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ORIGINAL RESEARCH

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Baseline Nutritional Status and In-Hospital Step Count are Associated with Muscle Quantity, Quality, and Function: Results of an Exploratory Study

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ABSTRACT

This exploratory study aimed to assess associations of baseline nutritional status and in-hospital step count with muscle quantity, quality, and function. Seventy-nine participants aged $\geq$70 years (mean age 79.1 years, 44.3% female) were recruited (elective colorectal surgery, emergency abdominal surgery, and general medical patients with infections). Baseline nutrition (Mini Nutritional Assessment) and in-hospital step count (Fitbit Inspire devices) were assessed. Ultrasound quadriceps, bioelectrical impedance analysis, and physical function were assessed at baseline and 7 ($\pm$2) days and 13 ($\pm$1) weeks post-admission/post-operatively. Baseline nutritional status was associated with baseline rectus femoris ultrasound echogenicity (normal: 58.5, at risk: 68.5, malnourished: 81.2; $p = 0.025$), bilateral anterior thigh thickness (normal: 5.07 cm, at risk: 4.03 cm, malnourished: 3.05 cm; $p = 0.021$), and skeletal muscle mass (Sergi equation) (normal: 21.6 kg, at risk: 18.2 kg, malnourished: 12.0 kg; $p = 0.007$). Step count was associated with baseline patient-reported physical function (<900 37.1, $\geq$900 44.5; $p = 0.010$). There was a significant interaction between nutrition, step count, and time for skeletal muscle mass (Janssen equation) ($p = 0.022$).

KEYWORDS
Sarcopenia; accelerometry; ultrasound

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Background

Acute sarcopenia (acute muscle insufficiency) is defined by the development of incident sarcopenia (low muscle strength with low muscle quantity and/or quality) within six months, normally following a stressor event.[1–3] It is increasingly recognized as a target for therapeutic trials.[4] Acute sarcopenia may lead on to the development of chronic sarcopenia over time,[1] which is known to impact upon quality of life.[5] Trials that demonstrate benefit in ameliorating negative changes in muscle quantity and function during hospitalization, therefore, have potential to improve quality of life of older adults following hospitalization in the longer-term. Interventions that have been previously trialed include physical activity, nutritional, neuromuscular electrical stimulation, and pharmaceutical (testosterone, nandrolone, erythropoietin).[4] A previous multi-center cohort study showed that patients at greatest risk of acute sarcopenia were those who were already vulnerable, but not yet fully dependent (i.e. living at home and mobile but with some dependency on others for help with daily tasks).[6] Mean step count over up to three consecutive days during hospitalization has previously been shown to be associated with functional decline from premorbid function (two weeks prior to hospitalization) to discharge, controlling for baseline functional status.[7] Physical activity measured by accelerometry has also been shown to be associated with severity of acute illness during hospitalization.[8] However, the benefits of physical activity upon skeletal muscle can be blunted when nutrition, particularly protein intake, is inadequate.[9] Interventional strategies where exercise has been combined with inadequate protein intake have proven ineffective in preventing muscle quantity loss in critical illness.[10] The interactions of the effects of nutrition and step count with dynamic changes in skeletal muscle in hospitalized older adults have not previously been characterized. This study aimed to assess the associations between in-hospital step count and baseline nutritional status with muscle quantity, quality, and function measurements.

Methods

Study design and setting

The protocol for the main study has been published previously[11] and the study was prospectively registered (NCT03858192). This exploratory study represents a *post hoc* analysis of the main study. Results from the main study have been published elsewhere.[12,13] Participants were recruited from a single center, the Queen Elizabeth Hospital Birmingham. Three groups of participants aged 70 years and older were recruited: patients expected to

