

# The Role of Hip Abductor Strength in Identifying Older Persons at Risk of Falls: A Diagnostic Accuracy Study

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**Background/Objectives:** Early detection of fall risk in persons older than 65 is of clinical relevance, but the diagnostic accuracy of currently used functional tests (eg short physical performance battery [SPPB] and timed up and go test [TUG]) to assess older persons' fall risks remains moderate. Recent literature highlights the importance of strong hip abductors to prevent falls. We thus aimed to assess the diagnostic accuracy of hip abductor strength measures to assess older persons' fall risks.

**Methods:** Hip abductor maximum voluntary isometric strength (ABD MVIS), rate of force generation (ABD RFG), and the SPPB and TUG functional fall risk assessments were assessed in 60 persons aged over 65 years ( $82.0 \pm 6.1$  years). The diagnostic accuracy (area under the curve [AUC], sensitivity [sens], specificity [spec], positive predictive value [PPV], negative predictive value [NPV], and positive and negative likelihood ratios [LR<sup>+</sup>, LR<sup>-</sup>]) was evaluated at a clinically important 90% sensitivity level. Cut-off values for clinical use were calculated.

**Results:** In our population, hip ABD MVIS (AUC 0.8, sens 90.6%, spec 57.1%, PPV 70.7%, NPV 84.2%, LR<sup>+</sup> 2.1, LR<sup>-</sup> 0.2, and cut-off value  $\leq 1.1$  N/kg) and hip ABD RFG (AUC 0.8, sens 90.6%, spec 46.4%, PPV 65.9%, NPV 81.3%, LR<sup>+</sup> 1.7, LR<sup>-</sup> 0.2, and cut-off  $\leq 8.47$  N/kg/s) show diagnostic accuracy comparable to other fall risk assessments (SPPB and TUG) and a high net sensitivity when used in a test battery.

**Conclusion:** Hip ABD MVIS or RFG shows good diagnostic accuracy to differentiate between older fallers and nonfallers compared to the chosen external criterion history of falls. The high net sensitivity when hip ABD MVIS or RFG is combined with currently used fall risk assessments shows promise in contributing value to a test battery and should be investigated further in longitudinal studies.

**Keywords:** measurement study, muscle strength, hip, functional performance, accidental falls, aged

## Introduction

The World Health Organization (WHO) reports a yearly fall rate of 28% to 35% in persons older than 65.<sup>1</sup> For persons living in long-term care institutions, percentages are even higher and lay between 30% and 50%.<sup>1</sup>

Various functional tests are currently used to assess older persons' fall risks (eg timed up and go test [TUG] and short physical performance battery [SPPB]). However, the diagnostic accuracy (eg sensitivity and specificity) of these functional tests remains moderate.<sup>2,3</sup> In addition, poor performance in a functional test indicates a fall risk but requires further tests to identify the underlying causes. It is thus

of utmost importance to develop and use valid diagnostic fall risk assessment tools that can be used in everyday clinical practice and that indicate parameters that need to be targeted.

A combination of various factors often leads to a fall incident (eg muscle weakness, gait and balance problems, poor footwear, or poor lighting),<sup>4</sup> which can cause serious consequences such as fractures, loss of independence,<sup>5</sup> and increased mortality.<sup>6</sup> Muscle strength has already been shown to be important in preventing falls.<sup>4</sup> Recent literature further underlines the significance of hip abductor muscle strength to maintain mediolateral balance control,<sup>7–9</sup> which is essential to avoid lateral and posterolateral falls.<sup>10</sup> This is of clinical relevance because posterolateral falls have high hip injury potential and lead to fractures.<sup>11–13</sup> In addition, it was shown that hip abductor muscle contractions at the moment of impact after a fall could substantially reduce stress at the femoral neck and likewise the risk of a femoral fracture.<sup>14</sup> Therefore, hip abductor strength could be a promising contributing factor for the assessment of fall risk and establishment of cut-off values, and diagnostic accuracy might improve the clinical decision-making process regarding individuals' fall risks.

Our previous work confirmed the importance of hip abductor muscle strength and showed that the strength of the hip abductor muscle groups can, among all hip muscle groups (flexors, extensors, internal and external rotators and adductors), best distinguish between older fallers and nonfallers.<sup>15</sup>

Therefore, the current study first aimed to investigate diagnostic accuracy (area under the curve [AUC], sensitivity [sens], specificity [spec], positive predictive value [PPV], negative predictive value [NPV], and positive and negative likelihood ratio [LR+, LR-]) of hip abductor strength (ABD maximum voluntary isometric strength [MVIS] and rate of force generation [RFG]) to distinguish between older fallers and nonfallers compared to a history of falling as the predefined reference standard. The second goal was to identify clinically relevant hip abductor strength (MVIS and RFG) cut-off values based on diagnostic accuracy outcomes to distinguish between older fallers and nonfallers evaluated by fall history as the same reference standard. The third aim was to compare the diagnostic accuracy of hip abductor strength with the diagnostic accuracy of currently used fall risk assessments (TUG and SPPB) in our population, as well as with published articles. The final goal was to calculate the net

sensitivity and specificity of our population for parallel testing of ABD MVIS or ABD RFG with the mentioned currently used TUG and SPPB fall risk assessments.

