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Original Research

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

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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 ± 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 $\text{Hip}^{\text{RTD}} < 0.25$ (body size in Newton-meters), and vibratory perception of <8 seconds yielded a sensitivity/specificity of 94%/80% for the identification of $\text{Ank}_{\text{PRO}} > 1.0°$.
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 ≥ 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) ≥ 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 evaluators (T.D. and J.K.R.) were blinded to laboratory-based dependent variables.

Manual Muscle Testing

Hip abduction muscle strength was evaluated by manual muscle testing (MMT) using standard techniques [19] by an experienced physical therapist (T.D.).

Lateral Plank Time

The subjects lay on a flat, cushioned surface with the right side down, the lateral aspect of the right foot in full contact with the horizontal surface, and the left foot directly on top of or behind the right. The right upper limb was placed under the shoulder with the elbow at 90° and directly under the shoulder with the forearm and palm in neutral or pronated position, according to subject preference. Pillows were placed under the axillary region as needed for shoulder support. The left arm was placed along the left lateral trunk and hips. The thighs were aligned with the trunk in the sagittal plane with the knees fully extended. Upon signal, the subject lifted hips and trunk from the support surface so as to align the trunk and thighs in the frontal plane, keeping the shoulders perpendicular to the support surface. The endpoint was when the thighs and trunk were no longer aligned despite 1 verbal reminder. The number of seconds that this position could be maintained was measured by a stopwatch. If the position could not be achieved with knees extended, the procedure was repeated with knees flexed (Figure 1A and B). The number of seconds that the subject achieved bridging with knees flexed was multiplied by 0.5, given the greater ease of that task. One brief practice trial to check understanding and positioning was allowed, then 1 minute of rest, followed by the data acquisition trial. The procedure was repeated on the left side, and the mean of the 2 responses was used for analyses.

Independent Variables (Hypothesis 2)

Achilles Reflex

The presence of Achilles reflex was determined using the standard percussion over the Achilles tendon, and also the plantar strike technique [24]. Facilitation included Jendrassik maneuvers and gentle plantar flexion. Reflexes were scored as 2 if consistently present without enhancing maneuvers, as 1 if present intermittently or only with maneuvers, and as 0 if never present.

Vibratory Sense

Clinical vibratory perception was determined using a 128-Hz tuning fork. The fork was first maximally struck against the palm and placed on the subject's clavicle for familiarization, with the subject saying "Now" when the vibration was no longer perceived. The procedure was then repeated on the left and right on the dorsal aspects of the great toes just proximal to the nailbeds [25]. The means of the 2 responses were used for analyses.

Proprioceptive Sense

Great toe proprioceptive sense was determined with the subjects seated with their legs hanging freely. The examiner held the medial and lateral aspects the distal phalanx of the great toe with thumb and index finger. The toe was moved up and down with the subject watching to confirm understanding of the task. Then, with eyes closed, the toe was moved randomly by small increments of approximately 1 to 2 cm, with movements occurring at random intervals varying from a few seconds to 10 seconds. The subject responded "up" or "down" in response to the toe motion [26]. There were 5 trials on each side. Incorrect responses included indicating the wrong direction or not responding to a movement. The number of correct responses of the 10 trials was used for analysis.

Monofilament Testing

Great toe monofilament perception was determined by touching a 1.28 monofilament to the dorsum of the great toe at random intervals 5 times on both sides. Incorrect responses included not responding to a touch, or indicating a touch when none had occurred.

Pinprick Sensation

Great toe pinprick sensation was evaluated by using a standard safety pin to prick the skin over the dorsum of the great toes bilaterally. The subject responded by saying "sharp" or "not sharp."

