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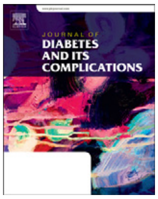

Assessment of lower leg muscle force distribution during isometric ankle dorsi and plantar flexion in patients with diabetes: a preliminary study

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ABSTRACT

Aim: The aim of this study was to evaluate the differences in ankle muscle strength using hand-held dynamometry and to assess difference in the isometric muscle force distribution between the people with diabetes and control participants.
Methods: The maximal muscle strength of ankle plantarflexion, dorsiflexion, eversion, inversion, lesser toes flexors and extensors, hallux flexors, and extensors was assessed in 20 people with diabetes and 20 healthy participants using hand-held dynamometry. The maximal isometric ankle plantarflexion and dorsiflexion were imported to OpenSim software to calculate 12 individual muscle (8 plantarflexors and 4 dorsiflexors) forces acting on ankle joint.
Results: A significant reduction in ankle strength for all measured actions and a significant decrease in muscle force for each of the 12 muscles during dorsi and plantar flexion were observed. Furthermore, the ratios of agonist to antagonist muscle force for 6 of the muscles were significantly different between the control group and the group with diabetes.
Conclusions: It is likely that the muscles for which the agonist/antagonist muscle force ratio was significantly different for the healthy people and the people with diabetes could be more affected by diabetes.

1. Introduction

Type 2 diabetes (DM2) is accompanied by a wide range of impairments. Previous investigations have shown that DM2 is associated with a loss of mobility (Lalli et al., 2013; Orr, Tsang, Lam, Comino, & Singh, 2006) and reduced muscle strength (Andreassen, Jakobsen, & Andersen, 2006). Several studies have also described impairment of gait (Brach, Talkowski, Strotmeyer, & Newman, 2008; Raspovic, 2013), foot ulceration (Raspovic, 2013) and increased risk of falling (Lalli et al., 2013) in neuropathic diabetic patients. Furthermore, a reduced walking speed, along with a compromised static and dynamic balance, have also been observed in older diabetic patients with neuropathy (Lalli et al., 2013). In addition, Andersen, Gjerstad, and Jakobsen (2004) and Andersen, Nielsen, Mogensen, and Jakobsen (2004) showed that DM2 is associated with loss of muscle strength around the ankle and knee joint, and Mueller, Minor, Sahrmann, Schaaf, and Strube (1994) revealed that diabetic neuropathic patients were unable to generate sufficient ankle joint moment, with a consequent reduction in the dynamic function during walking, resulting in a smaller step length and stride, reducing gait speed and cadence.

While neuropathy has been associated with impaired mobility, loss of muscle strength and decreased health-related quality of life, as reviewed elsewhere (Van Schie, 2008), several factors could be responsible for this limited mobility and decreased muscle strength in diabetic patients; such as intrinsic abnormalities in diabetic muscle, impaired capillary recruitment, peripheral arterial disease and diabetic polyneuropathy (Andersen, Gjerstad, et al., 2004; Andersen, Nielsen, et al., 2004; Lalli et al., 2013, Van Schie, 2008).

Although, most in vivo studies have analyzed muscle performance under isokinetic conditions (both active (Hatef, Bahrpeyma, & Tehrani, 2014) and passive (Hajrasouliha, Tavakoli, Esteki, & Nafisi, 2005)), a simple, widely used and objective tool in a clinic for measuring muscle strength is hand-held dynamometer (Abizanda et al., 2012). Hand-held dynamometers have been shown to be reliable for testing a number of muscle groups including those of the ankle (Burns, Redmond, Ouvrier, & Crosbie, 2005; Wang, Olson, & Protas, 2002), but this device does not give any information about the

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Conflict of interest: The authors declare no conflict of interest with regards to the material presented in this paper.

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individual muscle forces distribution. Since muscle forces cannot be measured invasively (Pandy, 2001), these quantities are determined using indirect methods combining kinematic and kinetics analysis.

Muscle force distribution problem within biomechanics deals with the determination of the internal forces acting on the musculoskeletal system using the known resultant inter-segmental forces and moments. The force distribution across human joints is typically represented with an indeterminate set of system equations; this means that there are more unknowns than the number of equations that are most often used for calculating the muscle, ligament, and bone forces acting in and around joints. The analysis of muscle forces distribution is currently one of the major issues raised in biomechanics, requiring the use of sophisticated optimization models (Delp et al., 2007).

There has been a paucity of studies that investigate the individual muscle force distributions in people with diabetes. In light of the lack of such data, the aim of this pilot study was to evaluate differences in foot and ankle isometric muscle strength and to assess the difference in individual muscle force distributions between the people with diabetes and healthy controls.