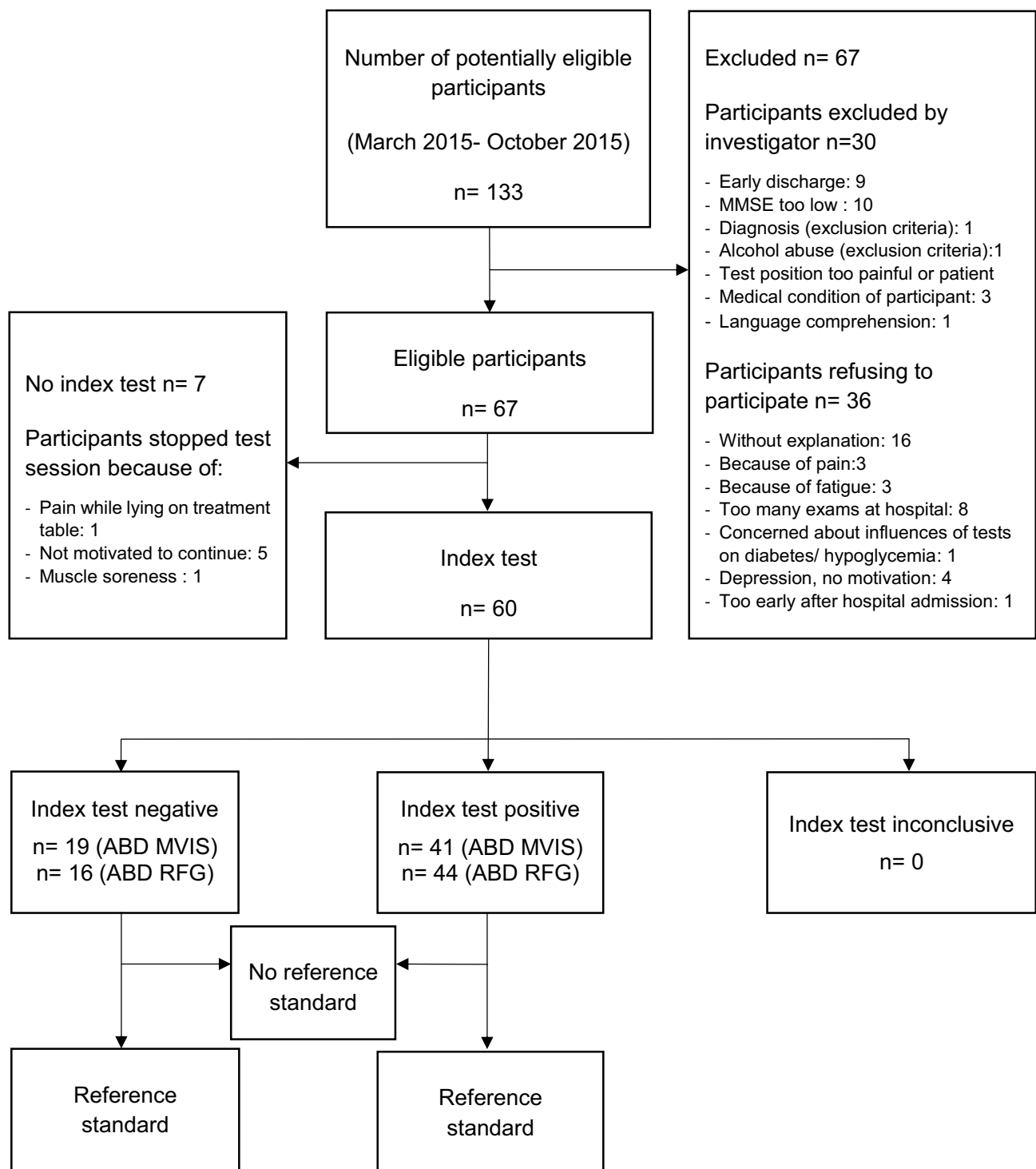
We tested three hypotheses. First, hip abductor strength has a good diagnostic accuracy ( $\geq 0.9$ ) for clinical use to distinguish between older fallers and nonfallers. Second, the diagnostic accuracy of hip abductor strength shows values comparable to the diagnostic accuracy of currently used fall risk assessments (TUG and SPPB). Third, hip abductor strength (ABD MVIS and RFG), as a not yet systematically assessed parameter in the construct of fall risk, shows high accuracy in recognizing fallers in parallel testing with TUG and SPPB.