Dependent Variables (Hypothesis 1)

Hip^{RTD} was determined, as per prior work, using a custom, whole-body dynamometer (BioLogic Engineering, Inc) [9,12]. To determine the moment arm, the location of the (vertical) axis of the center of rotation of the dynamometer's low inertia torque arm was marked with a white cross on the black colored horizontal bed of the dynamometer. One axis of the cross spanned the width of the bed forming a so-called reference line; the other ran along the midline of the long axis of the bed. The bed was made of a firm pad such as found on clinical examination tables. The subject was asked to lie down supine along the long axis bed of the dynamometer. The location of the greater trochanter was palpated, and the subject was asked to position her- or himself with the greater trochanter directly over the reference line. The midsagittal plane of the subject's pelvis was then moved 10 cm off the center line, based on 2 separate publications of hip anthropometric data [27,28] of the dynamometer bed, so that the contralateral side of the

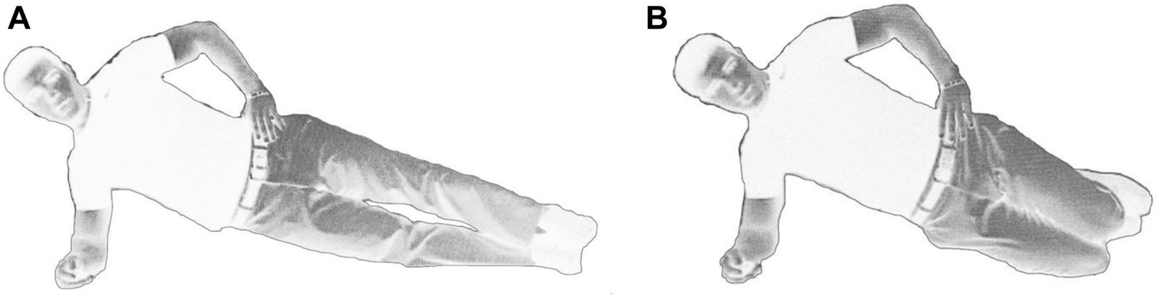

Figure 1. (A and B) Posture that subjects achieved for lateral plank time with knees extended (A) and flexed (B).

pelvis pressed against a vertical padded support and was held there with a seat belt. The weight of the distal part of the subject's ipsilateral test leg was placed into an L-shaped support pad at the end of the torque arm, where it was strapped in place. Next, the experimenter made slow abduction/adduction movements with the torque arm and test leg while watching the movement of the ipsilateral hip joint relative to the bed. With the ankle held firmly at the distal end of the torque arm, the cranio-caudal position of the subject on the bed was then adjusted in a caudal direction until the pelvis no longer migrated cranially or caudally as the test leg (on the torque arm) was abducted and adducted back and forth. Once craniocaudal movement of the pelvis was minimized relative to the bed, the hip joint center was, by definition, coincident with the rotation axis of the torque arm, at least in the craniocaudal direction (which is the most critical adjustment for measuring hip abduction torque). The dynamometer was fitted with internal hardware to automatically measure the lever arm from the center of the ankle support pad to the torque arm axis of rotation to the nearest millimeter. The dynamometer was fitted with internal hardware to automatically measure the lever arm from the center of the ankle support pad to the torque arm axis of rotation to the nearest millimeter. When used to measure isometric torque, the dynamometer measured the maximum isometric force and rate of torque that the subject exerted against the ankle pad in Newtons. Its software then multiplied that force by the machine-measured lever arm (in meters) to obtain the resulting maximum isometric hip abduction strength (in units of nanometers) and rate of torque development (in nanometers per second). Subjects exerted a hip abduction force against the lever arm, given the instruction to perform it "as fast and as hard as possible" for 3 seconds. Subjects received verbal encouragement. Three trials were performed with 1 minute of rest between trials. Subjects performed analogous maneuvers in the opposite direction for hip adduction testing. Signals were amplified to volt levels before being acquired, using a 12-bit analog-to-digital converter sampling at 100 Hz. The maximal rate of torque development measures were normalized for individual body size by dividing by each subject's body height multiplied by weight in units of nanometers [29]. The peak value of rate of torque development was found following the methods that we described in Thelen et al [30], whereby 5-point numerical differentiation was used for the torque-time data under isometric conditions. The mean peak value obtained from the 3 trials for each test type was used for the statistical analyses.

