



Unraveling physical performance over time in hospitalized older patients with walking limitation: the role of ultrasound-derived vastus lateralis muscle thickness

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Abstract Acute hospitalization is a critical stressor that often leads to functional decline in older patients, highlighting the need for simple markers to identify at-risk individuals. Ultrasound is a feasible bedside tool for muscle mass assessment and has been proposed as a marker of physical function, but its prognostic value remains unclear. This study aimed to explore the association between ultrasound-derived muscle thickness (US-MT) and physical performance over time—gait speed (GS) and 30-s sit-to-stand (30s STS)—and selected clinical outcomes. In this prospective cohort study conducted in a geriatric

department, adults aged ≥ 65 years with admission-related walking limitations were assessed at admission, discharge, 1 month, and 3 months. US-MT of the vastus lateralis was assessed at admission using ultrasonography. Longitudinal associations between US-MT and GS and 30s STS were examined using mixed-effects models. Associations with length of hospital stay (LOS), 3-month falls incidence, and 3-month mortality were examined using regression models. Among 243 participants, GS and 30s STS increased from admission to follow-up. Greater admission US-MT was modestly associated with faster GS in women (0.037 m/s; 95% CI 0.022–0.051) and with better 30s STS performance across sexes (IRR 1.24; 95% CI 1.00–1.53) across all time

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points. US-MT was not associated with trajectories of physical performance or with LOS, falls, or mortality. These findings suggest that admission US-MT may provide complementary bedside information on physical performance level, rather than serving as a standalone marker of recovery or clinical prognosis. ClinicalTrials.gov: NCT05798169

Keywords Ultrasonography · Vastus lateralis · Muscle thickness · Sit-to-stand · Gait speed · Geriatric

Introduction

The global increase in the population of adults aged 65 years and older is accompanied by a rising number of acute medical admissions [1]. Acute hospitalization represents a critical stressor for older adults and is frequently associated with functional decline, particularly among individuals who are already frail or present with pre-hospital impaired mobility, such as walking and sit-to-stand limitations [2, 3]. Notably, more than half of older patients fail to regain their pre-hospital functional level within 1 year following admission [4]. In this context, patients with admission-related walking limitation constitute a clinically relevant subgroup, as they combine acute mobility vulnerability with potential for functional recovery. Early identification of patients at risk of poor recovery is therefore essential to support risk stratification, targeted interventions, and discharge planning [3]. Objective measures of physical performance, such as gait speed (GS) and the 30-s sit-to-stand test (30s STS), are established predictors of functional trajectories and adverse outcomes, including falls and mortality [5]. However, their applicability may be limited in some patients in the acute phase of hospitalization due to the complex interplay of acute illness, multimorbidity, frailty, and cognitive impairment [6, 7]. Muscle mass is another key determinant of function and recovery in older adults [8]. While computed tomography and magnetic resonance imaging are considered gold standards for muscle mass assessment, their routine clinical use is limited by cost, availability, and—particularly for computed tomography—radiation exposure [9]. More accessible alternatives, including dual-energy X-ray absorptiometry and bioelectrical impedance analysis, are constrained by limited availability or susceptibility to fluid-related measurement error, respectively

[9]. In this context, B-mode point-of-care ultrasound has emerged as a promising adjunct for muscle assessment [10]. This technique can be applied at the bedside, including in frail or bedridden patients, and is therefore well suited for use in acute care settings [11, 12]. Beyond estimating muscle mass, ultrasound-derived muscle variables—most commonly assessed as muscle thickness—have been proposed as markers of physical function [13]. Muscle thickness contributes to muscle force [14, 15], and several studies have demonstrated associations between ultrasound-derived muscle thickness (US-MT) and muscle strength [16] as well as physical performance measures, including GS and 30s STS, in community-dwelling older adults [17–20]. Furthermore, emerging evidence suggests that US-MT predicts clinically relevant outcomes, such as functional level, rehospitalization, falls, and mortality, in hospitalized older patients [21–23]. Collectively, these findings suggest that US-MT may reflect aspects of muscle health relevant for functional recovery. However, existing evidence remains limited, particularly with regard to longitudinal outcomes in acutely hospitalized populations [24]. Emerging evidence further suggests potential sex-specific differences in the relationship between US-MT and physical function, although such analyses remain limited [25]. Importantly, it remains unclear whether US-MT reflects the baseline level of physical performance, recovery potential following acute illness, or both. Distinguishing between these constructs is essential when evaluating the clinical utility. Accordingly, the primary aim of this study was to explore whether vastus lateralis (VL) US-MT assessed at hospital admission is associated with physical performance over time, and to distinguish whether these reflect performance levels or recovery trajectories of GS and 30s STS performance from admission to 3-month follow-up in acutely hospitalized older patients. Secondary aims were to examine associations between admission US-MT and length of hospital stay (LOS), 3-month falls incidence, and 3-month mortality.