## Methods

We performed a validity study to evaluate the diagnostic accuracy of hip ABD MVIS and ABD RFG for the fall risk evaluation of persons' older than 65. The Standards for Reporting of Diagnostic Studies (STARD)<sup>16</sup> were followed (Figure 1 shows the STARD flow chart to report participants' flow through the study). Participants were simultaneously recruited from the Geriatric Department of the University Hospitals of Geneva and from an ambulatory setting. They were included when they were  $\geq 65$  years, had a body mass index (BMI) between 17 and 35 and were able to walk household distances. We excluded participants in case of a positive history or evidence of any significant central nervous system dysfunction, neuromuscular disorders except a distal symmetric peripheral neuropathy, evidence of vestibular dysfunction, moderate or severe dementia (Minimal Mental State Exam (MMSE)  $< 18$ ), a fracture of the lower limb and/or joint replacement within the previous year and any lower limb or back pain that adversely affects the strength tests.<sup>15</sup>

This study is an extended evaluation and a next step to the results we presented in our previous article in which, as a first step, we evaluated which of the hip muscle groups is the most important to differentiate between older fallers and nonfallers.<sup>15</sup> In the current study, we examine the diagnostic accuracy of hip abductor muscle strength to decide whether this parameter should be integrated into a test battery to assess older persons' fall risks. The diagnostic accuracy of a test is expressed by the area under the curve [AUC], sensitivity [sens], specificity [spec], positive predictive value [PPV], negative predictive value [NPV], and positive and negative likelihood ratio [LR+, LR-].

The area under the receiver operating curves is the AUC, the higher the value of the AUC the better a test discriminates between two groups.<sup>17</sup> Sensitivity and specificity reflect the



**Figure 1** STARD diagram of participants' flow through the study.

intrinsic quality of a test and show the ability of a measurement instrument to detect true positives or true negatives, respectively.<sup>18</sup> The likelihood ratio is calculated based on sensitivity and specificity.<sup>18</sup> The positive likelihood ratio is a value for how much more likely a positive test result

is in people with the disease than in people without the disease.<sup>18</sup> How much less likely a negative test result is in people with the disease than in people without the disease is expressed by the negative likelihood ratio.<sup>18</sup> The larger the value above one (for LR+), respectively the smaller the value

below one (for LR-), the more valuable is the test result.<sup>18</sup> Positive and negative predictive values are the probability of the disease in a patient with a positive test result or the probability of not having the disease when the test result is negative, respectively.<sup>17</sup>

The study was conducted according to the Declaration of Helsinki and the local ethics committee (commission cantonale d'éthique de la recherche Geneva, CCER) approved the study protocol (14–235). Participants received verbal and written information about the study content, and they signed informed consent forms prior to the first tests.

## Procedure

All of the included patients' demographic data (eg age, sex, and BMI) were extracted from the clinical database. The reference standard fall history was collected by verbal questioning.

Thereafter, trained physical therapists (blinded to the participants' fall histories) assessed the Falls Efficacy Scale International (FES-I),<sup>19</sup> Mini Mental State Examination (MMSE),<sup>20</sup> the SPPB<sup>21</sup> and TUG<sup>22</sup> functional fall risk assessments, as well as participants' hip abductor strength (MVIS and RFG) following our study protocol's procedure.

### Index Measure: Hip Abductor Strength

Hip abductor strength was measured in Newtons (N) using an analog dynamometer (Sensix, Poitiers, France) with a range from 0 to 667 N and a precision of 0.002 N.<sup>23</sup> The Delsys System (Trigno sensor, Delsys, Inc., Boston, MA) coupled with the calibrated dynamometer digitalized the output (3.3 V) with a sampling rate of 1926 Hz and a 16-bit resolution.<sup>23</sup>

For hip abductor strength (ABD) tests, participants lay on their sides and performed hip ABD with the upper leg in a 10° abducted position.<sup>23</sup> The lower leg was at 45° of knee and hip flexion for stabilization. Participants were asked to keep the knee of their tested leg extended with the hip in a neutral or slightly extended position.<sup>23</sup> For the test, the examiner manually supported the leg's starting position 1 cm from the dynamometer that was positioned 5 cm proximal to the malleolus externus.<sup>23,24</sup>

To measure MVIS and RFG, participants were asked to push as hard and fast as possible against the dynamometer,<sup>25</sup> hold the pressure for 3 s, and relax.<sup>26</sup> To avoid bias through dynamometer destabilization or the testing person's strength, the dynamometer was fixed to a metallic frame at the appropriate height for the described 10° abduction starting position.