Dependent Variable (Hypothesis 2)

To determine AnkPRO subjects stood with the (dominant) test foot in a 40 × 25-cm cradle that was rotated by an Aerotech 1000 servomotor equipped with an 8000-line rotary encoder as described by Son et al [11] (Figure 2). After an audible cue, a single ankle inversion or eversion rotation of 0.1° to 3° magnitude was randomly presented at 5° per second. The subject then pressed a joystick handle in the direction of the perceived foot rotation. Four blocks of 25 trials (randomly, 10 eversion, 10 inversion, and 5 dummy trials) were presented interspersed with 2- to 5-minute rest intervals. The outcome measure was the ankle proprioception threshold (TH100), defined as the

Figure 2. Apparatus for determining ankle inversion/eversion proprioceptive thresholds (Ank$_{PRO}$).

smallest rotational displacement of the ankle that a subject could reliably detect with 100% accuracy [11]. A summary measure of ankle proprioception was found from the sum of the inversion and eversion proprioception thresholds.

Statistical Analyses

Statistics were performed using SPSS for Windows (version 20.0; SPSS, Inc, Chicago IL). All data were included in the analyses, with no exclusion of outliers. The analytic methods summarized below were used to determine the strength of the relationships between the independent/clinical and dependent/laboratory-based variables.

Hypothesis 1

The relationships hip MMT (hypothesis 1a) score and LPT (hypothesis 1b) with HipRTD were evaluated with Pearson correlation coefficients (r).

Hypothesis 2

Ank_{PRO} differences between categories of Achilles reflex (hypothesis 2a) were determined using analysis of variance. Ank_{PRO} differences between categories of monofilament perception (hypothesis 2d) and pinprick sensation (hypothesis 2e) were determined using standard *t*-tests. The relationships between Ank_{PRO} and great toe vibratory (hypothesis 2b) and proprioceptive sense (hypothesis 2c) were determined using Pearson correlation coefficients.

Multivariate linear regression analyses were used to compare the relative strengths of clinical variables with respect to predicting Hip^{RTD} and Ank_{PRO}.

Receiver operating characteristic (ROC) curves were generated to identify continuous variable thresholds that most reliably identified subjects with strong versus weak Hip^{RTD} as defined by 0.25, and precise versus imprecise Ank_{PRO} as defined by 1.0°. These points were chosen because of prior research identifying these values as those that best identified patients at increased risk for fall and injury [9].

Results

Subjects

Of the original 91 individuals considered for the study, 21 failed the initial telephone screening and 18 declined participation. Of the remaining 52 individuals, 5 failed the screen and 3 had scheduling conflicts. Of those 44 persons, 2 dropped out because of medical concerns. The remaining 42 individuals comprised the study sample and were enrolled and evaluated. Ank_{PRO} data were lost for 1 subject, and so 41 subjects remained (20 women and 21 men, aged 69.1 ± 8.3 years), including 25 with diabetic neuropathy of varying severity and 16 without diabetes or neuropathy. There were no adverse events related to the evaluations.

Hypothesis 1

MMT hip abductor strength showed significant, but relatively weak, associations with Hip^{RTD} (r/*P* values = 0.313/.044 and 0.356/.021 for hip abductor and adductormotion, respectively; Figure 3A). LPT demonstrated a strong positive relationship with Hip^{RTD} ($r = 0.61$ and 0.67 for hip abductor and adductor motion, respectively; $P < .001$ for both; scatter plot depicted for the latter in Figure 3B). When MMT and LPT were entered into a regression model, MMT was not a significant predictor of Hip^{RTD} (β and *P* values = 0.689/<.001 and −0.063/.664 for LPT and MMT, respectively). ROC analysis demonstrated that LPT of 12 seconds yielded a sensitivity of 91% and a specificity of 80% for identifying $Hip^{RTD} < 0.25$, with the corresponding area under the curve = 0.91 (95% confidence interval = 0.82-1.0).

