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**Investigating the predictive ability of gait speed and quadriceps strength for incident falls in community-dwelling older women at high risk of fracture**

**SHORT TITLE:** Gait speed, quadriceps strength and falls

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**ABSTRACT**

Gait speed is a recommended geriatric assessment of physical performance, but may not be regularly examined in clinical settings. We aimed to investigate whether quadriceps strength tests demonstrate similar predictive ability for incident falls as gait speed in older women. We investigated 135 female volunteers aged mean  $\pm$  SD  $76.7 \pm 5.0$  years (range 70 – 92) at high risk of fracture. Participants completed gait speed assessments using the GAITRite Electronic Walkway System, and quadriceps strength assessments using a hand-held dynamometer. Participants reported incident falls monthly for  $3.7 \pm 1.2$  years.  $N = 99$  (73%) participants fell 355 times during the follow-up period (mean fall rate 83 per 100 person years). We observed a reduced odds ratio for multiple falls (0.83, 95% CI 0.70 – 0.98) and a reduced hazard ratio for time to first fall (0.90, 95% CI 0.83 – 0.98), according to quadriceps strength. There was also a significantly shorter time to first fall for those with low quadriceps strength ( $<7.0$ kg; lowest tertile) compared with those with normal quadriceps strength (estimated means [95% CI] 1.54 [1.02, 2.06] vs 2.23 [1.82, 2.64] years;  $P = 0.019$ ), but not for those with low ( $<1.0$ m/s) vs normal gait speed ( $P = 0.15$ ). Quadriceps strength is a significant predictor of incident falls over three years amongst community-dwelling older women at high risk of fracture. Quadriceps strength tests may be an acceptable alternative to gait speed for geriatric assessments of falls risk.

**Keywords:** Falls, gait, sarcopenia, physical performance

## 1. INTRODUCTION

In older adults, low gait speed predicts adverse events including incident mobility limitations, disability, hospitalisation, loss of independence and falls (Cesari et al., 2005; Fried, Bandeen-Roche, Chaves, & Johnson, 2000; Guralnik et al., 2000; Montero-Odasso et al., 2005). This has led to recommendations for the assessment of gait speed in the clinical setting to identify older patients at risk of functional decline (Abellan Van Kan et al., 2009) and those with sarcopenia. Both the European Working Group on Sarcopenia in Older People (EWGSOP) and International Working Group on Sarcopenia (IWG) have recently developed consensus definitions of sarcopenia (Cruz-Jentoft et al., 2010; Fielding et al., 2011) which include an assessment of gait speed. The EWGSOP classify sarcopenia as low gait speed ( $<0.8\text{m/s}$ ) or low grip strength in combination with low muscle mass (Cruz-Jentoft, et al., 2010), while the IWG classify sarcopenia as low gait speed ( $<1.0\text{m/s}$ ) in combination with low muscle mass (Fielding, et al., 2011). These algorithms have been formulated in an effort to increase the previously poor attention to sarcopenia by providing practitioners with standardised diagnostic criteria for sarcopenia (Janssen, 2011).

Sarcopenia is an independent risk factor for falls and so clinicians may utilise sarcopenia algorithms in falls risk stratification processes (Landi et al., 2012). However, there is controversy associated with the assessment of gait speed in an operational definition of sarcopenia. Gait speed is not an assessment of muscle function alone, given that it is influenced by other parameters including neurological factors and cardiovascular fitness (Bijlsma et al., 2012), and Morley has noted that the use of gait speed to diagnose sarcopenia results in overlap with definitions of frailty (Morley, 2012). Furthermore, despite the relative simplicity with which gait speed can be assessed (Studenski et al., 2011), practitioners may

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hold perceptions that such measurements require substantial space, equipment and time to complete (Cesari, et al., 2005).