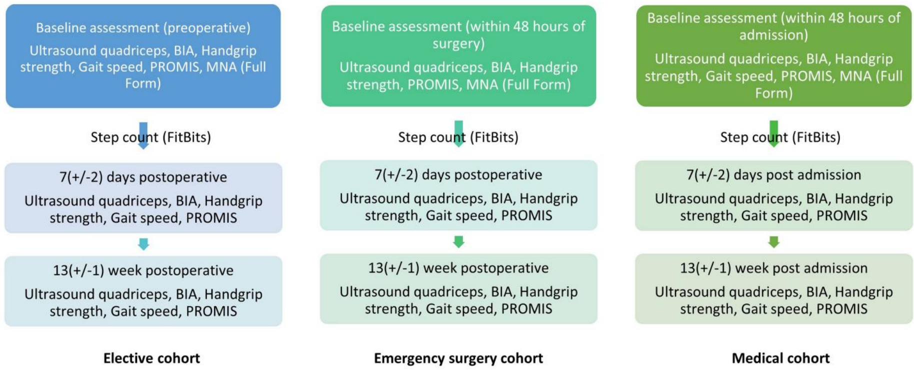

Figure 1. Study schema showing timing of assessments performed at each timepoint in study.

undergo elective colorectal surgery, patients who had undergone emergency abdominal surgery, and general medical patients with acute infectious diseases. Participants were excluded if they were considered to be imminently approaching the end of life, or if they were unable to understand verbal or written English. Ethical approval was obtained from Wales Research Ethics Committee 4. Participants provided written informed consent or consultee declaration was obtained if they were deemed to lack capacity to consent for themselves. Baseline assessments were performed in preoperative assessment clinic in the elective cohort, within 48 hours of surgery in the emergency surgery cohort, and within 48 hours of admission in the medical cohort. Further assessments were performed at 7 (±2) days post-operatively/post-admission, and 13 (±1) weeks post-operatively/post-admission. Figure 1 demonstrates the timing of the assessments relevant to this analysis that were performed at each timepoint. If participants were discharged home prior to assessment at 7 (±2) days, then the investigator contacted the participant to arrange to review them in their own home within the same timeframe. Recruitment and assessments were performed by a clinician with training and expertise in geriatric medicine.

Muscle quantity and quality assessment

Muscle quantity and quality were assessed at each timepoint using quadriceps ultrasound and bioelectrical impedance analysis (BIA).[11] Bilateral anterior thigh thickness (BATT) was calculated as the total thickness of the right and left rectus femoris and vastus intermedius muscles, measured at the midpoint between the greater trochanter and lateral joint line in the transverse plane using a linear probe (Venue 50, GE Healthcare).[14] Rectus femoris echogenicity was measured using longitudinal images taken at the same location by grey scale analysis using Image J software.[14] Skeletal muscle mass (SMM) was calculated from BIA measurements (Bodystat Quadscan 4000) using two previously validated equations: SMMJanssen[15] and SMMSergi[16] (Table S1, Supplement). Both equations were used in wider analysis and it was unknown which would demonstrate the greatest sensitivity to change and associations with outcomes in this exploratory study.

Physical function assessment

Handgrip strength was measured at each timepoint using a Jamar dynamometer. Participants were advised to squeeze as hard as they were able to, and the best result from two measures on each side was used in analysis.[17] Usual gait speed was measured at each timepoint across a four meter course, by advising participants to walk at a "comfortable pace,"[18] except for emergency surgery patients at baseline assessment, where this was not possible. Patient-reported physical function was assessed using the Patient-Reported Outcomes Measurements Information System (PROMIS®) item bank V2.0 Physical Function Short Form 10b questionnaire at each timepoint.[19] Raw scores were entered into the HealthMeasures Scoring Service, powered by Assessment Center℠ to derive *T*-scores.

Nutritional assessment

Baseline nutritional assessment was performed using the Mini Nutritional Assessment (Full Form) (MNA).[20] Participants were categorized as normal (24–30 points), at risk of malnutrition (17–23.5 points), or malnourished (less than 17 points).