Hypothesis 2

Subjects with normal Achilles reflexes demonstrated significantly more precise Ank_{PRO} than subjects without reflexes (1.0° ± 0.8° versus 2.9° ± 1.3°; $P < .001$) or with reflexes obtained with maneuvers (2.1° ± 1.1°; $P = .008$; Figure 4A). Vibratory sensation at the great toe correlated strongly with Ank_{PRO} ($r = -0.704$; $P < .001$; Figure 3C). The association was negative, with longer times of vibration perception correlating with smaller (more precise/better) Ank_{PRO}. Great toe proprioceptive sense correlated significantly and negatively with Ank_{PRO} ($r = -0.534$; $P < .001$; Figure 3D), with a greater number of correct responses correlating with smaller Ank_{PRO}. Of note, 11 subjects with accurate responses on 8 or more trials demonstrated imprecise Ank_{PRO} (>1.0°). Subjects with intact sensation to monofilament testing had significantly smaller (more precise) Ank_{PRO} values as compared to subjects who did not (0.8° ± 0.3° versus 2.3° ± 1.0°, respectively; $P < .001$; Figure 4B; 2 subjects were intact on 1 side only and were excluded from analysis). Subjects with intact pin sensation ($n = 18$) demonstrated more precise Ank_{PRO} than subjects without ($n = 19$; 1.0° ± 0.8° versus 2.6° ± 1.3°; $P < .001$; Figure 4C).

Multivariate analyses demonstrated that the best model prediction of Ank_{PRO} was the combination of vibratory and monofilament sensations (β/*P* values were −0.327/.037 and −0.456/.005, respectively). The overall model fit (R^2) was 0.519. ROC analysis showed that vibratory perception time at the great toe of 8 seconds yielded a sensitivity of 94% and a specificity of 80% for the identification of Ank_{PRO} >1.0°, with an area under the curve value of 0.95 (95% confidence interval = 0.88-1.0).

Discussion

In this study, we have found statistically and clinically significant correlates to laboratory-measured Hip^{RTD}