Assessments of quadriceps strength are common in research settings and quadriceps strength is an independent predictor of incident falls, fractures and mortality in older adults (Lord et al., 1994; Newman et al., 2006; Nguyen, Pongchaiyakul, Center, Eisman, & Nguyen, 2005). These tests may also be more easily performed than gait speed assessments in the clinical setting, as they require less time and space, and can be performed with the patient sitting or lying down. As a result, quadriceps strength tests may be an appropriate substitute for gait speed assessments for clinicians attempting to identify patients at risk of incident functional declines. The aim of this study was to investigate whether quadriceps strength tests demonstrate similar predictive ability for incident falls as gait speed in older women.

## **2. MATERIALS AND METHODS**

### **2.1 Study Design and Participants**

This study was completed as part of the Vital D study; a single-centre, double-blind, randomized, placebo-controlled trial involving women 70 years or older residing in southern Victoria, Australia (latitude 38°S). The recruitment protocol has been described previously (Sanders et al., 2009). Briefly, participants were recruited between 2003 and 2005 and were randomly assigned to receive either a single oral dose of cholecalciferol 500,000 IU or matched placebo each year for three to five years until study completion in 2008. The study was approved by the institutional ethics review boards of Barwon Health and the University of Melbourne and carried out in compliance with the Helsinki Declaration. All participants provided written informed consent. Community-dwelling women (n=2258) defined as being at higher risk of hip fracture participated in the study. A subset of 150 participants was randomly selected to participate in a sub-study, which included annual clinical measurements. The present study utilises data from this sub-study, including clinical measurements taken prior to the first annual supplementation dose and self-reported incident falls during the three to five year follow-up, as described below.

### **2.2 Baseline measurements**

Height and weight were measured with footwear removed using a wall-mounted tape measure and set of electronic scales, respectively. Body mass index (BMI) was calculated as  $\text{kg/m}^2$ .

Quadriceps strength was measured using a hand-held dynamometer (HHD; Lafayette Nicholas Manual Muscle Testing System model 01163, SI Instruments, Hilton, Australia), a valid and reliable instrument for assessing lower-limb strength in older adults (Wang, Olson,

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& Protas, 2002). Quadriceps strength was tested with the participant in a supine position, with left leg straight and raised to 10cm above the bench surface. The HHD was held by the tester proximal to the mid-tibia and the participant provided resistance against the applied downward force. The peak force required to break an isometric muscle contraction is measured by the HHD as the examiner applies a resistive force. Three trials were performed at the mean score was taken as the criterion value for quadriceps strength. A trained examiner conducted all assessments and the intra-class correlation coefficient for the three trials was 0.97 (95% CI 0.96 – 0.98).

Gait speed was evaluated using the GAITRite® Electronic Walkway System (CIR Systems Inc., Clifton, NJ, USA), a valid and reliable clinical tool for the objective assessment of gait (Bilney, Morris, & Webster, 2003). Participants were instructed to walk along the length of the walkway at a self-selected comfortable pace. The walkway was positioned to provide a three-metre 'lead in' distance and two-metre 'lead off' distance to achieve steady state walking. Participants performed three trials with footwear removed and a rest period between each consecutive trial. Data from walking trials two and three were combined to provide a mean value for each gait variable (Bilney, et al., 2003).

### 2.3 Incident falls

Participants recorded incident falls daily using postcard calendars and returned them monthly to the study centre for three to five years following the first annual supplementation date. Falls were defined as “*an event reported either by the faller or a witness, resulting in a person inadvertently coming to rest on the ground or another lower level, with or without loss of consciousness or injury*”(Rubenstein, Robbins, Josephson, Schulman, & Osterweil, 1990). This definition was explained to participants and reinforced twice yearly via newsletter. All contact with participants regarding incident falls was by mail and telephone.

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Falls were recorded using postcard calendars completed daily by writing “*F*” if they had a fall, fracture, or both and “*N*” if they did not and were returned monthly by prepaid post (Sanders, et al., 2009). When a fall or fracture was indicated, a standardized questionnaire recording details was administered by telephone.