Step count

Step count was measured during the inpatient stay from initial post-operative/post-admission assessment to 7 (±2) days post-operatively using Fitbit Inspire devices worn on the non-dominant wrist. This was included as an optional aspect of the study. Mean daily step count was calculated from days where whole day data was available (i.e. excluding the days that the device was applied or removed for data extraction). Participants were advised to wear the device all the time but were able to remove the device when washing or sleeping for comfort. Participants were categorized as having <900 or ≥ 900 steps/day as per previously validated cutoffs for functional decline.[7]

Frailty assessment

Frailty was assessed at each timepoint using both a frailty index[21] and Clinical Frailty Scale (CFS).[22] The variables included within the frailty index were adapted from those previously validated within the electronic Frailty Index (eFI), which was developed from a UK community population.[23] The CFS was assessed by a clinician with expertise in geriatric medicine, based on function two weeks prior to admission. All information from a full comprehensive assessment including Katz[24] and Lawton[25] Activities of Daily Living (ADLs) were used when assessing the CFS.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics Version 26 (IBM Corp). This study represents a substudy of the main study. The study was initially powered to enable detection of clinically significant differences in muscle and physical function measurements within groups (45 to follow-up in each group). In light of recruitment to the study being paused during the Coronavirus 2019 (COVID-19) pandemic, the recruitment target was revised to enable detection of differences across groups (45 to follow-up across groups). Descriptive statistics were summarized at baseline according to categories of nutrition and step count. Statistical significance of differences were analyzed using analysis of variance (nutrition) or independent samples *t*-tests (step count) for parametric continuous variables, Kruskal–Wallis (nutrition) or Mann–Whitney *U* tests (step count) for non-parametric continuous or ordinal variables, and chi-squared tests for proportions. Statistical significance of differences in muscle quantity, quality, and physical function measurements between nutrition and step count groups, and between timepoints were analyzed using linear mixed models (parametric variables) or generalized linear mixed models (non-parametric variables). Interaction terms for nutrition × timepoint, step count × timepoint, and nutrition × step count × timepoint were included within the models. Estimated marginal means across timepoints and groups were calculated from these models. Statistical significance was set at $p < 0.050$.

Results

Eighty-one participants were recruited to this study. Two participants were excluded from this analysis (one elective admission in the emergency surgery cohort and one emergency surgery participant did not undergo surgery). Recruitment and drop-out rates are shown in Figure S1 (Supplement). Full feasibility analysis and screening and recruitment rates have been published previously.[26] Fitbit data were collected for 51.5% (35/68) of participants across all groups, with no significant difference between groups. Baseline nutritional status was assessed in all participants. Baseline characteristics are shown in Table 1. The mean age of participants was 79.1

Table 1. Baseline characteristics of participants separated by nutritional status and step count.

			Nutrition				Step count		
		Overall ($N = 79$)	Normal ($N = 33$)	At risk ($N = 40$)	Malnourished ($N = 6$)	p Value	<900/day ($N = 20$)	≥900/day ($N = 15$)	p Value
Age (years)—mean (SD)		79.1 (6.6)	77.6 (6.4)	80.7 (7.0)	77.7 (2.7)	0.114	79.7 (7.8)	75.9 (4.2)	0.098
Sex—% females (*N*)		44.3% (35)	42.4% (14)	42.5% (17)	66.7% (4)	0.518	50.0% (10)	40.0% (6)	0.557
Ethnicity—% (*N*)	White British	93.7% (74)	97.0% (32)	92.5% (37)	83.3% (5)	0.336	90.0% (18)	93.3% (14)	0.416
	White Irish	2.5% (2)	0% (0)	2.5% (1)	16.7% (1)		0% (0)	6.7% (1)	
	Indian	2.5% (2)	3.0% (1)	2.5% (1)	0% (0)		5% (1)	0% (0)	
	Arab	1.3% (1)	0% (0)	2.5% (1)	0% (0)		5% (1)	0% (0)	
Group—% (*N*)	Elective surgery	30.4% (24)	54.5% (18)	15.0% (5)	0% (0)	0.001*	30.0% (6)	40.0% (6)	0.826
	Emergency surgery	17.7% (14)	15.2% (5)	22.5% (9)	0% (0)		15.0% (3)	13.3% (2)	
	Medical	51.9% (41)	30.3% (10)	62.5% (25)	100%		55.0% (11)	46.7% (7)	
Body mass index (kg/m^2)—mean (SD)		26.5 (6.5)	28.4 (5.2)	25.8 (7.2)	20.4 (2.7)	0.010*	26.0 (7.8)	26.9 (5.2)	0.715
Baseline nutrition—% (*N*)	Normal	37.1% (13)	100% (33)	0% (0)	0% (0)	NA	30.0% (6)	46.7% (7)	0.135
	At risk	51.4% (18)	0% (0)	100% (40)	0% (0)		65.0% (13)	33.3% (5)	
	Malnourished	11.4% (4)	0% (0)	0% (0)	100% (6)		5.0% (1)	20.0% (3)	
Step count	Median (IQR)	708 (250–1,690)	1,028 (386–2,366)	491 (180–951)	2,023 (735–4,454)	0.072	338 (95–642)	1,812 (1,232–2,792)	<0.001
	<900—% (*N*)	57.1% (20)	46.2% (6)	72.2% (13)	25.0% (1)	0.135	100% (0)	0% (0)	NA
	≥900—% (*N*)	42.9% (15)	53.8% (7)	27.8% (5)	75.0% (3)		0% (0)	100% (0)	
Baseline frailty index—mean (SD)		0.27 (0.11)	0.22 (0.10)	0.31 (0.11)	0.33 (0.05)	0.001*	0.29 (0.10)	0.26 (0.11)	0.491
Baseline CFS—median (IQR)		4 (3–5)	3 (2.5–3)	4.5 (4–5)	4.5 (3.75–5.25)	<0.001*	5 (3–5)	3 (3–4)	0.006*
C-reactive protein (48 hours post-surgery or admission)—median (IQR)		109 (75.75–181.25)	100 (70–151.5)	113 (78–194)	177.5 (94.25–248.75)	0.234	91 (76–145)	100 (65–163)	0.849