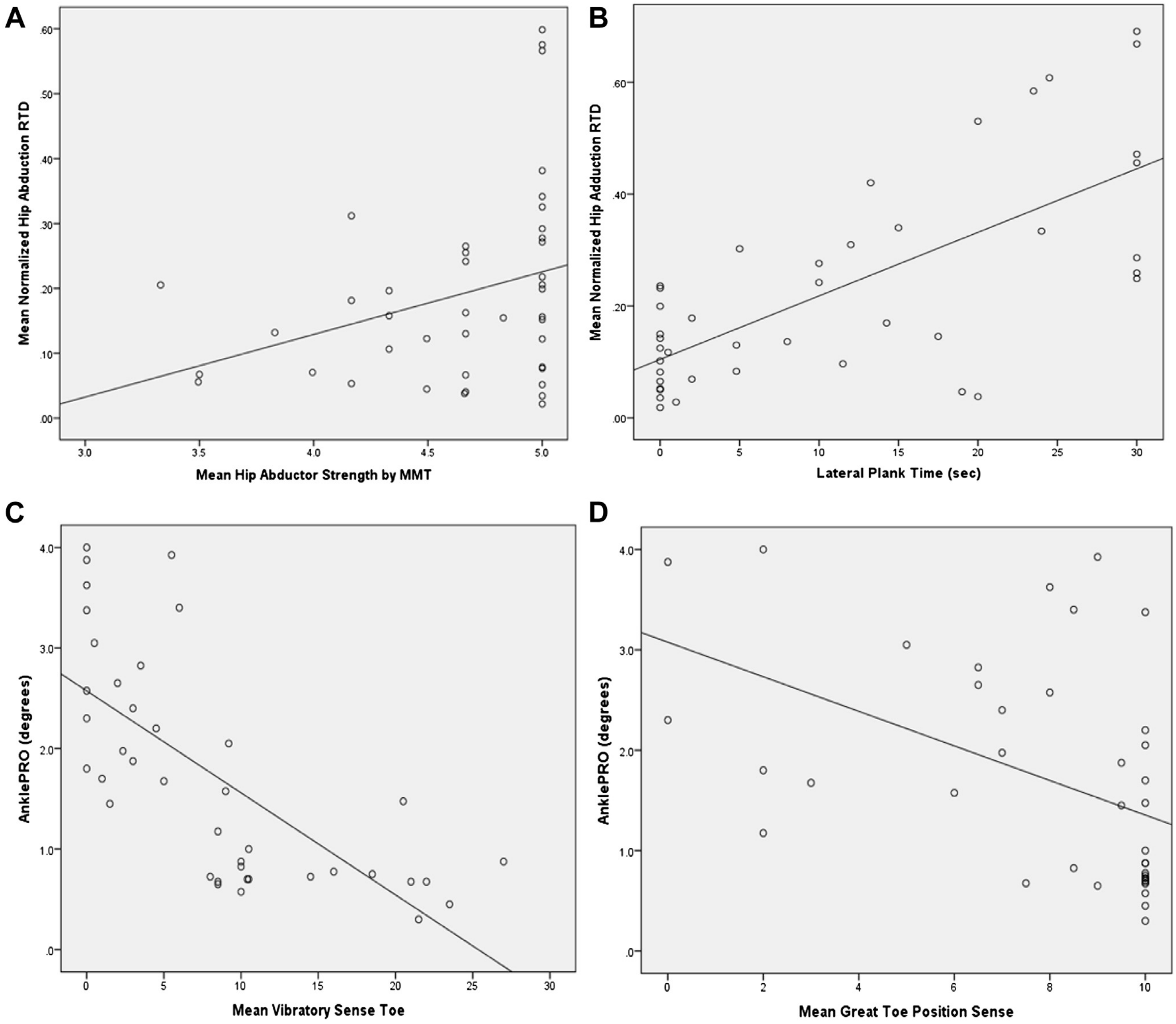

Figure 3. (A—D) Scatter plots of continuous clinical variables and frontal plane hip RTD (A and B, top left and right) and Ank_{PRO} (C and D, bottom left and right). Pearson correlation coefficient (r)/*P* values: (A) 0.31/.044; (B) 67/<.001; (C) = −0.70/< .001; and (D) = −0.47/.002.

and Ank_{PRO} data obtained in a cohort of older subjects with a range of peripheral neurologic function. LPT was the strongest predictor of Hip^{RTD} and, notably, a better predictor than MMT, which was a relatively weak predictor. Vibratory and monofilament perception at the great toe were most strongly predictive of precise Ank_{PRO}. An intact Achilles reflex also predicted more precise Ank_{PRO}, and any 2 of the 3 tests predicted approximately 50% of Ank_{PRO} variability. The presence of pinprick sensation at the great toe was also associated with more precise Ank_{PRO}, but there were several cases of coarse proprioception in subjects with intact pin sensation. Surprisingly, great toe position sense was only weakly predictive of Ank_{PRO}.

Few studies have compared MMT with more objective measures of hip strength. Aitkens et al [31] compared hip flexion/extension MMT with quantitative isometric strength using a force transducer and peak maximum voluntary force. Subjects with full (5/5) strength by MMT demonstrated widely varying isometric strength values, and there were no differences in strength between muscle groups with MMT grades 5/5 and 4/5. These findings parallel our data in which 5/5 MMT strength represented a broad range of Hip^{RTD} (Figure 3A). Of interest, hip abduction MMT score also demonstrated a similarly weak relationship with laboratory-based hip abduction maximal voluntary torque ($r/P = 0.354/.021$, respectively; unpublished data). Taken together, the data suggest that MMT scores are only weakly related to laboratory-based strength measures, particularly when scores are in the range of 4-5.

In prior work, we found that fibular motor amplitude accounted for nearly 60% of Ank_{PRO} variability [21]. The current study builds on this by providing additional