## 2.4 Statistical analyses

Independent samples t-tests and a Chi-square test initially examined differences in baseline characteristics for participants who reported or did not report an incident fall. Receiver operating characteristic curves were obtained for gait speed and quadriceps strength to determine their ability to predict incident falls. Area under the curve (AUC) was estimated for both of the independent variables and MedCalc software version 12.3 (MedCalc, Belgium) was used to implement the DeLong method of pairwise comparisons to assess whether there was a statistically significant difference between the AUCs for gait speed and quadriceps strength.

Multinomial logistic regression analyses were used to examine associations of gait speed and quadriceps strength with single and multiple falls during the follow-up period. To allow comparisons with previous studies with shorter falls reporting periods, we also completed these analyses with falls data restricted to the first 12 months after baseline. These analyses were adjusted for age at baseline, treatment group and years in the study, as well as the baseline value of the other independent variable of interest (ie gait speed or quadriceps strength). Additionally, we examined associations of gait speed and quadriceps strength with falls occurring after 12 months, with further adjustment for the number of falls reported within the first 12 months.

Cox proportional hazards regression models were used to determine the relative hazard ratios for time to first fall associated with baseline gait speed and quadriceps strength,

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respectively. We performed unadjusted models and adjusted models that controlling for the covariates described above. Hazard ratios with 95% confidence intervals were calculated.

To determine the potential for operational cut-points of gait speed and quadriceps strength to discriminate time to first fall in older women, Kaplan-Meier survival curves compared the time to first fall amongst those with low vs normal gait speed, and those with low vs normal quadriceps strength at baseline. The IWG criterion of  $<1.0\text{m/s}$  was used as the operational definition for low gait speed (Fielding, et al., 2011), and quadriceps strength of  $<7.0\text{kg}$  (ie the lowest tertile for baseline quadriceps strength) (Nguyen, et al., 2005) was used as the operational definition for low quadriceps strength. A log rank test was applied to each curve to assess the equality of survival between gait speed and quadriceps strength categories.

For all analyses,  $P$ -values  $< 0.05$  or 95% confidence intervals (CI) not including the null point were considered statistically significant. All analyses were performed using SPSS Statistics 19 (IBM, USA).

### 3. RESULTS

One hundred and thirty-five female volunteers aged (mean  $\pm$  SD)  $76.7 \pm 5.0$  years; range 70 – 92) completed baseline assessments and incident falls data were collected for a mean of  $3.7 \pm 1.2$  years (range: 0.2 – 5.2 years). Ninety-nine (73%) participants fell a total of 355 times during the follow-up period (mean fall rate 83 per 100 person years). Table 1 presents baseline characteristics of fallers and non-fallers. There were no differences between groups for age, anthropometrics, or 25(OH)D levels. There was a greater proportion of vitamin D-treated participants amongst fallers compared to non-fallers, but this difference was not significant. Two participants were unable to complete quadriceps strength tests. Gait speed was slightly lower amongst fallers and this association approached significance ( $P = 0.075$ ), while quadriceps strength was significantly lower for fallers compared to non-fallers.

We obtained receiver operating characteristic (ROC) curves to compare the ability of gait speed and quadriceps strength to predict incident falls in older women (Figure 1). The AUCs for both baseline gait speed and quadriceps strength were significantly different from 0.5 ( $P$ -values 0.045 and 0.001, respectively). Quadriceps strength (AUC = 0.69) demonstrated a larger AUC than gait speed (AUC = 0.61), but the DeLong method of pairwise comparison indicated that this difference was not significant ( $P = 0.20$ ).

Table 2 presents associations of gait speed and quadriceps strength with single and multiple falls during the follow-up period. These analyses demonstrated that the odds of multiple falls for the entire follow-up period were reduced by 17% per 1kg increase in quadriceps strength in this cohort, but the association with single falls did not achieve significance ( $P = 0.095$ ). Similarly, we observed a 17% reduction in odds for multiple falls during the first 12 months of follow-up per 1kg increase in quadriceps strength. There was no association for quadriceps strength with multiple falls occurring after the first 12 months of

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follow-up, but odds of a single fall decreased by 28% per 1kg increase in quadriceps strength, after further model adjustment for falls occurring within the first 12 months of follow-up. There were no associations between gait speed and single or multiple falls.