*Statistical significance at $p < 0.05$ level.

(6.6), and 44.3% were female. There were no significant differences between nutrition and step count groups in terms of age, sex, or ethnicity of participants. However, a greater proportion of at risk or malnourished participants were medical patients and had greater frailty indices and CFS compared to those with normal nutrition. Participants with lower step counts also had higher CFS at baseline.

Muscle quantity and quality

Table 2 demonstrates results of mixed models with estimated marginal means derived from interaction terms with timepoint. These results are shown graphically for muscle quantity and quality in Figure 2. Participants with greater risk of malnutrition had significantly lower BATT, SMMSergi, and SMMJanssen, and higher echogenicity across timepoints. Differences were statistically significant for SMMJanssen with a model including interaction terms for nutrition, step count, and timepoint together. Non-statistically significant lower BATT, SMMSergi, and SMMJanssen, and higher echogenicity were demonstrated for participants with lower step counts.

Muscle and physical function

No associations were demonstrated between nutrition and PROMIS *T*-score or gait speed. Handgrip strength was lower in participants with greater risk of malnutrition (Figure 2), although these differences were not statistically significant. Participants with lower step count had significantly lower PROMIS *T*-scores across all timepoints, but step count was not predictive of differences across timepoints. Lower handgrip strength and slower gait speeds were demonstrated in participants with lower step counts, but these differences were not statistically significant (Table 3).

Discussion

In this study, baseline nutritional status was associated with baseline muscle quantity (BATT, SMMSergi, SMMJanssen) and quality (low rectus femoris echogenicity). This suggests that malnutrition is associated with the development of chronic sarcopenia, but the relationship with acute sarcopenia is unclear. This study was exploratory in nature, and further evaluation of the trends demonstrated in this study may assist in planning of future higher powered observational and targeted interventional studies. We have demonstrated that it is feasible to conduct a study of this design on a complex heterogeneous population, and that it is possible to perform a comprehensive nutritional assessment on all participants. The use of Fitbit devices was shown to be feasible in half of participants; further studies may be valuable

Table 2. Estimated marginal means with 95% confidence intervals for muscle quantity and quality measures derived from mixed models for nutritional status and step count across timepoints.