Methods

Study design and setting

This study was designed as a single-center prospective cohort study and is reported in accordance with

the STROBE guidelines [26]. The study was embedded within the robot-assisted physical training of older patients during acute hospitalization randomized controlled trial (ROBUST RCT), which has been described in detail elsewhere [27]. The present cohort included participants from both the intervention and control arms of the ROBUST trial. Although derived from this parent trial, the current analyses were conducted as an independent study and separately registered at ClinicalTrials.gov (ID: NCT05798169). Data were collected at the Department of Geriatric Medicine, Odense University Hospital, Svendborg Hospital. Patients were admitted with acute illness, and the hospital receives individuals from both urban and rural catchment areas, making its patient population broadly representative of other hospital intake regions in Denmark. From January 5, 2023, to September 12, 2024, admissions were screened for eligibility every day, with screening prioritizing the most recently admitted patients.

Participants

Patients aged ≥ 65 years were eligible for inclusion. Individuals who were fully independent in walking without aids, as well as those who were non-ambulatory prior to hospitalization, were excluded. Accordingly, the cohort represented an intermediate-function subgroup with preserved pre-hospital ambulation and walking limitation at inclusion. Additional exclusion criteria included severe cognitive impairment (e.g., dementia or delirium), terminal illness, or clinical instability (Early Warning Score > 7), recent major surgery or acute fractures of the lower extremities, conditions precluding safe mobilization (e.g., femoral or pelvic metastases, elevated intracranial pressure, extensive pressure ulcers), an admission duration > 48 h at the time of screening, or a body weight > 165 kg.

Data collection

Participants underwent standardized in-person assessments conducted by trained research staff at predefined time points: admission (≤ 48 h), discharge (on the day of discharge), 1-month, and 3-month follow-up. The primary exposure variable, US-MT of the VL, was assessed at admission. Outcome variables were measures of physical performance, with GS as the primary outcome and 30s STS performance

as the secondary outcome, assessed at admission, discharge, 1-month, and 3-month follow-up. Other secondary outcomes included LOS, 3-month falls incidence, and 3-month mortality. Participant characteristics collected at admission included information on sex, age, height, weight, body mass index (BMI), civil status, functional level determined by the Barthel Index (BI), level of C-reactive protein (CRP), Mini-Mental State Examination (MMSE), and primary reason for admission.

Ultrasound-derived muscle thickness

All ultrasound assessments were performed by a single trained operator, a physiotherapist with a Master's degree in sports science, with prior experience in using ultrasound for muscle assessment among acutely hospitalized older patients and publications within the field [28]. Prior to data collection, the operator underwent both theoretical and practical training from an experienced physician (> 1000 scans), who also provided expert support when needed. Examinations adhered to the protocol by Ticinesi et al. [12] and the SARCUS recommendations from Perkisas et al. [11]. A B-mode ultrasound system (GE Venue R2, GE Healthcare, Chicago, IL, USA) equipped with an 8–13 MHz linear probe was used. Participants rested supine with knees extended for approximately 5 min before imaging. Scans were obtained from the distal third of the VL on the self-reported dominant leg. The measurement site was identified by marking 65% of femur length—the distance from the greater trochanter to the tibiofemoral joint line—and aligning this mark with the distal edge of the probe to ensure perpendicular placement along the VL mid-sagittal plane. Rich amounts of gel were applied, and minimal pressure was used. Three longitudinal images were captured, with full probe repositioning between acquisitions. Images were pseudo-anonymized and stored securely for later offline analysis. All analyses were conducted by the same examiner at least 3 months after data collection to reduce bias. US-MT was quantified in NIH ImageJ (version 1.42q) as the distance between the superficial and deep aponeuroses at mid-image, measured perpendicular to the deep aponeurosis. The mean of the three measurements was used for analysis. Intra-rater reliability for US-MT measurements was assessed and was excellent (ICC = 0.94).