We performed Cox proportional hazards regression models to determine the relative risks for time to first fall associated with baseline gait speed and quadriceps strength, respectively (Table 3). Unadjusted analyses (Model 1) revealed that the association of gait speed with time to first fall approached but did not achieve significance ( $P = 0.06$ ), whilst quadriceps strength was significantly associated with time to first fall ( $P = 0.003$ ). These observations were maintained after adjustment for potential confounders (Model 2). The relative hazard for time to first fall decreased by around 10% per additional kg of baseline quadriceps strength in this cohort of older women.

Finally, we investigated potential operational cut-points for gait speed and quadriceps strength. The IWG criterion of  $<1.0\text{m/s}$  was used as the cut-point for low gait speed, and quadriceps strength of  $<7.0\text{kg}$  (ie the lowest tertile for baseline quadriceps strength) was used as the cut-point for low quadriceps strength. Utilising these operational definitions, 49 (36%) and 42 (32%) participants were categorised with low gait speed and low quadriceps strength, respectively, but only 20 (15%) met both definitions. Kaplan-Meier survival curves determined the time to first fall according to categories of gait speed and quadriceps strength. Log rank tests demonstrated a significantly shorter time to first fall for those with low quadriceps strength compared to those with normal quadriceps strength (Figure 2B; estimated means [95% CI]: 1.54 [1.02, 2.06] vs 2.23 [1.82, 2.64] years;  $P = 0.019$ ). No significant differences in time to first fall were observed between those with low vs normal gait speed (Figure 2A).

#### 4. DISCUSSION

The primary finding of this study was that quadriceps strength, but not gait speed, was a significant predictor of multiple falls and time to first fall over three years amongst community-dwelling older women at high risk of fracture. To our knowledge, ours is the first study to compare the predictive ability of gait speed and quadriceps strength tests for incident falls over several years in older women. Our findings indicate that quadriceps strength assessments may be a suitable alternative to gait speed for identifying female patients with sarcopenia or who are at risk of falls.

The odds of any falls and recurrent falls are increased by almost two- and over three-fold, respectively, for older adults with lower-extremity muscle weakness (Moreland, Richardson, Goldsmith, & Clase, 2004). In the present study, we observed a 10% reduction in the relative hazard for time to first fall for each additional kilogram of quadriceps strength assessed by a HHD. This is a similar observation to that of a study of over 1,500 Chinese older adults that reported a 12% decrease in relative risk of falls during a one-year follow-up for each additional kilogram of knee extension power (Chu, Chi, & Chiu, 2005). These findings indicate that quadriceps strength is a clinically relevant independent predictor of falls risk, and support evidence that lower-extremity strengthening exercise may be an effective component of falls prevention interventions for older women (Campbell et al., 1997).

Evidence suggests that physiological performance may be similar in non-fallers and single fallers, but significantly compromised in multiple or recurrent fallers (Masud & Morris, 2001). In support of this, we observed that increased quadriceps strength was associated with reduced odds for multiple, but not single, falls over both 3 years and 12 months of follow-up. Interestingly however quadriceps predicted reduced odds for single falls after 12 months of follow-up alone, when falls during the initial 12 months of follow-up were

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adjusted for. These data suggest that assessments of quadriceps strength may have discriminatory ability to identify both single and multiple fallers amongst community-dwelling older women.

We observed no association between gait speed and incident falls in this study. While the relationship has not been extensively explored, there is evidence of an association between low gait speed and risk of falling in older adults (Abellan Van Kan, et al., 2009; Chu, et al., 2005; Montero-Odasso, et al., 2005). However, in the Health ABC Study, low gait speed was independently associated with increased odds of a past-year fall for men, but not women (de Rekeneire et al., 2003). A previous study of older community-dwelling Australian women reported that gait symmetry and double-support duration were the variables most strongly associated with recurrent falls in the subsequent year (Hill, Schwarz, Flicker, & Carroll, 1999), suggesting that gait speed itself may not be the most important characteristic of mobility limitation in predicting older women at risk of an incident fall.