		Nutrition			*p Value*		Step count		*p Value*		
		Normal	At risk	Malnourished	*Nutrition*	*Nutrition × timepoint*	<900/day	≥900/day	*Steps*	*Steps × timepoint*	*Steps × nutrition × timepoint*
BATT (cm)	Baseline	5.07 (4.33–5.82)	4.03 (3.33–4.73)	3.05 (1.51–4.60)	*0.021**	*0.741*	3.86 (2.87–4.86)	4.24 (3.51–4.97)	*0.315*	*0.543*	*0.909*
	7 days	4.66 (3.95–5.37)	3.82 (3.15–4.49)	2.71 (1.24–4.18)			3.29 (2.34–4.24)	4.17 (3.47–4.87)			
	13 weeks	5.05 (4.17–5.93)	4.10 (3.26–4.94)	2.39 (0.53–4.25)			3.59 (2.43–4.74)	4.11 (3.17–5.04)			
Echogenicity	Baseline	58.5 (51.0–65.9)	68.5 (61.3–75.7)	81.2 (65.7–96.8)	*0.025**	*0.461*	71.4 (61.4–81.4)	67.4 (60.0–74.8)	*0.466*	*0.989*	*0.065*
	7 days	58.2 (51.6–64.8)	65.0 (58.1–72.0)	75.2 (61.4–89.0)			67.6 (58.7–76.5)	64.6 (57.9–71.3)			
	13 weeks	62.7 (54.6–70.8)	71.8 (64.1–79.6)	73.2 (56.7–89.8)			71.1 (61.0–81.1)	67.5 (58.7–76.3)			
SMMSergi (kg)	Baseline	21.6 (18.9–24.3)	18.2 (15.6–20.7)	12.0 (6.6–17.5)	*0.007**	*0.363*	16.2 (12.6–19.7)	18.3 (15.7–20.9)	*0.302*	*0.472*	*0.265*
	7 days	22.0 (19.0–25.0)	18.0 (15.3–20.8)	11.8 (5.8–17.7)			16.4 (12.6–20.3)	18.1 (15.3–21.0)			
	13 weeks	22.3 (19.5–25.1)	17.3 (14.5–20.0)	13.1 (7.4–18.8)			16.0 (12.4–19.7)	19.0 (16.2–21.9)			
SMMJanssen (kg)	Baseline	25.0 (21.2–29.5)	20.6 (17.6–24.0)	13.4 (9.6–18.7)	*0.004**	*0.209*	18.1 (14.6–22.5)	20.0 (17.0–23.4)	*0.369*	*0.164*	*0.022*
	7 days	25.8 (21.3–31.4)	20.0 (16.7–23.9)	12.3 (8.4–18.1)			17.8 (13.8–22.8)	19.3 (16.0–23.3)			
	13 weeks	24.6 (21.1–28.7)	19.2 (16.6–22.2)	13.9 (10.2–19.1)			17.1 (14.0–20.9)	20.5 (17.6–23.9)			
	7 days	0.52 (0.39–0.69)	0.47 (0.31–0.69)	0.62 (0.35–1.08)			0.47 (0.32–0.68)	0.60 (0.46–0.80)			
	13 weeks	0.72 (0.54–0.97)	0.53 (0.40–0.71)	0.52 (0.28–0.95)			0.53 (0.36–0.77)	0.65 (0.47–0.89)			

BATT: bilateral anterior thigh thickness; SMMSergi: skeletal muscle mass (Sergi equation); SMMJanssen: skeletal muscle mass (Janssen equation).
p values are shown in italic. *Statistical significance at $p < 0.05$ level.

