Can Step-Based Metrics Predict Current and Future Health-Related Fitness and Patient-Reported Outcomes among Women Diagnosed with Breast Cancer?

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ABSTRACT

MATTHEWS, C. E., J. VALLANCE, J. MCNEIL, C. W. WAGONER, Q. WANG, L. DICKAU, M. L. MCNEELY, S. N. CULOS-REED, L. YANG, K. S. COURNEYA, and C. M. FRIEDENREICH. Can Step-Based Metrics Predict Current and Future Health-Related Fitness and Patient-Reported Outcomes amongWomen Diagnosed with Breast Cancer?. *Med. Sci. Sports Exerc.*, Vol. 58, No. 1, pp. 78–85, 2026. **Purpose:** Wearable sensors that track physical activity in daily life may offer insights that help health care providers optimize care plans for individuals with cancer. Therefore, we examined the links between lower health-related fitness and worse patient-reported health and various step-based metrics. **Methods:** The Alberta Moving Beyond Breast Cancer Study enrolled 1528 women recently diagnosed with breast cancer and measured health-related fitness and patient-reported health outcomes near diagnosis and 1 yr later. Step counts and intensity (cadence, peak steps) were measured by activPAL® over 7 d at baseline. We estimated cross-sectional associations (odds ratios (OR)) at baseline and prospective associations between low baseline stepping and low fitness and poorer health at 1 yr, adjusting for age, demographics, height, weight, and cancer diagnosis/treatment. **Results:** At baseline, 1408 breast cancer survivors (mean age, 56 yr; early stage (90%)) provided valid activPAL measures (mean, 5.5 d of wear). Taking <5000 steps per day (lower quintile) at baseline was associated with lower aerobic fitness, muscular strength and endurance, lower physical and mental quality of life, and greater fatigue and upper extremity disability at baseline and 1 yr later. Taking <5000 steps per day at baseline was associated with a greater risk of moving from favorable to unfavorable categories of aerobic fitness (OR, 2.64), curlups (OR, 1.84), chest endurance (OR, 2.38), self-reported health (OR, 2.37), physical quality of life (OR, 2.13), and fatigue (OR, 1.81) 1 yr later. Preferred cadence and peak stepping were inconsistently associated after adjustment for total steps. **Conclusions:** Although our findings need to be replicated, they suggest that simple step counts measured near diagnosis could help health care providers assess the fitness and health status of women recently diagnosed with breast cancer and improve their survivorship care plans. **Key Words:** CANCER SURVIVORSHIP, QUALITY OF LIFE, AEROBIC FITNESS, MUSCULAR STRENGTH, FATIGUE

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Digital health technologies have emerged as an important adjunct to clinical research and medicine (1,2), including oncology (3). In addition to supporting the adoption and maintenance of physical activity (4), sensor-based estimates of step counts and stepping intensity measured in the daily life of individuals diagnosed with cancer may offer unique insights into their health status (2,5,6). Wearable sensors that track steps are widely available, are relatively inexpensive, and may provide clinically relevant data (e.g., digital biomarkers [3]) that may assist in optimizing care for these individuals.

In the general population, lower daily step counts have been associated with increased risk for mortality (7), higher prevalence of metabolic syndrome (8,9), and an increased prevalence of (10) and risk for depression (11). In addition, ambulatory function appears to be reduced in many older cancer survivors and is associated with poorer survival (12). Previous studies among individuals with cancer have used wearable sensors to measure daily activity in response to exercise interventions (13,14), describe the potential health benefits of increased activity (15–17), and track activity levels during active treatment (18–21). Recently, intensive near real-time tracking of daily activity has been utilized to predict adverse clinical outcomes during treatment through advanced modeling strategies (20,22). Fewer studies have examined whether more easily obtained measures of step counts and stepping intensity (e.g., average values from the past week) assessed early after a breast cancer diagnosis could help to identify women with lower physical fitness and poorer health outcomes at the time of diagnosis and during the postdiagnosis survivorship period (5).

We used a discovery-based approach to investigate the potential for lower step counts and stepping intensity in daily life assessed shortly after a breast cancer diagnosis to be associated with lower health-related fitness (e.g., aerobic fitness, muscular strength) and poorer patient-reported health outcomes (e.g., fatigue, depression, diminished quality of life, upper extremity limitations). We examined these cross-sectional associations at baseline and also investigated prospective associations between lower step-based metrics near diagnosis and health-related fitness and self-reported health outcomes 1 yr later.