Participants repeated the test 3 times per leg with a break of 1 min between trials. In accordance with our pilot tests, the mean of the 6 trials was retained for further analyses. Details of the measurement procedure and information about the feasibility and reliability of the test are described elsewhere.<sup>15,23</sup>

### Functional Fall Risk Assessments

**Short physical performance battery:** The SPPB estimates the function of the lower limbs. It is divided into 3 parts: the evaluation of standing balance, walking speed, and lower limb strength with a 5 sit to stand test.<sup>21,27</sup> The final score ranges from 0 to 12 points and is calculated by summarizing the scores of the 3 parts.

**Timed up and go test:** For the TUG, participants were asked to get up from a chair with armrests, walk 3 m at usual gait speed, perform a turn, and return to the chair to sit down again. Participants were allowed a test trial. Thereafter, the time needed to complete the task once was recorded in seconds.<sup>28</sup>

### Reference Standard: Fall History

To classify our study participants into fallers and nonfallers, a history of falls during the previous 12 months was chosen as a reference standard. A faller was defined as a participant who reported one or more falls within the previous year.<sup>29</sup> Participants who did not report a fall were classified as nonfallers.<sup>29</sup> Participants were informed that a fall was defined as an event resulting in a person inadvertently coming to rest on the ground, floor, or other lower level.<sup>1</sup> We did not include falls resulting from unavoidable environmental hazards, such as a chair collapsing.<sup>22</sup>

## Sample Size

We expected to find high sensitivity levels comparable with currently used fall risk assessment tools (sensitivity between 0.6 and 0.9). To test the null hypothesis,  $H_0$ : sensitivity = 0.6 ( $H_1$ : sensitivity  $\neq$  0.6) with an expected sensitivity of 0.9, a minimum sample of  $n = 19$  persons with the disease (fallers) and a total sample of  $n = 48$  is appropriate to achieve a <5% significance level and 80% power.<sup>30</sup> To compensate for an expected 20% dropout rate, we aimed to include 60 participants.

## Statistics

Statistical analyses were performed with Stata version 14.1 (College Station, Texas 77845, USA).

## Data Processing

After downloading raw data to a computer, Matlab (Mathworks, Natick, MA, USA) was used to process the force data. A low-pass filter (75 ms moving average) suppressed high-frequency noise. The MVIS was defined as the highest force generated by the subject within 3 s from the beginning of the test. The RFG was evaluated within a 50 ms time window after 10% of the MVIS was reached.<sup>23</sup> MVIS and RFG were normalized to body mass.<sup>15</sup>

## Main Analyses

The characteristics of the study sample were described with mean and standard deviations. Area under the curves were calculated from logistic regressions with their corresponding 95% confidence intervals (95% CI).

To achieve a high probability to detect as many persons at risk of falls as possible, high test sensitivity is important (ie a test's ability to detect affected persons). A way to increase the "certainty" of detecting at-risk persons is to perform two different tests simultaneously (parallel testing), which leads to a gain in sensitivity (net sensitivity).

To obtain a high number of true positives (and consequently a lower number of false negatives), we decided to evaluate the diagnostic accuracy of our index measure closest above the clinically important 90% sensitivity level for discrimination. Therefore, sensitivity and specificity (with corresponding 95% confidence intervals) were calculated based on cut-offs closest to the value that yielded in a sensitivity of  $\geq 0.9$ . Positive and negative predictive values, as well as likelihood ratios for positive (LR+) and negative (LR-) tests, were calculated (with corresponding 95% confidence intervals) accordingly.

For the calculations of the net sensitivity and net specificity, we additionally present the calculations with the Youden Index, Youden's J ( $J = \text{Sensitivity} + \text{Specificity} - 1$ ) with the corresponding cut-offs. We further analyzed and presented indices for discrimination and calibration of our logistic regression models.

Finally, we also calculated calibration plots of the logistic regression model with the Hosmer–Lemeshow test, with a significance level (type-I error) of 5%. We plotted our observed values for falls against the predicted probabilities of falls for groups defined by ranges of 20% for the predicted risk, as well as their slopes and intercepts.<sup>31</sup>

## Results

We evaluated the diagnostic accuracy of hip abductor MVIS and RFG in 60 participants (mean age 82 years,

SD 6.61 years, 28 older nonfallers and 32 older fallers). The descriptive statistics for age, sex, BMI, FES-I, MMSE, SPPB, and TUG are presented in [Table 1](#).

The diagnostic accuracy (AUC, sens, spec, PPV, NPV, and LR+ and LR-) to discriminate between older fallers and nonfallers using hip abductor MVIS and RFG as well as the corresponding cut-off values of our sample are presented in [Table 2](#).