Outcome measurements

Physical performance

GS was measured using the 4-m gait speed test [29]. In cases where the 4-m course was not feasible because of limited space, such as patient isolation due to infectious disease or restricted space in participants' homes, a 3-m version was allowed to maximize feasibility and reduce missing data. This pragmatic adaptation was considered acceptable because GS measured over very short distances, including 2.45 m, has been shown to correlate closely with GS measured over longer distances of 6–10 m [30]. Briefly, a 4- or 3-m walkway was marked with clear start and finish lines. Participants were instructed to walk at their usual, self-selected pace, starting from a static position behind the start line and beginning on the verbal cue "Ready–Set–Go." Timing started when the first foot crossed the start line and stopped once the first foot fully crossed the finish line. The examiner walked close by for safety, and walking aids were permitted if needed. Two trials were performed, and the fastest speed (m/s) was used for analysis. Participants unable to walk unassisted at the assessment time were assigned a GS of 0 m/s. This coding was used to distinguish inability to walk from missing data. The examiner made every effort to ensure that participants used the same walking aid across time points. In cases where this was not possible, the corresponding assessments were excluded from subsequent analyses. Lower-extremity performance was measured using the 30s STS [31]. A standard chair (seat height 43 cm) was placed against a wall. Participants sat centered on the seat with their back straight, feet flat, and arms crossed. Following a demonstration by the examiner, participants were instructed to stand up and sit down as many times as possible within 30 s, without using their hands. Verbal encouragement was given. A repetition was counted only when full hip extension was achieved. A digital stopwatch was used for timekeeping. The total number of completed repetitions was recorded for analysis.

Clinical outcomes

LOS was calculated as the number of calendar days between admission and discharge, based on electronic medical records. For participants who died during

hospitalization, the recorded date of death replaced the discharge date to reflect the actual LOS. Three-month fall incidence from hospital admission to 3-month follow-up was self-reported and categorized as 0, 1, or > 1 fall [32]. A fall was defined as "an event in which a person inadvertently comes to rest on the ground, floor or another lower surface" [33]. Three-month mortality was defined as a binary outcome (dead/alive) based on registered dates of death within 90 days from hospital admission. Participants who were alive at 3 months were classified as survivors.

Statistical analysis

Participant characteristics at admission were summarized stratified by sex using means and standard deviations (SD) or medians and interquartile ranges (IQR), as appropriate, while categorical variables were presented as counts and percentages. Between-sex differences were assessed using two-sample *t*-tests or Mann–Whitney *U*-tests for continuous variables and Pearson's χ^2 tests for categorical variables. Longitudinal associations between admission US-MT and GS and 30s STS from admission to 3-month follow-up were examined using mixed-effects regression models under a missing-at-random assumption [34]. GS, treated as a continuous approximately normally distributed outcome, was analyzed using linear mixed-effects models, whereas 30s STS, representing count data with excess zero values, was analyzed using mixed-effects negative binomial models. Both models included random intercepts and random slopes for time, with time specified as a categorical fixed effect. Potential effect modification by time and sex was assessed by including time $\times$ US-MT and sex $\times$ US-MT interaction terms, which were evaluated using likelihood ratio tests. Only statistically significant interaction terms were retained in the final models. Adjusted analyses included age, BMI, and RCT arm. For GS, regression coefficients (β) represent absolute changes in m/s per 1-mm higher US-MT. For 30s STS, results are presented as incidence rate ratios (IRRs) per 1-mm higher US-MT. Model assumptions were evaluated using residual diagnostics, including histograms and Q–Q plots of residuals and random effects. Secondary outcomes were analyzed using Cox proportional hazards regression for LOS, ordinal logistic regression for 3-month falls, and logistic regression for 3-month mortality.

These analyses were restricted to complete cases and adjusted for age, sex, BMI, and RCT arm. For GS, a sensitivity analysis excluding observations coded as 0 m/s was conducted to examine the influence of potential floor effects. To assess potential bias due to missing follow-up data, baseline characteristics were compared between participants with and without follow-up assessments. No a priori sample size calculation was performed, as the analyses were based on the available cohort from a randomized controlled trial. Statistical significance was defined as $p < 0.05$. All analyses were conducted using Stata (version 18.5; StataCorp LLC, College Station, TX, USA).

Results

Participant characteristics

A flowchart of participant inclusion is shown in Fig. 1. Of 2250 screened admissions, 668 patients were eligible, and 464 were included. Of these, 243 participants had admission US-MT and GS available

and were included in the longitudinal analyses. Missing admission ultrasound data primarily reflected the limited availability of the trained ultrasound operator during ward admissions. The availability of GS measurements declined over time, primarily due to withdrawal of participation, logistical constraints, and death, with 193 participants assessed at discharge, 107 at 1-month follow-up, and 55 at 3-month follow-up. Data availability for all secondary outcomes, including 30 s STS, is provided in Supplementary Table 1.