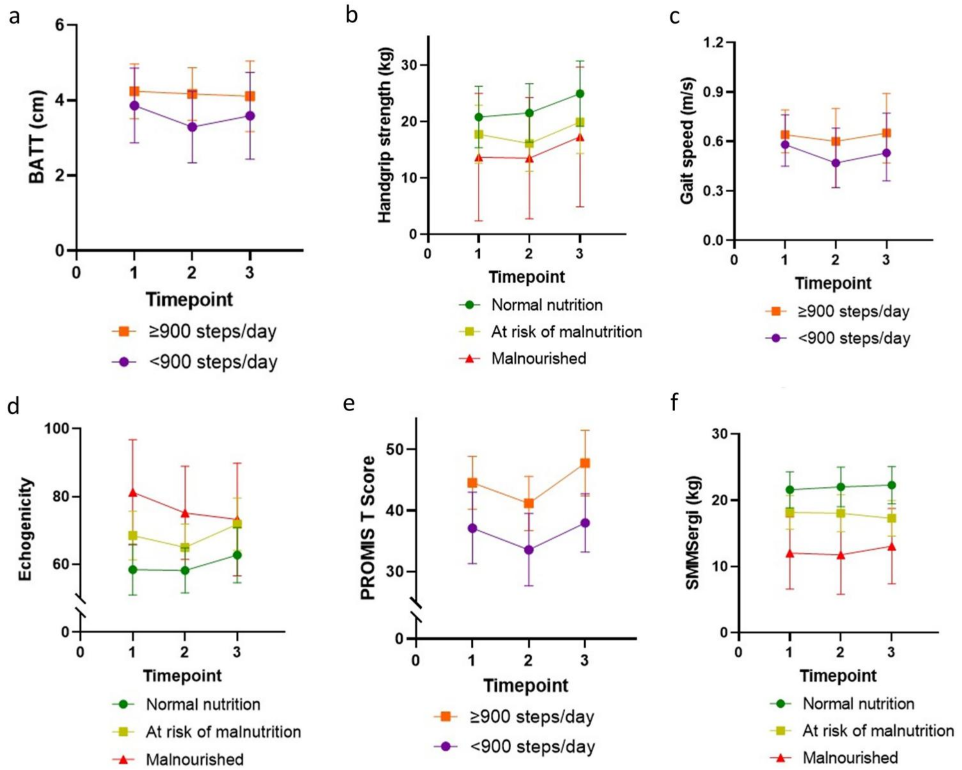

Figure 2. Estimated marginal means of muscle quantity and quality, and physical function measurements according to nutritional status and step count. BATT: bilateral anterior thigh thickness; PROMIS: Patient-Reported Outcomes Measurements Information System, *T*-score for physical function; SMMSergi: skeletal muscle mass (Sergi equation).

to assess how uptake and compliance with devices can be improved. It should be noted that the use of the Fitbit devices was an optional aspect of the study design. However, nutritional status was not associated with physical function or performance, indicating that additional factors are involved in these pathways. Although not statistically significant, results suggested that the most malnourished participants were the least likely to recover acute losses in muscle quantity. Malnourished hospital patients represent a specific group to target further research in larger powered studies.

Conversely, step count was significantly associated with patient-reported physical function, although this does not necessarily indicate causation. Step count itself could be considered a marker of physical function, rather than low step count being causative of declines in physical function. Although not statistically significant, muscle quantity, quality, and strength were consistently reduced with reduced step count, and there was suggestion of greater acute decline in BATT. This implies that a low step count in-hospital may be acutely detrimental regardless of baseline muscle size, and that step count may not simply be a marker of baseline function.

Table 3. Estimated marginal means with 95% confidence intervals for physical function measures derived from mixed models for nutritional status and step count across timepoints.

		Nutrition			*p value*		Step count		*p value*		
		Normal	At risk	Malnourished	*Nutrition*	*Nutrition × timepoint*	<900/day	≥900/day	*Steps*	*Steps × timepoint*	*Steps × nutrition × timepoint*
PROMIS	Baseline	45.9 (41.5–50.3)	38.9 (34.7–43.0)	37.7 (28.6–46.8)	*0.145*	*0.081*	37.1 (13.2–43.0)	44.5 (40.2–48.8)	*0.010**	*0.988*	*0.848*
	7 days	38.0 (33.6–42.4)	35.7 (31.4–40.1)	38.3 (29.1–47.5)			33.6 (27.6–39.5)	41.1 (36.7–45.6)			
	13 weeks	45.30 (39.9–50.7)	38.7 (33.9–43.6)	51.1 (39.2–63.0)			38.0 (33.2–42.7)	47.7 (42.4–53.1)			
Handgrip strength (kg)	Baseline	20.8 (15.3–26.2)	17.7 (12.6–22.9)	13.7 (2.4–25.0)	*0.285*	*0.598*	15.8 (8.6–23.1)	19.0 (13.6–24.3)	*0.357*	*0.845*	*0.977*
	7 days	21.5 (16.3–26.7)	16.1 (11.2–21.0)	13.5 (2.8–24.3)			15.1 (8.2–22.0)	19.0 (13.8–24.1)			
	13 weeks	24.9 (19.1–30.7)	19.9 (14.3–25.5)	17.3 (4.9–29.7)			18.4 (10.8–25.9)	23.1 (16.7–29.4)			
Gait speed (m/s)	Baseline	0.71 (0.58–0.87)	0.70 (0.55–0.89)	0.47 (0.31–0.69)	*0.498*	*0.202*	0.58 (0.45–0.76)	0.64 (0.53–0.79)	*0.262*	*0.734*	*0.485*
	7 days	0.52 (0.39–0.69)	0.47 (0.31–0.69)	0.62 (0.35–1.08)			0.47 (0.32–0.68)	0.60 (0.46–0.80)			
	13 weeks	0.72 (0.54–0.97)	0.53 (0.40–0.71)	0.52 (0.28–0.95)			0.53 (0.36–0.77)	0.65 (0.47–0.89)			