A longitudinal analysis of the MOBILIZE Boston Study has revealed a U-shaped relationship between gait speed and subsequent falls; participants with both low ( $<0.6\text{m/s}$ ) and high ( $\geq 1.3\text{m/s}$ ) gait speeds had significantly increased falls rates compared to those with normal gait speeds ( $\geq 1.0\text{m/s}$  and  $<1.3\text{m/s}$ ). Moreover, high gait speed was associated with an increased rate of outdoor falls (Quach et al., 2011). Thus, whilst it is likely that low gait speed is an indicator of physiological parameters that may predispose older women to falls (such as poor neuromuscular function, balance etc.), the predictive validity of gait speed for identifying future fallers may be reduced given that those with higher gait speed may have greater falls risk due to increased activity levels.

To increase the assessment and treatment of age-related functional declines in the clinic, practitioners require well-defined measurements and thresholds. The EWGSOP and IWG have attempted to address this issue by developing clinically-relevant algorithms for

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diagnosing sarcopenia, which include assessment of gait speed, muscle strength and muscle mass (Cruz-Jentoft, et al., 2010; Fielding, et al., 2011). In the present study, a substantial proportion of participants (36%) were classified as having low gait speed according to the IWG cut-point of 1.0m/s, but we did not observe a significant difference in the time to first fall for these participants compared to those with normal gait speed. Conversely, there was a significantly shorter time to first fall for participants classified as having low quadriceps strength according to the lowest tertile for this measure. In the Dubbo Osteoporosis Epidemiology Study, participants in the lowest tertile for quadriceps strength had a three-fold increased risk of hip fracture during the 14-year follow-up period (Nguyen, et al., 2005). Whilst further research is required to develop standardised guidelines for the assessment of muscle strength in clinical practice, we propose that the lowest tertile of an age-matched population may be an acceptable cut-point for identifying female patients at increased risk of future falls and fractures.

There are several limitations to the findings of this study. It should be noted that AUC analysis indicated that the accuracy of both gait speed and quadriceps strength for classifying fallers, whilst significantly better than chance, was poor. However, the AUC for quadriceps strength of 0.69 closely approached the value of 0.70 which Hosmer and Lemeshow have proposed may indicate acceptable discrimination for a diagnostic measure (Hosmer & Lemeshow, 2000). Additionally, the Nagelkerke R square statistic revealed that our multinomial logistic regression model explained only 15% of the variance in falls risk over three years, reflecting the fact that numerous other physiological factors not examined in this study may be important contributors to falls risk (Rubenstein, 2006). The sample size was relatively small and the observed associations may be generalised only to older women who may be considered at risk of hip fracture. Also, cut-points for low quadriceps strength using different testing protocols to that in the current study need to be investigated. Nevertheless,

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we believe that the testing procedure used in this study may be well-suited to the clinical setting; the test can be performed with a HHD which is low-cost, can be performed with the patient lying on a bed and can be performed by patients with existing mobility limitations. In addition, the test itself requires minimal space and time to complete and requires minimal training to administer reliably (Wang, et al., 2002).

**5. CONCLUSIONS**

Quadriceps strength is a significant predictor of multiple falls and time to first fall over three years amongst community-dwelling older women at high risk of fracture. Further research is required to determine whether quadriceps strength may be an acceptable alternative to gait speed in sarcopenia case-finding algorithms that may be applied in clinical settings where gait speed assessment is not feasible.