Participant characteristics at admission are presented in Table 1. The most common primary admission categories were respiratory disease (20.2%), musculoskeletal/fall/fracture/pain-related conditions (16.5%), and urinary/renal/urogenital conditions (13.6%). A full overview of descriptively grouped primary admission categories is provided in Supplementary Table 2. The cohort comprised 243 participants, of whom 110 (45.7%) were women. The mean age was 84.0 ± 6.1 years. Median GS and 30 s STS were 0.49 m/s (IQR 0.34–0.62) and 0 repetitions (IQR 0–4), respectively. Median BI score was

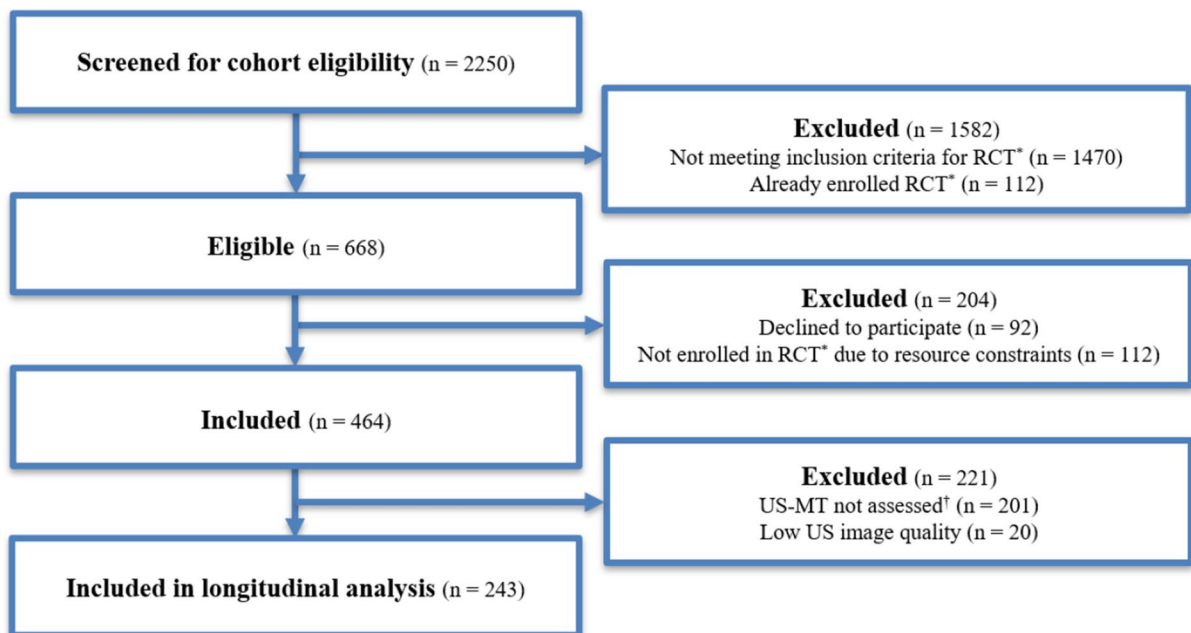


Fig. 1 Flow of participants and availability of gait speed measurements. Notes: Mixed-effects models included all participants with admission ultrasound-derived muscle thickness (US-MT) and gait speed (GS) data ($n = 243$), irrespective of

follow-up completeness. The number of available GS assessments was 243 at admission, 193 at discharge, 107 at 1-month follow-up, and 55 at 3-month follow-up. *ROBUST RCT. †Not enrolled due to ultrasound operator unavailability

Table 1 Participant characteristics and measurement data at admission stratified by sex

Notes: *BI*, Barthel Index; *BMI*, body mass index; *CRP*, C-reactive protein; *GS*, gait speed; *MMSE*, Mini-Mental State Examination; *30 s STS*, 30-s sit-to-stand; *US-MT*, ultrasound-derived muscle thickness. Data are presented as mean $\pm$ standard deviation (SD), median with interquartile range (IQR), or *n* (%). *p*-values represent between-sex comparisons (**p* < 0.05, ***p* < 0.01)

Characteristic	Total	Women	Men
Sex, <i>n</i> (%)	243 (100.0)	110 (45.3)	133 (54.7)
Age (yrs)	84.0 (6.1)	84.8 (6.2)	83.4 (6.0)
Height (cm)	169.3 (8.7)	162.3 (5.6)	175.0 (6.4) **
Weight (kg)	68.4 [59.1–79.0]	63.4 [54.1–70.0]	74.8 [66.1–81.5] **
BMI (kg/m ²)	23.9 [21.5–26.6]	23.2 [20.9–26.9]	24.1 [21.9–26.5]
Civil status, <i>n</i> (%)			
- Living alone	150 (61.7)	84 (76.4) **	66 (49.6)
- Married/cohabiting	93 (38.3)	26 (23.6)	67 (50.4) **
MMSE (0–30)	23 [20–26]	22 [20–26]	24 [20–27]
CRP (mg/L)	68.0 [19–137]	66.5 [16–130]	68.0 [27–137]
BI (0–100)	71 [55–85]	75 [59–86]	67 [54–81] *
US-MT (mm)	16.5 (3.0)	15.0 (2.4)	17.8 (2.8) **
GS (m/s)	0.49 [0.34–0.62]	0.49 [0.35–0.61]	0.49 [0.35–0.63]
30 s STS, (repetitions)	0 [0–4]	0 [0–5]	0 [0–5]