The diagnostic accuracy to distinguish between older fallers and nonfallers of ABD MVIS, ABD RFG, TUG, and SPPB shows comparable values (values range between the following: sens 90.6–93.9%, Spec 46.4–71.5%, PPV 65.9–78.4%, NPV 81.3–88.2%, LR+ 1.7–3.2, LR- 0.1–0.2). However, hip ABD MVIS shows a slightly higher diagnostic accuracy (AUC 0.8 [95% CI, 0.7–0.9], sens 90.6% [75.0–98.0], spec 57.1% [37.2–75.5], PPV 70.7% [51.8–92.5], NPV 84.2% [62.3–92.5], LR+ 2.1 [1.4–3.3], LR- 0.2 [0.1–0.5]) than hip ABD RFG (AUC 0.8 [95% CI, 0.7–0.9], sens 90.6% [75.0–98.0], spec 46.4% [27.5–66.1], PPV 65.9% [45.8–90.8], NPV 81.3% [57.3–90.7], LR+ 1.7 [1.2–2.4], LR- 0.2 [0.1–0.6]) ([Table 2](#)). The cut-off values to distinguish between fallers and nonfallers are  $\leq 1.1$  N/kg for ABD MVIS and  $\leq 8.5$  N/kg/s for ABD RFG.

In [Table 3](#), the cross-tabulation of the index tests (hip ABD MVIS or RFG) is presented against the results of the reference standard. This allows to identify the true positive, true negative, false positive and false-negative cases. Our ABD MVIS and RFG model, as well as SPPB and TUG, showed good calibration (small discrepancy between predicted probability of falls on the x-axis and observed proportion of falls on the y-axis, all P values > 0.05, [Figure 2](#)). This means that for example for the hip ABD MVIS values ([Figure 2A](#)) for the participants we

**Table 1** Characteristics of our study participants

Variable	Total Group Mean (SD)	Fallers Mean (SD)	Nonfallers Mean (SD)
Sex (F/M)	38/22	21/11	17/11
Age (years)	81.2 (6.6)	83.3 (6.2)	80.4 (6.8)
Weight (kg)	65.9 (12.1)	63.8 (12.7)	68.3 (11.2)
BMI (kg/m <sup>2</sup> )	24.3 (3.4)	24.3 (3.9)	24.3 (2.9)
Hospitalized (%)	71.7	96.9	42.9
MMSE	26.0 (3.5)	24.3 (3.6)	27.8 (2.1)
FES-I	24.5 (7.1)	26.5 (7.0)	22.2 (6.5)
SPPB	8.2 (3.1)	6.3 (2.3)	10.3 (2.4)
TUG (s)	15.9 (9.0)	20.0 (9.4)	11.3 (5.8)

**Abbreviations:** BMI, body mass index; MMSE, mini mental state examination; FES-I, falls efficacy scale international; SPPB, short physical performance battery; TUG, timed up and go test; s, seconds.

**Table 2** The diagnostic accuracy to discriminate between older fallers and nonfallers of hip abductor strength (MVIS and RFG) and the performance tests SPPB and TUG, as well as their corresponding cut-off values evaluated by the closest sensitivity value >90%

Variable	AUC (95% CI)	Sens % (95% CI)	Spec % (95% CI)	PPV % (95% CI)	NPV % (95% CI)	LR+ (95% CI)	LR- (95% CI)	Cut-off
ABD MVIS (N/kg)	0.8 (0.7, 0.9)	90.6 (75.0, 98.0)	57.1 (37.2, 75.5)	70.7 (51.8, 92.5)	84.2 (62.3, 92.5)	2.1 (1.4, 3.3)	0.2 (0.1, 0.5)	≤1.1
ABD RFG (N/kg/s)	0.8 (0.7, 0.9)	90.6 (75.0, 98.0)	46.4 (27.5, 66.1)	65.9 (45.8, 90.8)	81.3 (57.3, 90.7)	1.7 (1.2, 2.4)	0.2 (0.1, 0.6)	≤8.5
SPPB (/12)	0.9 (0.8, 1.0)	90.6 (75.0, 98.0)	71.4 (51.3, 86.8)	78.4 (60.5, 94.9)	87.0 (67.4, 94.6)	3.2 (1.7, 5.8)	0.1 (0.0, 0.4)	≤9.0
TUG (sec)	0.8 (0.7, 0.9)	93.8 (79.2, 99.2)	53.6 (33.9, 72.5)	69.8 (53.9, 82.8)	88.2 (63.6, 98.5)	2.0 (1.3, 3.0)	0.1 (0.0, 0.5)	≥10.0

**Abbreviations:** AUC, area under the curve; Sens, sensitivity; Spec, specificity; PPV, positive predictive value; NPV, negative predictive value; LR+, positive likelihood ratio; LR-, negative likelihood ratio; 95% CI, 95% confidence interval; ABD MVIS, hip abductor maximum voluntary isometric strength; ABD RFG, hip abductor rate of force generation; SPPB, short physical performance battery; TUG, timed up and go test; sec, seconds; N, Newton; s, seconds.