2. Materials and methods

2.1. Participant recruitment and preparation

Forty-eight people with diabetes and severe neuropathy with a mean age of 59 ± 8.02 years, height of 1.66 ± 0.1 m and weight of 74.8 ± 7.23 kg participated in the study. Following a statistical analysis (detailed Section 2.4.1) a subset of 20 of the 48 diabetic patients with mean age of 59 ± 9.84 years, height of 1.63 ± 0.1 m, weight of 71.6 ± 12.1 kg and average duration of diabetes 14 ± 7.8 years were selected for analysis. The diagnostic criteria for composing the groups with signs and symptoms of neuropathy were based on the measurement of VPT at the Hallux, first, third or fifth metatarsals. The voltage was slowly increased at the rate of 1 V/sec and the VPT value was defined as the voltage level that produced a vibration that was sensed by the subject. The mean of the four records was calculated and neuropathy was diagnosed if the average was more than 25 V (Young, Breddy, Veves, & Boulton, 1994). Twenty healthy volunteers with mean age of 60.7 ± 7.5 years, height of 1.64 ± 0.6 m and weight of 73.2 ± 6.12 kg were screened and included in the study. In both groups, the numbers of men and women were the same—10 in each. A t-test was performed and showed no significant age differences between the healthy and diabetic group. The ethical approval was sought and granted by the local research ethics committee and all volunteers provided full informed consent.

2.2. Instrumentation and data collection

Isometric muscle strength was measured using a Citec hand-held dynamometer (CIT Technics, Haren, the Netherlands). The manufacturer's data state that the device was factory calibrated to a sensitivity of 0.1% and a range of 0–500 N. The hand-held dynamometer (HHD) measures the peak force produced by a muscle as it contracts while pushing against an object. A recent systematic review of HHD for assessment of muscle strength in the clinical setting found the instrument to be a reliable and valid tool (Stark, Walker, Phillips, Fejer, & Beck, 2011). Isometric muscle strength was assessed using the 'make test', whereby the examiner held the HHD stationary while the participants actively exerted a maximal force. All tests were performed with the participants in a supine position with hips and knees extended and the lower limb stabilized proximal to the ankle joint as directed by (CIT Technics, Haren, the Netherlands). The HHD was positioned against the lateral border of the foot distal to the base of the 5th metatarsal head to measure eversion; to the medial border of the foot, near the base of the 1st metatarsal head to measure inversion; against the metatarsal heads on the plantar surface of the foot to measure plantarflexion, and on the dorsal aspect of the foot proximal to the metatarsal heads to measure dorsiflexion and over the interphalangeal joint of the hallux for hallux plantarflexion and dorsiflexion. For testing of the lesser digits, the dynamometer was placed on the plantar surface of the digits. Moreover, for testing both the hallux and lesser toe strength, the ankle was passively placed in maximum plantar flexion to prevent co-contraction of the ankle plantar flexor muscles influencing the result.

Each participant performed submaximal test movements for familiarization prior to testing. Testing of each muscle group required a contraction of 3–5 seconds. Three repetitions were obtained for each muscle group, for each leg with a minimum rest period of 10 seconds between each contraction. The average of the three contractions was used for analysis as mean values have been shown to be more reliable than maximal values (Van den Beld, Van der Sanden, Sengers, Verbeek, & Gabreels, 2006). Verbal encouragement was given during each contraction. To assess repeatability of measurements, coefficients of variation (CVs) were calculated, which expresses between-trial variability as a percentage. It was suggested that CV values of 0.60 and greater indicate poor repeatability, 0.4–0.60 fair repeatability, 0.20–0.40 good repeatability and 0.20 and less excellent repeatability (Krysicki, Bartos, Dyczka, Królikowska, & Wasilewski, 2006). All values measured with HHD achieved good and excellent repeatability.

2.3. Musculoskeletal model

A generic musculoskeletal model with 19 degrees-of-freedom and 92 musculo-tendon actuators was used to generate the simulation in OpenSim 2.4 (Stanford, USA) (Delp et al., 2007). The model was dimensioned to represent a subject with a body mass of 72.6 kg. The feet of each subject were scaled to match the anthropometry, which was measured before the experiment. An inverse kinematics problem was solved to calculate the joint angles of the musculoskeletal model that best reproduce the experimental kinematics of the subject that was distributed with OpenSim software. Following this step, individual muscle forces were computed using the computed muscle control (CMC) tool. CMC is an optimization based control technique designed specifically for controlling dynamic models that are actuated by redundant sets of actuators whose force generating properties may be nonlinear and governed by differential equations. The purpose of (CMC) is to compute a set of muscle excitations that will drive a dynamic musculoskeletal model to track a set of desired kinematics in the presence of applied external forces (Thelen & Anderson, 2006). The OpenSim force data file was modified to allow simulations. For each subject plantarflexion force measured with HHD was put as a vertical force applied to toes as a body force and for each subject dorsiflexion force measured with HHD was applied as a vertical force with the same line as plantarflexion force but opposite direction also applied to toes as a body force. While the anterio-posterior and medio-lateral components of the ground reaction force are important during gait, in an isometric contraction we made sure that the measuring head of the dynamometer was held perpendicular to the plantar surface (in plantarflexion) and to the dorsal surface (in dorsiflexion). In this condition only the vertical component of the force causes a moment around the centre of rotation of the joint. Since the lever arm was perpendicular to the line of action of the force, the measured force by the dynamometer was the only component that exists during isometric dorsi and plantar flexion. For each person from the control and diabetic groups, muscle force distribution for each of the 12 muscles (8 ankle plantarflexors: flexor digitorum, flexor hallucis, gastrocnemius lateral head, gastrocnemius medial head, peronus brevis, peronuslongus, soleus, tibialis posterior and 4 ankle dorsiflexors: extensor digitorum, extensor hallucis, peroneus tertius, tibialis anterior) acting on the ankle joint was calculated.