Table 2 Length of hospital stay, falls incidence, and mortality

Outcome	Value
LOS (days)	5 [3–7]
3-month fall incidence	
0 falls	58 (66.0)
1 fall	15 (17.0)
>1 fall	15 (17.0)
3-month mortality	28 (11.5)

Notes: *LOS*, length of hospital stay. Data are presented as median [IQR] or *n* (%). Falls incidence is based on participants with available 3-month follow-up data (*n* = 88); mortality is based on all participants (*n* = 243)

71 (IQR 55–85), and women had higher BI scores than men (*p* < 0.05). Mean US-MT was 16.5 ± 3.0 mm overall and was higher in men than in women (*p* < 0.05). Clinical outcomes for the total cohort are presented in Table 2.

Associations between admission muscle thickness and physical performance over time

Admission US-MT was associated with GS across the follow-up period. Table 3 summarizes the associations between admission US-MT and GS over time. Compared with admission, adjusted mean GS was higher at discharge, at 1-month, and at 3-month follow-up (*p* < 0.001), indicating overall improvement during and after hospitalization. There was no evidence that the pattern of improvement over time

differed between women and men. The association between admission US-MT and GS appeared to differ by sex. In women, each 1-mm higher US-MT was associated with a 0.037 m/s higher adjusted GS (*p* < 0.001), whereas no statistically significant association was observed in men (0.011 m/s, *p* = 0.121). There was no indication that the association between US-MT and GS varied across time points, indicating that admission US-MT was related to performance level rather than to recovery trajectories. Adjustment for age, BMI, and RCT arm did not materially alter these findings. Sensitivity analyses are reported in “[Sensitivity analysis](#).” The fully adjusted GS model is presented in Supplementary Table 3. Figure 2 illustrates these findings, showing a clearer separation between US-MT levels in women than in men, in line with the statistically significant association observed only in women.

Admission US-MT was positively associated with 30 s STS performance across the follow-up period. Table 4 summarizes the associations between admission US-MT and 30 s STS performance over time. The expected number of 30 s STS repetitions increased over time in both women and men. Compared with admission, the adjusted mean rate of repetitions was higher at discharge, at 1-month, and at 3-month follow-up (all *p* < 0.001), indicating substantial functional improvement during and after hospitalization. Each 1-mm higher admission US-MT was associated with a 24% higher expected number of repetitions (IRR = 1.24, 95% CI 1.00–1.53, *p* = 0.049).

Fig. 2 Model-based gait speed trajectories by sex and admission ultrasound-derived muscle thickness. Notes: Model-estimated (marginal predicted) gait speed trajectories from admission to 3-month follow-up in women and men, stratified by admission ultrasound-derived vastus lateralis muscle thickness (US-MT). Solid lines represent marginal predicted values and dashed lines 95% confidence intervals. Low, median, and high US-MT correspond to the 10th, 50th, and 90th percentiles of the overall sample distribution. Models are adjusted for age, BMI, and RCT arm