**Table 3** Cross tabulation of the index measure (Left; ABD MVIS, Right; ABD RFG) against the reference standard history of falling

Hip ABD MVIS ≤1.1 N/kg	Fall History		Total	Hip ABD RFG ≤8.47 N/kg/s	Fall History		Total
	Positive	Negative			Positive	Negative	
Positive	29	12	41	Positive	29	15	44
Negative	3	16	19	Negative	3	13	16
Total	32	28	60	Total	32	28	60

**Abbreviations:** ABD MVIS, hip abductor maximum voluntary isometric strength; ABD RFG, hip abductor rate of force generation.

predicted about a 10% risk of falls (x-axis) we really observed a risk of falls of about 10% (y-axis). A perfect prediction lays on the 45° line. The net sensitivities and specificities for the parallel testing of the currently used TUG and SPPB fall risk assessment tools with hip ABD MVIS and RFG of our population are presented in Table 4 (once for sensitivity ≥90% and once for the sensitivity evaluated with the Youden Index). Table 4 shows that performing 2 tests simultaneously (ABD MVIS or ABD RFG combined with either TUG or SPPB) leads to a very high net sensitivity (between 96.5 and 99.4) in our study sample.

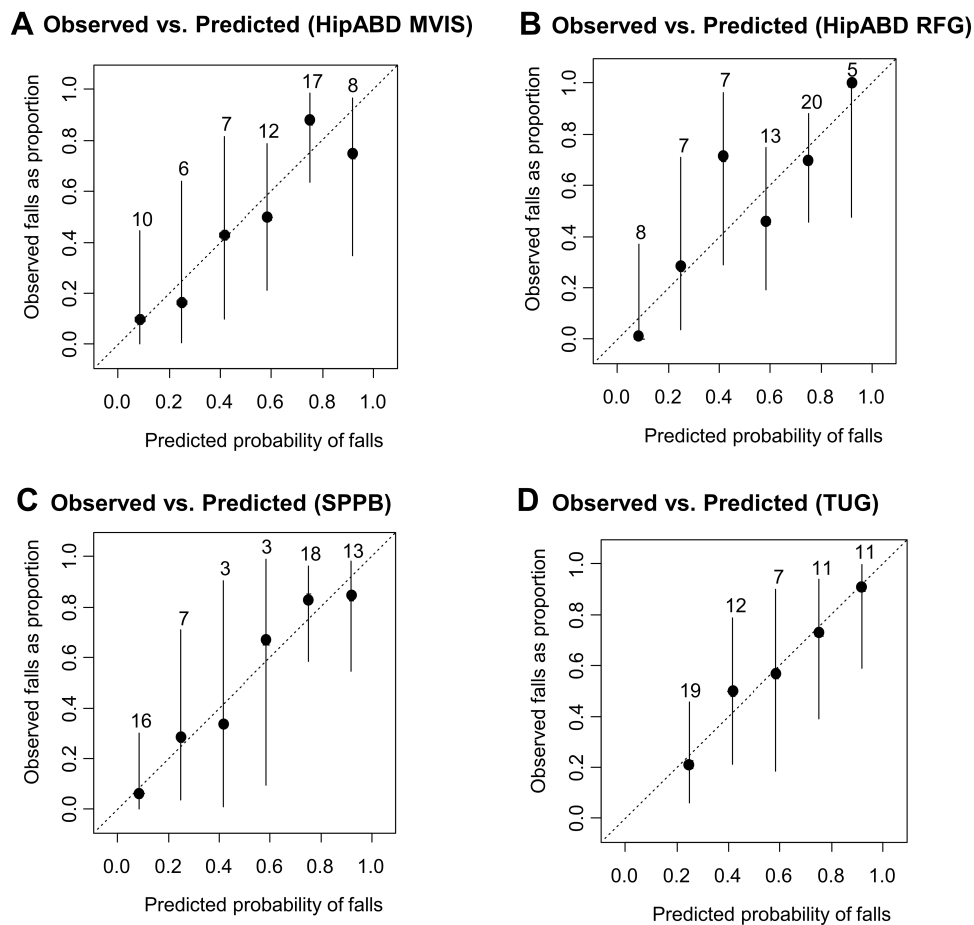
## Discussion

We hypothesized the following; first, for clinical use, hip abductor strength has good diagnostic accuracy to distinguish between older fallers and nonfallers. Second, the diagnostic accuracy of hip abductor strength is comparable with the diagnostic accuracy of currently used fall risk assessments (TUG and SPPB). Third, hip abductor strength (ABD MVIS and RFG) shows good values by which to recognize fallers in parallel testing with TUG and/or SPPB.

