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Original Research

Accuracy of Clinical Techniques for Evaluating Lower Limb Sensorimotor Functions Associated With Increased Fall Risk

Alex Donaghy, MD, Trina DeMott, MS, Lara Allet, PhD, Hogene Kim, PhD, James Ashton-Miller, PhD, James K. Richardson, MD

Abstract

Background: In prior work, laboratory-based measures of hip motor function and ankle proprioceptive precision were critical to maintaining unipedal stance and fall/fall-related injury risk. However, the optimal clinical evaluation techniques for predicting these measures are unknown.
Objective: To evaluate the diagnostic accuracy of common clinical maneuvers in predicting laboratory-based measures of frontal plane hip rate of torque development (Hip^{RTD}) and ankle proprioceptive thresholds (Ank_{PRO}) associated with increased fall risk.
Design: Prospective, observational study.
Setting: Biomechanical research laboratory.
Participants: A total of 41 older subjects (aged 69.1 $\pm$ 8.3 years), 25 with varying degrees of diabetic distal symmetric polyneuropathy and 16 without.
Assessments: Clinical hip strength was evaluated by manual muscle testing (MMT) and lateral plank time, defined as the number of seconds that the laterally lying subject could lift the hips from the support surface. Foot/ankle evaluation included Achilles reflex and vibratory, proprioceptive, monofilament, and pinprick sensations at the great toe.
Main Outcome Measures: Hip^{RTD}, abduction and adduction, using a custom whole-body dynamometer. Ank_{PRO} determined with subjects standing using a foot cradle system and a staircase series of 100 frontal plane rotational stimuli.
Results: Pearson correlation coefficients (r) and receiver operator characteristic (ROC) curves revealed that LPT correlated more strongly with Hip^{RTD} ($r/P = 0.61/<.001$ and $0.67/<.001$, for abductor/adductor, respectively) than did hip abductor MMT ($r/P = 0.31/.044$). Subjects with greater vibratory and proprioceptive sensation, and intact Achilles reflexes, monofilament, and pin sensation had more precise Ank_{PRO}. LPT of $<$12 seconds yielded a sensitivity/specificity of 91%/80% for identifying $Hip^{RTD} <$ 0.25 (body size in Newton-meters), and vibratory perception of $<$8 seconds yielded a sensitivity/specificity of 94%/80% for the identification of $Ank_{PRO} >1.0^{\circ}$.
Conclusions: LPT is a more effective measure of Hip^{RTD} than MMT. Similarly, clinical vibratory sense and monofilament testing are effective measures of Ank_{PRO}, whereas clinical proprioceptive sense is not.

Introduction

Given the importance of maintaining the ability to walk for function and exercise [1,2], clinicians need bedside techniques for measuring lower limb neuromuscular capacities. However, many clinical techniques for determining lower limb function are unsupported by objective measures. In prior work we found that frontal plane hip strength and ankle proprioception were critical to the ability to maintain unipedal balance, which in turn has been associated with frailty [3], aging [4], and risk of injury from falls [5]. In addition, human biomechanical studies suggest that in the whole-body inverted pendulum model of bipedal walking, the hip exerts a primary influence on equilibrium [6]. Furthermore, hip adduction/abduction controls foot placement which is the primary method for managing frontal plane balance [7]. As such, rapidly available frontal plane strength at the hip is essential for safely traversing obstacles and avoiding falls [8,9], particularly lateral falls which have the greatest likelihood of being associated with hip fracture [10]. Ankle proprioceptive precision (Ank_{PRO}) also plays a critical role in balance, independent of hip strength [11,12]. Moreover, AnkPRO

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becomes less precise with age [13] and diabetic polyneuropathy (DPN) [14], both of which are potent risk factors for falls.

The usual clinical technique for measuring hip strength, manual muscle testing (MMT), is criticized due to its ordinal scale, difficulty with positioning to isolate the hip ab/adductors, and lack of adjustment for body mass [15,16]. Accordingly, MMT of the lower limbs lacks sensitivity to strength impairments, resulting in poor diagnostic accuracy [17]. Although hand held dynamometers are an option, lower limb strength measurement with these devices is subject to error due to difficulties with stabilization [18].