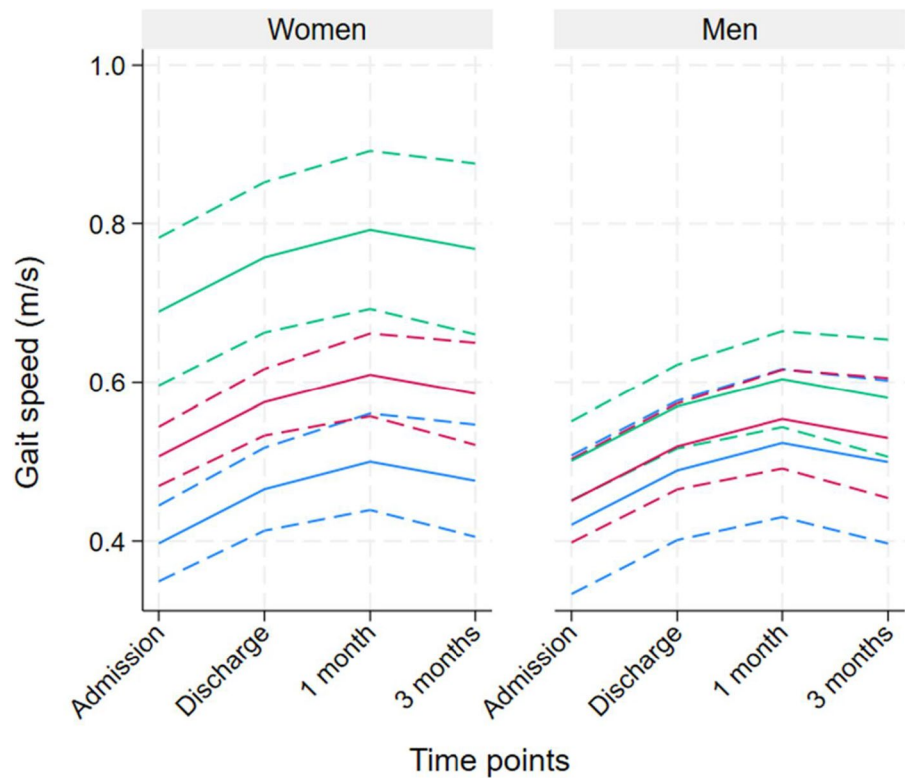


Table 3 Association between admission ultrasound-derived muscle thickness and gait speed over time

Predictor	β (m/s)	95% CI	p-value
Time points (reference: admission)			
Discharge vs admission	0.069	0.044–0.093	< 0.001
1 month vs admission	0.103	0.061–0.144	< 0.001
3 months vs admission	0.079	0.024–0.134	0.005
US-MT (per 1 mm increase)			
Women	0.037	0.022–0.051	< 0.001
US-MT $\times$ men (interaction)	–0.026	–0.043––0.007	0.021

Notes: ^aAdmission is the reference time. ^bUS-MT, ultrasound-derived vastus lateralis muscle thickness at admission. β , regression coefficient; CI, confidence interval. Models adjusted for age, BMI, and RCT arm. The effect of US-MT in men is given by the sum of the main effect and the interaction term. Participants included ($n = 243$)

There was no evidence of sex-specific differences in overall 30s STS performance or in the association between US-MT and 30s STS performance. No

Table 4 Association between admission ultrasound-derived muscle thickness and 30-second sit-to-stand performance over time

Predictor	IRR	95% CI	p-value
Time point (reference: admission)			
Discharge vs admission	2.55	1.79–3.65	< 0.001
1 month vs admission	6.55	3.34–12.91	< 0.001
3 months vs admission	9.22	3.65–25.87	< 0.001
US-MT (per 1 mm increase)	1.24	1.00–1.53	0.049

Notes: Admission is the reference time point. US-MT, ultrasound-derived vastus lateralis muscle thickness assessed at admission; IRR, incidence rate ratio; CI, confidence interval. Models adjusted for age, BMI, and RCT arm. Participants included ($n = 240$)

interaction between US-MT and time was observed, indicating that admission US-MT was related to performance level rather than to recovery trajectories. Adjustment for age, BMI, and RCT arm did not materially alter these findings. The fully adjusted 30s STS model is presented in Supplementary Table 4.

Association between muscle thickness and clinical outcomes

Admission US-MT was not associated with LOS (HR 1.01, 95% CI 0.95–1.06; $p=0.821$), 3-month falls (OR 0.93, 95% CI 0.75–1.15; $p=0.50$), or 3-month mortality (OR 0.94, 95% CI 0.80–1.10; $p=0.441$).

Sensitivity analysis

Sensitivity analyses comparing admission characteristics between participants with and without follow-up data are presented in Supplementary Table 5. Baseline characteristics were largely comparable across groups, with the only difference observed at 3 months, where participants with missing data had slightly lower BMI ($p<0.05$). Excluding 0 m/s observations did not materially alter the interpretation of the GS findings.

Discussion

This study explored the associations between US-MT of VL at hospital admission and levels and trajectories of physical performance over time, as well as selected short-term clinical outcomes, in acutely hospitalized older patients with admission-related walking limitation. We found that US-MT was associated with GS in women, but not in men, and with 30s STS performance across sexes. Importantly, US-MT was not associated with recovery trajectories over time but instead reflected differences in physical performance level that persisted across the recovery period. No associations were identified between US-MT and clinical outcomes including LOS, 3-month falls incidence, and 3-month mortality.

Principal findings and interpretation

The association between US-MT and GS requires careful interpretation. Among women, greater US-MT was associated with faster GS, but the effect was modest: each 1-mm increase in US-MT corresponded to a 0.037 m/s higher GS. In men, the effect was smaller (0.011 m/s per 1 mm) and not statistically significant. Both estimates fall below commonly suggested thresholds for clinically meaningful changes in GS (≈ 0.1 m/s)[29]. This indicates that