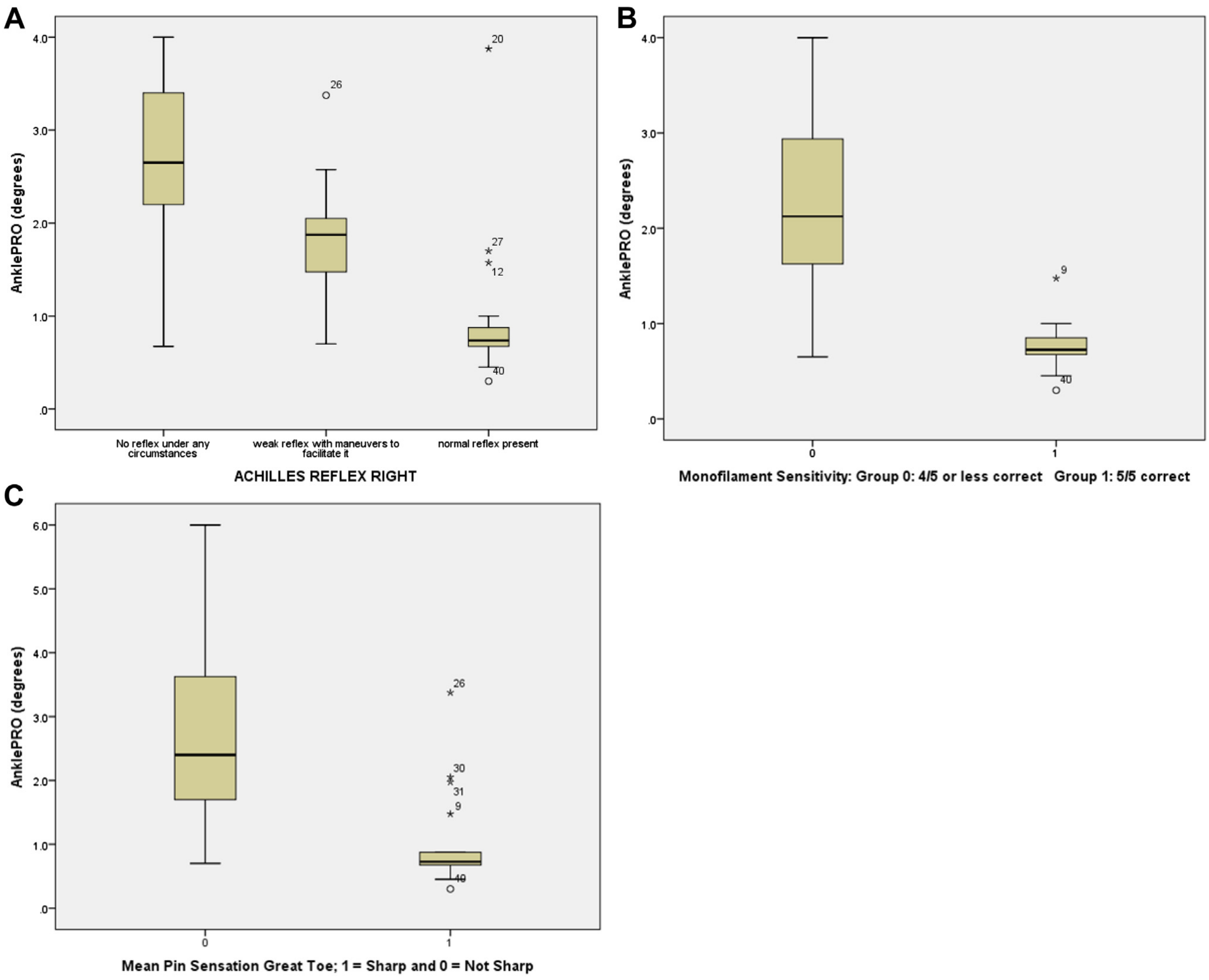

Figure 4. (A—C) Boxplots demonstrating between group AnkPRO differences for categorical clinical variables (A and B, top left and right). *P* values for differences: (A) $P < .001$ for subjects with versus without Achilles reflexes, and $P = .008$ for subjects with reflexes obtained with maneuvers; (B) $P < .001$; (C) $P < .001$.

clinical options for assessing Ank_{PRO}. To our knowledge, no other studies have evaluated the ability of bedside clinical techniques to predict Ank_{PRO}. However, Simmons et al [32] found balance impairments in diabetic patients with sensory cutaneous deficits (as measured by monofilament testing), but not in diabetic subjects with preserved cutaneous sensation. Our results may provide a mechanism for these findings by identifying a direct relationship between monofilament testing and ankle proprioceptive precision. Others have found that clinical proprioceptive testing, which poorly predicted Ank_{PRO}, is of uncertain efficacy in identifying proprioceptive function. For example, Beckmann et al [33] found no difference in great toe movement sense in a group of subjects with known proprioceptive dysfunction related to multiple sclerosis or vasculitis as compared to control subjects. Moreover, poor clinical position sense re-test reliability at the wrists in healthy subjects has been noted, prompting the suggestion that clinical position sense testing is inherently flawed [34].