Our results support our hypotheses. In our population, hip ABD strength shows good diagnostic accuracy to distinguish between older fallers and nonfallers,

comparable to values of other functional fall risk and/or mobility assessment tools. Hip ABD MVIS (AUC 0.8 [95% CI, 0.7–0.9], cut-off value ≤ 1.1 N/kg) shows a slightly higher diagnostic accuracy than hip ABD RFG (AUC 0.8 [95% CI, 0.7–0.9], cut-off ≤ 8.5 N/kg/s) (Table 2). ABD MVIS's slightly better diagnostic accuracy compared to ABD RFG seems rather unexpected as clinically one can assume that RFG is more important in fall prevention since a fast recovery step after tripping is necessary to regain balance and prevent falls.<sup>32</sup> However, this might be because our participants' ABD MVIS and RFG were evaluated within the same trial. For older persons, our combined instructions to push as hard and as fast as possible to evaluate ABD MVIS and ABD RFG in the same trial was very complex. Therefore, for a clear differentiation of the 2 variables (MVIS and RFG), we recommend a separation of the trials to evaluate ABD MVIS and ABD RFG in future studies.

For clinical use, a quick and easy assessment with good diagnostic accuracy is essential. So far, various studies have assessed the diagnostic accuracy of the TUG or the SPPB to assess older persons' fall risks, 2 tests that are easily applicable in a relatively short timeframe.<sup>2,33</sup> Within our population, the ABD MVIS, ABD RFG, TUG, and SPPB showed comparable diagnostic accuracy (Table 2). This might be surprising as the hip ABD MVIS and ABD



**Figure 2** The calibration plots for the A) hip abductor maximum voluntary isometric strength (ABD MVIS), B) hip abductor rate of force generation (ABD RFG), C) the short physical performance battery (SPPB) and D) the timed up and got test (TUG) show good calibration (small discrepancy between predicted probability of falls and observed proportion of falls, all  $p$ -values  $> 0.05$ ).

RFG evaluate only one specific dimension of the 3 often-named fall-influencing parameters (ie strength, balance, and gait characteristics).<sup>34</sup> Nevertheless, the influence of the hip abductors on older persons' decreased mediolateral balance control<sup>7-9</sup> and the femoral-neck-stress-reducing hip abductor muscle contraction at the moment of impact after falling<sup>14</sup> gives an indication of the importance of this hip muscle group in relation to falls. Therefore, evaluating and understanding the construct of older persons' fall risks might benefit from the additional assessment of hip abductor strength as a not yet systematically assessed parameter to currently used fall risk assessments evaluating complementary aspects of falls.

In Barry et al.<sup>2</sup> systematic review, including retrospective and prospective studies of community-dwelling persons, the TUG showed an overall AUC of 0.57 (95% CI, 0.54–0.59) to discriminate between fallers and nonfallers. In another study, the AUC of the TUG to differentiate between persons who

fell 6 months prior to hospitalization and persons who did not fall was 0.58.<sup>34</sup> The AUC for prospectively assessed in-hospital and in-hospital injurious falls ranged between 0.64 and 0.67.<sup>34</sup> The AUC of the TUG in our study was 0.8 (95% CI, 0.7–0.9), which is somewhat higher than the AUC in the aforementioned articles.

In Lauretani et al.<sup>3</sup> the SPPB showed an AUC of 0.7 (95% CI, 0.6–0.7) to differentiate between persons who fell in the previous 12 months and nonfallers in an outpatient population.<sup>3</sup> The AUC of the SPPB to identify persons who fell in the 6 months prior to hospitalization was 0.57, and in the same study, it was between 0.68 and 0.72 for the prospective assessment of in-hospital and in-hospital injurious falls.<sup>34</sup> For our population, we calculated an AUC of 0.8 (95% CI, 0.7–0.9), which is again higher than the previously stated values. One explanation for the higher AUC in our study might be the rather heterogeneous study population because we recruited in- and outpatients; it is likely that the

**Table 4** Calculation of net sensitivity for parallel testing of one of the currently used fall risk assessment tools (TUG or SPPB) with the index measure (ABD MVIS or ABD RFG) of our population