although US-MT may reflect aspects of lower-limb muscle size relevant to walking, its standalone association with GS is limited in magnitude. A similar pattern was observed for 30s STS performance, where greater US-MT was associated with a 24% increase in the number of repetitions, with no evidence of sex-specific differences. However, the wide confidence intervals indicate limited precision, suggesting that the strength of this association should be interpreted with caution. Importantly, no interaction between US-MT and time was observed for either GS or 30s STS. This suggests that baseline US-MT was associated with physical performance level, but not with the trajectory of recovery. The observed improvement in GS and 30s STS from admission to follow-up is clinically plausible, as admission assessments were performed during the acute phase of illness, when mobility may have been transiently reduced by symptoms, inflammation, fatigue, bed rest, or treatment-related factors. Later assessments may therefore reflect partial recovery toward pre-hospital functional capacity. These findings should be interpreted in the context of the inherently multifactorial nature of GS and STS. Both outcomes depend on a complex interplay of physiological and contextual factors, including balance, coordination, motivation, fear of falling, pain, cognitive function, chronic disease burden, and the severity of acute illness. In acutely hospitalized older adults, these factors may overshadow the contribution of muscle morphology to objectively measured physical performance. This may explain why US-MT demonstrated only modest associations with GS and STS, despite its biomechanical relevance. This interpretation is consistent with previous literature showing that US-MT is more strongly associated with direct measures of muscle strength and power than with performance-based outcomes. Several studies have demonstrated consistent associations between quadriceps muscle thickness and knee extension strength in healthy populations [17, 18, 35]. Similarly, Yuan et al. reported that US-MT correlates more strongly with strength and power than with GS and STS and found weak associations with these performance-based outcomes, closely aligning with the present findings [36]. Nevertheless, GS and STS remain clinically relevant, ecologically valid measures of functional capacity, and even modest associations with US-MT may therefore hold clinical value.

Sex-specific findings

The observed sex-specific association between US-MT and GS warrants further consideration. In the present study, US-MT was associated with GS in women but not in men. This finding aligns with recent work by Yuan et al., who also reported sex-specific associations between US-MT and measures of muscle strength and physical performance in older adults [25]. While biological explanations may contribute, including differences in muscle mass distribution and muscle quality, the findings may also reflect differences in baseline functional status between men and women in the current study cohort.

Functional performance in acutely hospitalized older adults is influenced not only by muscle morphology but also by broader factors such as frailty, comorbidity, and functional independence. Differences in these domains between sexes may influence the extent to which muscle thickness contributes to observable performance. In this context, muscle thickness may play a relatively larger role in determining performance in individuals with lower overall functional reserve, which could partly explain the stronger association between US-MT and GS observed in women. These findings indicate that it could be important to consider sex-specific mechanisms when interpreting muscle morphology-function relationships in heterogeneous clinical populations.

Clinical outcomes and implications

The finding that admission US-MT was not associated with any of the clinical outcomes suggests that a one-dimensional measure of local muscle size (e.g., muscle thickness) does not adequately capture the multifactorial nature of these outcomes. Importantly, these null findings should not be interpreted as evidence that muscle size more broadly is unrelated to clinical outcomes. Muscle thickness was selected as a clinically feasible one-dimensional measure, whereas cross-sectional area and muscle volume may better capture muscle size but are more technically demanding and may be limited by the transducer field of view. Furthermore, LOS is influenced by the acute medical course, discharge planning, social circumstances, and organizational factors, which may attenuate associations. Although rectus femoris muscle thickness has previously been

associated with LOS in more homogeneous cohorts [37], such relationships may be less apparent in heterogeneous acutely ill older patients. Falls and mortality are driven by factors beyond local muscle morphology, and the clinical outcome analyses were limited by a few observations and events, particularly for falls and 3-month mortality. The absence of statistically significant associations should therefore be interpreted as inconclusive rather than as evidence of no prognostic relevance. Overall, our findings suggest that admission to US-MT alone has limited prognostic utility for clinical outcomes in the acute care of older patients.

Strengths and limitations

This study has several strengths. It included a relatively large and well-characterized cohort of acutely hospitalized older patients. Ultrasound assessments were performed using a standardized and previously validated protocol by a single experienced operator, supported by excellent intra-rater reliability. Functional outcomes were assessed using consistent procedures by trained clinicians, thereby minimizing measurement error. The focus on the vastus lateralis (VL) muscle—a muscle central to functional tasks such as walking and sit-to-stand—enhances the clinical relevance of the findings. Furthermore, the prospective design with repeated assessments enabled longitudinal evaluation, and the use of mixed-effects modeling allowed inclusion of all available data while appropriately accounting for incomplete follow-up.