PROMIS: Patient-Reported Outcomes Measurements Information System, *T*-score for physical function.
p values are shown in italic. *Denotes statistical significance at $p < 0.05$ level.

There was a statistically significant interaction term between nutrition, step count, and timepoint for SMMJanssen, although there were no statistically significant differences for interaction terms with timepoint and either nutrition or step count alone. Low step count was associated with declines in muscle quantity with normal nutrition, whereas high step count was associated with recovery of muscle quantity with malnutrition.

Results in the context of other literature

These results are consistent with previous studies, which have demonstrated low fat-free mass measured by BIA in malnourished (defined by Subjective Global Assessment) hospitalized patients admitted with exacerbations of chronic obstructive pulmonary disease,[27] and older hospitalized patients at high risk of malnutrition (defined by the Short Nutritional Assessment Questionnaire).[28] The latter study included serial measurements and no change in muscle mass during hospitalization was demonstrated regardless of nutritional status.[28]

The cutoff of 900 steps/day was used as this has previously been demonstrated to predict decline in functional independence, as measured by the Barthel index and instrumental ADLs, during hospitalization.[7] A unit-tailored mobility program with a specific goal of at least 900 steps/day was shown to be associated with a lesser decline in ADLs in a quasi-experimental study.[29] However, a subsequent study suggested that this cutoff may have high specificity but low sensitivity for hospital associated disability; lower step count was demonstrated in patients experiencing declines in ADLs.[30] The results of this study suggest that 900 steps/day may be a functionally significant cutoff, but analysis of linear trends in a larger powered study would be valuable.

Considering underlying mechanisms of the associations encountered, 14 days of reduced steps in healthy older adults have been shown to be associated with declines in leg fat-free mass measured using dual energy X-ray absorptiometry (DXA). These declines were associated with reduced postprandial rates of muscle protein synthesis.[31] This suggests that reduced step count is associated with anabolic resistance; thus, negative effects may be exacerbated if protein intake is especially low. This is consistent with the results of our study, demonstrating an interaction between nutrition and step count in terms of change in SMMJanssen over time, and suggests that interventions may be most effective when targeted toward physical activity and nutrition together.

Limitations

We acknowledge that there are a number of important limitations related to this study. Firstly, the MNA provides an assessment of nutrition over the preceding three months[20] and is less sensitive to acute illness related effects. We did not record nutritional intake during hospitalization in this study, and it is unclear how this may have impacted upon dynamic changes. Secondly, we recognize that there are limitations in the use of Fitbit devices as opposed to raw accelerometry data. In older adults with very low step count, this may have led to a floor effect, and it was not possible to assess for the effects of differences in position.[32] Additionally, although step count provides a quantitative estimate of physical activity, it does not differentiate between resistance exercise, aerobic exercise, and simple mobilization. Thirdly, no gold standard measure of muscle quantity (DXA, magnetic resonance imaging, or computer tomography[2]) was used in this study. Fluid balance affects estimation of SMM with BIA[33] and may affect ultrasound measurements in the presence of significant edema.[34] Research by our group also previously demonstrated that ultrasound in particular can be affected by changes in position. However, these changes were not significant with only minor changes in body position, and variability with position was less pronounced with BIA.[35] Fourthly, due to recruitment challenges during the COVID-19 pandemic, it was not possible to recruit sufficient numbers of participants to meet the original sample size target. The study was not powered toward this exploratory study, and particularly recruitment technique was not modified to increase the number of malnourished participants included within the study. The number of participants who met criteria for being malnourished at baseline was particularly small, and confidence intervals were wide. This may explain why nutritional status was not associated with physical function/performance, as similar trends to other measures were demonstrated in those with normal and at risk nutrition. Fifthly, there were higher rates of frailty and medical patients amongst participants who met criteria for malnutrition, and higher rates of frailty at baseline in participants with low step counts. The direction of causality is unclear for these associations. Finally, we analyzed our results assessing changes across all three groups. This is particularly relevant when considering the applicability of baseline assessments, which were performed pre-insult in the elective group but during the acute phase of illness in the emergency surgery and medical groups. As the MNA assesses nutritional status over the previous three months, this should not have affected the overall assessment of nutritional status. However, we acknowledge that there are important differences in the clinical characteristics of these three populations.