LPT offers some advantages over MMT that may explain its superior prediction of frontal plane Hip^{RTD}. Positioning is less of a concern, as the lateral plank posture is known to activate frontal plane hip and trunk musculature [35]. LPT exploits Rohmert Law [36], which describes the exponential decrease in a maximum isometric force with time. Expressed another way, Rohmert Law states that a patient with strong hip muscles will be able to hold the lateral plank position for much longer than a patient with weak hips. Therefore, the time that LPT is held is directly related to the initial maximal strength. Furthermore, LPT provides more reliable long-lever arm conditions [37] and a more continuous measure that is inherently adjusted for body mass, whereas MMT offers none of these advantages. The potential clinical utility of lower limb clinic strength measurements that intrinsically adjust for body mass is further suggested by Rainville et al [38], who demonstrated that unilateral quadriceps weakness due to L3/L4 radiculopathy was best detected by a single leg sit-to-stand test.

The strong relationships identified between clinical vibratory and light touch sensation, Achilles reflex, and Ank_{PRO} are consistent with all being measures of distal large-fiber sensory function. In contrast, pin sensation was less strongly related to Ank_{PRO}, with several subjects demonstrating intact pin sensation but coarse Ank_{PRO}. These data are consistent with pin sensation being more related to small-fiber afferent function, which can be relatively preserved in the setting of large-fiber neuropathy.

The study has potential clinical implications. Despite its disadvantages [17], MMT is the most commonly used method for evaluating muscle strength. However, the data presented suggest that LPT is superior to standard MMT, and that a cutoff of 12 seconds yields good specificity and sensitivity for detecting diminished frontal plane Hip^{RTD}. The results also suggest that clinical toe proprioceptive sense testing imprecisely determines Ank_{PRO}. However, semiquantified vibratory sensation and monofilament testing as described are reasonable estimates of Ank_{PRO}, with a vibratory threshold of 8 seconds achieving reasonable sensitivity and specificity for Ank_{PRO} of 1.0°.

Although the study has strengths, including novel results and strong correlations that allow a more efficient and precise bedside evaluation of lower limb neuromuscular functions that influence fall/injury risk [9], the work has limitations as well. We exclusively evaluated frontal plane function, so no comment can be made regarding sagittal plane strength or proprioceptive function. We evaluated older subjects with diabetic neuropathy, so the extension of our findings to other patient populations is uncertain. It should also be noted that when determining LPT, subjects performing the test with knees flexed had their recorded plank time reduced by 50% to account for the greater ease of the task. Although the knees-flexed LPT is unquestionably an easier task, the designated value of 0.5 was an estimate and thus represents a limitation. A small but apparent ceiling effect was noticed in LPT, as our cutoff for maximal performance was 30 seconds. Greater correlations might have been obtained if the LPT maximum had been increased to 60 seconds. In addition, 3 subjects were omitted from pinprick analysis because they had discrepant responses between the right and left sides. In addition, although our results suggest novel approaches to assess patient hip strength and ankle proprioceptive precision, they do not suggest therapeutic strategies for improvement in these measures. Prior work suggests that improvement in proprioceptive thresholds may not be feasible [19] but that hip strength can compensate for poor proprioception in preserving unipedal stance time [12]. In this way, individuals with distal polyneuropathy may benefit from hip-strengthening exercises. Lateral planks may be beneficial not only for predicting weak hips, as our results suggest, but also for strengthening them [39].

Conclusion

The data suggest that LPT is an effective clinical measure of laboratory-based frontal plane hip motor function, Hip^{RTD}, whereas MMT is not. Furthermore, an LPT of 12 seconds appears to discriminate between patients with and without sufficient Hip^{RTD} to influence fall risk in this population. The data also suggest that clinical vibratory sense and monofilament testing are effective clinical measures of Ank_{PRO}, whereas clinical position sense is not. Vibratory sensation of 8 seconds appears to differentiate between patients with Ank_{PRO} greater than or less than 1.0°, a threshold associated with fall risk. These techniques may allow a more efficient and accurate bedside evaluation of lower limb neuromuscular attributes critical to the assessment of fall risk in the population evaluated.

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