Several limitations should also be considered. First, US-MT represents a relatively narrow, one-dimensional measure of local muscle size and does not capture cross-sectional area, whole-muscle volume, or qualitative aspects of muscle composition. Although muscle thickness is clinically feasible, cross-sectional area and muscle volume may provide more robust indicators of muscle size. Moreover, US-MT was assessed only at admission and therefore does not describe changes during hospitalization or the following recovery period. Second, the assessment was limited to the VL muscle, which may restrict generalizability to other muscle groups. Third, attrition at later follow-up time points reduced the precision of the estimates, although sensitivity analyses suggested limited evidence of systematic

bias. Regarding GS measurement, although the 4-m GS test was the standard protocol, a 3-m version was used when the standard course was not feasible. Despite strong correlations between short- and longer-distance GS tests, this pragmatic adaptation may have introduced measurement variability. In addition, assigning 0 m/s to participants unable to walk may have introduced a floor effect, although sensitivity analyses excluding these observations did not materially alter the findings. Fourth, the cohort represents a relatively frail and heterogeneous subgroup of older patients, which may limit generalizability to healthier and more homogeneous populations. Nevertheless, the cohort broadly resembles the Danish geriatric inpatient population described previously [38]. Fifth, residual confounding from unmeasured factors cannot be excluded. Sixth, the observational nature of the analyses precludes causal inference, and the modest effect sizes warrant cautious interpretation. In addition, the study was not specifically powered for the present exploratory clinical outcome analyses, and the limited number of available observations and events—particularly for falls and 3-month mortality—reduced statistical precision and increased the risk of type II error. The absence of a formal comorbidity index (e.g., Charlson Comorbidity Index) further limits the ability to fully account for illness burden. Several participants were admitted with conditions in which altered hydration may occur. This is particularly relevant because conditions associated with altered hydration or fluid shifts may have influenced both US-MT and the outcomes. Edema or fluid shifts may affect apparent muscle thickness independently of contractile tissue, whereas dehydration, cardiovascular or renal dysfunction, and electrolyte disturbances may affect physical performance and clinical outcomes. Thus, residual confounding and measurement influence related to fluid status cannot be ruled out. Finally, embedding the study within an RCT introduces potential selection bias, as patients with severe dementia, pre-hospital non-ambulatory status, and fully independent walking at inclusion were excluded. Selection bias may also have occurred because ultrasound assessment depended on the availability of a single trained operator, which was chosen to minimize between-operator variation but limited continuous assessment of all enrolled patients. Although primarily logistical, this may have contributed to the selection of participants who were easier

to assess. Furthermore, patients unable to tolerate ultrasound acquisition or complete gait speed testing may represent a frailer subgroup with greater illness burden and poorer outcomes. The analytical cohort may therefore have been relatively healthier than the broader target population, limiting generalizability. Substantial attrition at 1- and 3-month follow-up further reduced precision and may limit the generalizability of the longitudinal estimates.

Future directions

Future studies should adopt multidimensional ultrasound protocols including measures such as cross-sectional area, muscle volume, echo intensity, shear-wave elastography, and measures more closely related to muscle strength and power. These may provide a more complete characterization of muscle health and improve the prediction of functional and clinical outcomes. Integrating ultrasound data with assessments of strength, cognition, functional status, and inflammatory markers may improve characterization of functional status and recovery potential in acute care. Studies with extended follow-up could clarify the longer-term implications for clinical outcomes such as LOS, falls, and mortality.

Conclusion

Overall, in acutely hospitalized older patients with admission-related walking limitation, admission US-MT was associated with the level of subsequent physical performance over time—GS in women and 30s STS performance in both sexes—while showing no association with recovery trajectories or short-term clinical outcomes. Admission US-MT in this cohort therefore reflects attainable physical performance level rather than recovery rate or risk of adverse clinical outcomes. Admission US-MT may provide complementary information on muscle-related functional status, particularly when performance-based assessments are difficult to perform. However, given the modest effect sizes and absence of associations with recovery trajectories or clinical outcomes, US-MT should not be interpreted as a standalone marker of recovery potential or risk stratification in acute geriatric care.

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Author contribution Jeppe Grabov Phillip: conceptualization, methodology, funding acquisition, investigation, resources, data curation, project administration, formal analysis, writing—original draft. Hjalti Rúnar Oddsson: review and editing. Tahir Masud, Jesper Ryg, and Charlotte Suetta: supervision, funding acquisition, review and editing. Lisbeth Rosenbek Minet: conceptualization, methodology, funding acquisition, supervision, review and editing. All authors approved the final version before submission.

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Data availability The data that support the findings of this study are available upon reasonable request to jeppe.grabov.phillip@rsyd.dk.

Declarations

Ethics approval and consent to participate The ROBUST trial received ethical approval from the Regional Scientific Ethical Committee of Southern Denmark (Project-ID: S-20210029). All participants provided written informed consent. The present analyses were conducted using data collected within this ethically approved study.

Conflict of interest The authors declare no competing interests.

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