Recommendations for clinical practice and future research

Further research is warranted to establish the effectiveness of combined nutritional and physical activity interventions in hospitalized older adults. In-hospital supervised exercised interventions have been shown to be safe and effective for improving declines in functional independence in hospitalized older adults,[36] although few studies inform nutritional management of inpatients with or at risk of sarcopenia.[37] Large community studies are currently underway to establish the effectiveness of protein supplementation and resistance exercise to prevent and treat chronic sarcopenia.[38] This exploratory study provides important proof-of-concept results, but further larger powered observational studies are warranted to establish causality and underlying mechanisms of associations. This should in turn drive forward interventional studies and translation into clinical practice. Importantly, our study has shown that it is feasible to perform a comprehensive nutritional assessment in all three patient groups, and feasible to measure step count in at least half of participants. The identification of patients who are malnourished or at risk of malnutrition in hospital is important, and nutritional assessment should be incorporated into any Comprehensive Geriatric Assessment that includes assessment of frailty and sarcopenia status. Step count is not currently measured within routine clinical practice, but our study is confirmatory of previous studies, which have demonstrated that assessment of step count within a clinical environment is feasible. Routine use of physical activity monitors in hospital could allow real-time monitoring with trends over time, which could be viewed remotely in a similar manner to vital signs.

Conclusion

Baseline nutritional status is associated with baseline muscle quantity and quality in hospitalized older adults. Baseline physical function is associated with reduced step count during hospitalization. There is some suggestion that there may be interactions between the effects of nutritional status and physical activity in predicting dynamic changes in muscle quantity. Further research should aim to stratify and examine underlying mechanisms, to enable the development of targeted combined nutritional and physical activity interventions.

Take away points

- Our exploratory study shows that baseline nutritional status is associated with reduced muscle quantity and quality, and strength in older adults admitted to hospital, reaffirming the relationship between nutritional status and sarcopenia.
- Participants with lower patient-reported physical function as measured by the PROMIS *T*-score had lower in-hospital step count, which suggests that the PROMIS *T*-score is very predictive of objectively measured physical activity.

- In hospital, a combination of suboptimal baseline nutritional status and reduced step count leads to increased risk of loss of muscle quantity as measured by SMMJanssen.
- Interventions to target acute sarcopenia should therefore aim to target nutrition and physical activity together.

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Ethical approval

This research has been sponsored by and reviewed by the University of Birmingham research governance team. Ethical approval has been obtained from Wales Research Ethics Committee 4 (19/WA/0036), the Health Research Authority, and the University Hospitals Birmingham NHS Trust Research and Development department. Written informed consent was obtained from all participants who were considered to have capacity to consent for themselves. Written personal or professional consultee declaration was obtained if the participant was considered to lack capacity to consent to participation. The use of both informed consent and consultee declaration was approved by the ethics committee. All methods were performed in accordance with the relevant guidelines and regulations.

Author contributions

CW designed the research question and study protocol. TJ, CG, TM, and TP all contributed toward design of the study protocol. CW, ZM, and HM all significantly contributed toward recruitment and follow-up assessments of participants in the study. DL and BS contributed toward data collection. CW analyzed and interpreted the results and was responsible for manuscript preparation. All authors significantly contributed toward the writing of the manuscript and approved the final submitted version.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The anonymized dataset is available from the corresponding author upon reasonable request.

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