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## TABLES

**Table 1. Baseline characteristics of VITAL D sub-study participants categorised by incident falls status.**

|                            | Non-fallers (N = 36) | Fallers (N = 99) | P-value for difference |
|----------------------------|----------------------|------------------|------------------------|
| Age (y)                    | 76.1 ± 5.2           | 76.9 ± 4.9       | 0.431                  |
| Weight (kg)                | 71.5 ± 13.7          | 68.4 ± 13.0      | 0.234                  |
| Height (cm)                | 157.9 ± 5.4          | 157.5 ± 5.5      | 0.718                  |
| BMI (kg/m <sup>2</sup> )   | 28.6 ± 5.1           | 27.5 ± 4.7       | 0.239                  |
| 25(OH)D (nmol/L)           | 50.1 ± 15.5          | 53.5 ± 18.0      | 0.334                  |
| Vitamin D Treated (%)      | 47                   | 59               | 0.240*                 |
| Gait speed (m/s) (N = 133) | 1.1 ± 0.2            | 1.0 ± 0.2        | 0.075                  |
| Quadriceps strength (kg)   | 9.4 ± 2.7            | 7.6 ± 2.9        | 0.001                  |

± standard deviation

All tests are independent samples t tests, with the exception of \*Chi-square test

**Table 2. Associations of gait speed and quadriceps strength with single and multiple falls.**

|  | <b>Odds Ratios (95% CI)</b> |                           |                              |
|--|-----------------------------|---------------------------|------------------------------|
| <i>Falls during total follow-up (mean 3.7 ± 1.2 years)</i> |                             |                           |                              |
|  | Non-Faller<br>(N = 36 )     | Single faller<br>(N = 24) | Multiple faller<br>(N = 73 ) |
| Gait speed (cm/s)  | 1.00                        | 0.99 (0.96, 1.01)         | 0.99 (0.97, 1.01)            |
| Quadriceps strength<br>(kg)                                | 1.00                        | 0.84 (0.68, 1.03)         | 0.83 (0.70, 0.98)            |
| <i>Falls during first 12 months of follow-up</i>           |                             |                           |                              |
|  | Non-Faller<br>(N = 69)      | Single faller<br>(N = 36) | Multiple faller<br>(N = 28)  |
| Gait speed (cm/s)  | 1.00                        | 0.99 (0.97, 1.01)         | 1.01 (0.99, 1.04)            |
| Quadriceps strength<br>(kg)                                | 1.00                        | 1.03 (0.88, 1.20)         | 0.83 (0.69, 0.99)            |
| <i>Falls after first 12 months of follow-up*</i>           |                             |                           |                              |
|  | Non-Faller<br>(N = 53)      | Single faller<br>(N = 32) | Multiple faller<br>(N = 48)  |
| Gait speed (cm/s)  | 1.00                        | 1.00 (0.98, 1.03)         | 1.00 (0.98, 1.02)            |
| Quadriceps strength<br>(kg)                                | 1.00                        | 0.72 (0.59, 0.89)         | 0.92 (0.77, 1.10)            |

Models adjusted for age, treatment group, years in study and the opposite independent variable

\*Further adjusted for number of falls during first 12 months of follow-up

**Table 3. Results from Cox proportional hazards regression models examining associations of gait speed and quadriceps strength with time to first fall in VITAL D sub-study participants.**

|                          | Model 1*              | Model 2†          |
|--------------------------|-----------------------|-------------------|
|                          | Hazard Ratio (95% CI) |                   |
| Gait speed (cm/s)        | 0.99 (0.98, 1.00)     | 1.00 (0.99, 1.01) |
| Quadriceps strength (kg) | 0.90 (0.84, 0.97)     | 0.90 (0.83, 0.98) |

\*Unadjusted model

† Adjusted for age, treatment group, years in study and the opposite independent variable

**FIGURE LEGENDS**

**Figure 1. Receiver operator characteristic curve plots demonstrating the ability of baseline gait speed and quadriceps strength to identify participants who reported an incident fall in the VITAL D sub-study.**

**Figure 2. Kaplan-Meier survival curves for time to first fall amongst VITAL D sub-study participants according to baseline gait speed (A) and quadriceps strength (B) classifications.**

Figure 1