Ank_{PRO} is often estimated clinically by an examiner passively moving the ankle, or great toe, in the sagittal plane out of the patient's view while the patient states the direction of motion [19], however, the accuracy and precision of this subjective technique is not known. Laboratory-based techniques for assessing Ank_{PRO} are laborious, requiring excessive time and a dedicated hardware and software rendering them unsuitable for clinical use [11]. Functional measures of coordination such as one-legged stance are often considered measures of proprioceptive ability; however, they are confounded by muscle motor performance and as such do not accurately reflect proprioceptive abilities [12,20]. In prior work, we found that fibular motor amplitude was strongly associated with ankle proprioceptive thresholds [21], but this may require a consulting physician and is not immediately available at the bedside. We found no work validating bedside means for evaluating proprioceptive function; however, give that proprioceptive information is related to large fiber afferent function [22] we elected to see how well clinical tests of distal large fiber afferent function, and the commonly performed pinprick sensation, predicted Ank_{PRO}.

Therefore we performed a secondary analysis of clinical and laboratory-based measures of lower limb neuromuscular function in a group of older subjects with a spectrum of peripheral neurologic health and function. The goal of this research was to evaluate the diagnostic accuracy of clinical measures of hip strength and foot/ankle neuromuscular function to predict laboratory-based measures of hip motor function (in the form of frontal plane hip rate of torque development; Hip^{RTD}) and Ank_{PRO} associated with increased fall risk [9]. More specifically, we hypothesized that increased Hip^{RTD} would be associated with (hypothesis 1) increased manual muscle test score, and increased number of seconds that subjects could maintain a lateral plank posture. We also hypothesized that decreased (ie, more precise or better) Ank_{PRO} would be associated with the following (hypothesis 2): presence of an Achilles reflex; longer clinical vibratory perception; increased accuracy of clinical great toe proprioceptive sensation; increased accuracy of great toe monofilament perception; and presence of great toe pinprick sensation.

Methods

Subjects

As described in prior work [9], 41 subjects (16 healthy older individuals and 25 individuals with DPN) were recruited under a protocol approved by the University of Michigan Health System Institutional Review Board. Written informed consent was obtained from all participants. Subjects were recruited consecutively from July 2009 to January 2011, from the University of Michigan Orthotics and Prosthetics Clinic, Endocrinology Clinic, and the Older Americans Independence Center Human Subjects Core.

Inclusion Criteria for Subjects with DPN

Inclusion criteria for subjects with DPN included age 50-85 years, weight $<$136 kg, known history of diabetes mellitus, ability to walk household distances without assistance/assistive device, ankle dorsiflexion and inversion/eversion of at least antigravity (grade $\geq$3 by manual muscle testing), symptoms and signs consistent with DPN including the following: symmetrically altered sensation in lower extremities, Michigan Diabetes Neuropathy Score (MDNS) $\geq$10 [23] and electrodiagnostic evidence consistent with DPN as evidenced by bilaterally abnormal fibular motor nerve conduction studies (absent or amplitude $<$2 mV and/or latency $>$6.2 milliseconds and/or conduction velocity $<$41.0 m/s) stimulating 9 cm from recording site over the extensor digitorum brevis distally, and distal to the fibular head proximally.

Exclusion Criteria for Subjects with DPN

Subjects were excluded if they had had an accidental fall 1 month or less before testing, a history or evidence of any significant central nervous system dysfunction (ie, hemiparesis, myelopathy, or cerebellar ataxia), neuromuscular disorder other than DPN, evidence of vestibular dysfunction, angina or angina-equivalent symptoms with exercise, plantar skin sore or joint replacement within the previous year, symptomatic postural hypotension, significant musculoskeletal deformity, lower limb or spinal arthritis or pain that limited standing to less than 10 minutes; and ability to walk less than 1 block.

The remainder of the cohort were older adults who had no history of diabetes mellitus or neuropathic symptoms, had normal electrodiagnostic studies, and an MDNS $<$10. They otherwise met the same inclusion criteria as the DPN subjects.

Independent Variables (Hypothesis 1)

Independent variables were measured 1-2 weeks before laboratory-based evaluations, so that the