walking, muscle–tendon units (MTU) of the lower limb are naturally stretched (e.g. Ishikawa et al., 2005; Lichtwark and Wilson, 2006). This stretch is distributed between muscle and tendinous tissues depending on their relative stiffnesses (Rack and Westbury, 1984). Consequently, an increase in tendon stiffness may increase the stretch transferred to the muscle fibres during

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doi:10.1016/j.clinbiomech.2010.01.018

walking, which may in turn decrease movement efficiency by decreasing tendon elastic energy storage. As tendon disorganisation has been suggested to progressively increase with increasing diabetes duration (Batista et al., 2008), movement efficiency may also progressively decrease with increasing diabetes duration.

Based on the aforementioned neural and mechanical deficits observed in DM patients, one would expect tendon lengthening to be decreased during gait when compared to control subjects. This would change the pattern of stretch distribution within the MTU, and could have important functional consequences for muscle force production, afferent feedback and movement efficiency. The primary purpose of this study was to examine stretch distribution between muscle and tendinous tissues in the medial gastrocnemius (MG) MTU in long-term DM patients and control subjects during walking. An additional aim was to examine whether associations existed between diabetes duration and specific stretch, torque and gait parameters. It was hypothesised that DM patients would exhibit decreased rate of torque development and short latency stretch reflex (SLR) responses, as observed previously (Nielsen et al., 2004). During walking, it was anticipated that DM patients would exhibit attenuated tendon stretch responses compared to control subjects, and that this would be exacerbated as the duration of diabetes increased.

2. Methods

2.1. Subjects

To recruit DM patients, an advertisement was placed in a local publication. In total, 26 patients volunteered, 10 of whom did not meet the patient criteria. Three others withdrew from the measurements due to illness or injury, resulting in the collection of data from 13 patients (Table 1). Criteria for patient selection were: ability to comfortably walk 10 metres approximately 10 times with intermittent rest; diagnosis of DM; ability to walk independently without an assistive device; ability to lie supine; a minimum ankle range of motion of 40° (combined dorsi- and plantar flexion, which was determined prior to the measurements); unimpaired vision and hearing; and diabetes duration >10 years. Subjects were excluded if they had severe orthopedic abnormalities, severe neurological disorders, previous cerebrovascular accident, a history of plantar ulceration or previous lower extremity amputation. The mean duration of diabetes in the DM group was 31 ± 12 years (range 15–54). Patients with a long duration of diabetes were recruited to ensure a high frequency of late diabetic complications. The level of neuropathy was assessed using the neuropathy disability score (NDS; Young et al., 1993) and neuropathy was defined as NDS >5. All DM patients included in the study had an NDS score of $\leqslant$4. To recruit control subjects, an advertisement was placed in a local newspaper. In total, 32 subjects volunteered, and 12 were selected to enable age, height and body mass to be matched as closely as possible between groups (Table 1). Control subjects had no history of neuromuscular or skeletal disorders that could have influenced gait. A brief questionnaire was used to obtain medical and demographic data from all subjects. Patients and control subjects were all routinely active but did not regularly participate in sports. Prior to testing, the procedures were explained thoroughly, and all subjects provided written informed consent. All procedures conformed with the declaration of Helsinki, and the experiments were approved by the local ethics committees of the University of Jyväskylä and the Central Hospital of Central Finland, respectively.

Table 1
Subject characteristics.

	Controls	Patients
Age (years)	63 (6)	64 (9)
Height (cm)	167 (9)	171 (10)
Body mass (kg)	74 (9)	79 (13)
BMI (kg/m^2)	26.4 (2.4)	27.1 (3.8)
Gender	7 Male; 5 female	4 Male; 9 female
Diabetes type		5 Type 1; 8 type 2
Diabetes duration (years)		31 (12)
Dominant leg	2 Left; 10 right	4 Left; 9 right

2.2. Study protocol

Prior to the measurements, resting Achilles tendon length was determined in the right leg of all subjects. For this procedure, subjects lay supine with a fully extended knee and an ankle angle of 90° (neutral position). The point at which the muscle and outer tendon converged was visually identified using ultrasound, and marked on the skin. The distance between this point and the distal insertion point (also confirmed by ultrasound) was defined as resting tendon length.

In all testing conditions, electromyographic (EMG) activity was recorded in the MG, soleus (SOL) and tibialis anterior (TA) muscles of the right leg using bipolar surface electrodes (720, AMBU, Ballerup, Denmark) with a diameter of 5 mm and an inter-electrode distance of 2 cm. Before electrode placement, the skin was shaved, abraded and cleaned with alcohol to maximise EMG signal quality. The electrodes were positioned as close to the respective muscle mid-belly as possible without interfering with the ultrasound probe position (see below).

2.3. Stretch and maximum torque trials

In patients exhibiting signs of neurological impairment, stretch reflex amplitude and latency have been shown to be smaller and longer, respectively, compared to control subjects (Nielsen et al., 2004). To determine whether this was also the case for the present subject group, all of whom were classified as non-neuropathic, a series of rapid dorsiflexion stretches were performed. Subjects were seated in an ankle dynamometer, with the hip (120°), knee (180°) and ankle (90°) angles fixed (see Fig. 1). Two straps were used to attach the foot to the dynamometer pedal, and the thigh was strapped to the seat to minimise leg movement. The upper body was also strapped to the upper part of the seat. Ten passive dorsiflexion stretches were induced (3°; 120°/s), with a minimum of 15 s between consecutive trials. Throughout these trials, subjects completely relaxed the muscles of their right leg, and EMG activity was continuously monitored. Any trials showing deviation from the baseline EMG in any of the examined muscles prior to stretch were rejected.

Maximal voluntary contractions (MVC) were performed with the ankle plantar- and dorsiflexors. In all trials, subjects were instructed to develop maximum torque as quickly as possible. At least three contractions were performed for each muscle group in a random order, with rest periods of 2–3 min between trials. Each trial required the maximal moment to be maintained for 2–3 s. The trial exhibiting the highest peak moment value was selected as the MVC. Prior to all stretch and MVC trials, the ankle axis of rotation was carefully aligned with that of the ankle dynamometer. The order of the stretch and MVC trials was randomised.

2.4. Walking trials

During walking, an ultrasonographic device (Alpha-10; 7.5 MHz probes; Aloka, Japan) operating at 100 frames per second was used to measure the displacement of the MG muscle–tendon junction (MTJ), which was combined with the estimated displacement of