Current Fall Risk Assessment Tool	Sens (%)	Spec (%)	Index Measure	Sens (%)	Spec (%)	Net Sens For Parallel Testing (%)	Net Spec For Parallel Testing (%)
Sensitivity $\geq 90$							
TUG	93.8	53.6	ABD MVIS	90.6	57.1	99.4	30.6
TUG	93.8	53.6	ABD RFG	90.6	46.4	99.4	24.9
SPPB	90.6	71.4	ABD MVIS	90.6	57.1	99.1	40.8
SPPB	90.6	71.4	ABD RFG	90.6	46.4	99.1	33.2
Sensitivity Youden Index							
TUG	84.4	75.0	ABD MVIS	78.1	82.1	96.6	61.6
TUG	84.4	75.0	ABD RFG	75.0	71.4	96.1	53.6
SPPB	87.5	78.6	ABD MVIS	78.1	82.1	97.3	64.5
SPPB	87.5	78.6	ABD RFG	75.0	71.4	96.9	56.1

**Abbreviations:** TUG, timed up and go test; SPPB, short physical performance battery; ABD MVIS, hip abductor maximum voluntary isometric strength; ABD RFG, hip abductor rate of force generation.

different patient characteristics (eg results of the functional performance tests and hospitalization rate) could have led to a slight over- or underestimation of the discriminating ability of hip abductor strength. However, to the best of our knowledge, this study is one of the first that has calculated the diagnostic accuracy of hip abductor strength to differentiate between older persons at risk of falls and nonfallers. The inclusion of hospital inpatients and outpatients in a first step allowed the analysis of the variable hip ABD on its full applicability range. Future studies should thus confirm our result using longitudinal designs with a more homogenous sample.

A high sensitivity and specificity is of utmost clinical importance when assessing older persons' fall risks. Regarding the deleterious adverse effects a fall can have for older persons, we chose to determine the diagnostic accuracy by using a high preselected sensitivity of  $\geq 90\%$  instead of the often-used Youden Index. Our chosen approach to calculating the cut-off values implies accepting a small risk of treating too many rather than not enough older persons. For every test used to differentiate between older persons at risk or not at risk of falls, a very wide range of cut-off values is published, indicating that more than one fall risk test is necessary to classify a person into the categories "at risk" or "not at risk." To increase the certainty of detecting as many persons at risk of falls as possible, net sensitivity and specificity calculations should be performed. Parallel testing (performing 2 different tests simultaneously) increases the ability to detect persons at risk of falling (gain in net sensitivity but decrease in net specificity) and allows identification of the most accurate test battery to

assess older persons at fall risk. Therefore, we calculated the net sensitivity and specificity when using one of the commonly used fall risk assessment tools (SPPB and TUG) in parallel testing with hip ABD MVIS or ABD RFG in our study population. To make rendering comparisons with other studies easier, we also presented the calculation of the net sensitivity with the sensitivity evaluated by the Youden Index. The calculated net sensitivities in our study (between 96.5 and 99.4) are high and show a good ability of the hip ABD MVIS and RFG combined with the TUG and SPPB to detect persons at risk of falls. On the other hand, the net specificities are lower, indicating that the combination of hip ABD MVIS or RFG with the TUG or SPPB is not useful to detect nonfallers.

Hip abductor strength is easily and reliably assessable.<sup>23</sup> The inclusion of hospital inpatients and outpatients in this study allowed the analysis of the variable hip ABD on its full applicability range. Our chosen high sensitivity ( $\geq 90\%$ ) is a further strength of this study because our choice was to reduce the risk of excluding persons at risk of falls.

A limit of the present study is that the fall history data were not collected in a prospective way, in a rather heterogeneous sample of older participants, which might lead to a slight under- or overestimation of the diagnostic accuracy. It might be that a recall bias influenced the reported number of falls, which might have led to a misclassification. Our strength data are normalized to body mass but we did not take into account the specific weight and length of the participants' leg. This might have influenced the cut-off points of the ABD MVIS and RFG, respectively.



The above-mentioned results suggest that a proper hip abductor strength assessment can be used as a contribution to a test battery to assess patients' fall risks and indicate a possible weakness.

## Conclusion

Hip abductor strength (MVIS and RFG) shows good diagnostic accuracy to differentiate between older fallers and nonfallers. The high net sensitivity when hip ABD strength measurements (MVIS and RFG) are combined with currently used fall risk assessments shows its promising contributing value to a test battery. Hip abductor strength is an easily measurable parameter and should on a daily clinically basis be considered as an important influencing factor of fall risk. However, further research is needed. Future studies should find pragmatic solutions to reliably and validly assess hip abductor strength in a standard clinical setting and assess the validity of hip abductor strength to predict fall risk in longitudinal studies.

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## Author Contributions

All authors contributed to data analysis, drafting or revising the article, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

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## Disclosure

The authors declare no conflicts of interest in this work.

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