METHODS

Study design and population. The Alberta Moving Beyond Breast Cancer Study (AMBER) is a prospective study of newly diagnosed breast cancer patients recruited from 2012 to 2019. Women living in Edmonton or Calgary, Alberta, Canada, were eligible if they had stage I (≥T1c) to stage IIIc disease, were 18–80 yr old, could complete questionnaires in English, and were not pregnant. Participants were identified in Calgary through the Alberta Cancer Research Biobank and in Edmonton through the Cross Cancer Institute's New Patient Breast Cancer clinics via their treating oncologist and were further screened for eligibility by study staff (23). The Health Research Ethics Board of Alberta: Cancer Committee (HREBA.CC-17-0576) approved the study, and participants provided informed consent.

Data collection at baseline and 1 yr later consisted of self-reported surveys and in-laboratory measures of health-related fitness. Stepping measures at baseline only were used for this analysis. In most cases, baseline assessments were completed within 90 d of surgery and prior to adjuvant therapies. Participants who completed fewer than three cycles of chemotherapy or less than 11 fractions of radiation therapy were included.

Demographic, lifestyle, and clinical covariates. Baseline surveys captured demographics (age, marital status, ethnicity, education, income, employment), reproductive and medical history, hormone and medication use history, smoking and alcohol use, and comorbidities. Cancer diagnosis and treatment information were extracted from medical charts (i.e., diagnosis date, tumor stage, grade, histology, surgery type, and treatments received).

Sensor-based measures of step counts and intensity. We assessed step-based metrics at baseline including daily step counts, indicators of step intensity (cadence, peak steps), and the absence of extended stepping bouts lasting 10 or more minutes using the activPAL® monitor (PAL Technologies Inc., Glasgow, Scotland). This device samples three-dimensional acceleration at 20 Hz, and it is worn on the thigh. Participants were instructed to wear it for 7 d during waking hours (i.e., out of bed for the day as per a daily log). Raw data were initially processed to generate event files using activPAL® software (CREA v8.10.12.60) and then using the R-package *activPAL® processing* (v0.4.1) to generate summary metrics for the waking day (17). We included participants with at least one valid day of data and calculated mean values for the available valid days for total steps per day, preferred cadence in bouts lasting 1 to 10 min (cadence 1–10 m (steps per minute)), and the number of steps taken in the most active 6-min periods in the day (peak steps 6 m (step count)). We classified participants as taking no stepping events lasting at least 10 min during the week as "no bouts of ≥10+ m" or having one or more stepping events of this length (%). activPAL® performance for estimating step counts has been established as compared with direct observation in the laboratory and free-living studies for step counts and cadence in generally healthy populations (24,25).

Fitness and health outcome measures. To describe associations between stepping metrics, low levels of health-related fitness, and poorer self-reported health outcomes, we used established thresholds for each outcome when available or applied quintile-based thresholds of the measured distribution of the outcomes at baseline. The thresholds applied are reported in Supplemental Table 1 (Supplemental Digital Content, http://links.lww.com/MSS/D294, Description of health-related fitness and patient-reported health outcome thresholds classifying low fitness or poor health).

Health-related fitness. Certified exercise physiologists used standardized testing protocols at both sites (26). Cardiorespiratory fitness was measured via indirect calorimetry using the modified Bruce treadmill protocol and measured peak oxygen consumption ($\dot{V}O_{2peak}$) (26). Ventilatory threshold was determined using Wasserman's V-Slope method (27) by two independent observers expressed in absolute ($L \cdot min^{-1}$) and relative terms (% $\dot{V}O_{2peak}$). Muscular fitness was assessed by combined

right and left handgrip strength using a dynamometer, abdominal endurance (number of consecutive partial curlups completed), and upper and lower body muscular strength and endurance tests (chest and leg press) (26). Maximal strength was assessed by an 8- to 10-repetition test to predict 1-repetition maximum (1-RM) (28). Muscular endurance was assessed as a multiple-repetition maximum based on 50% of predicted 1-RM for the chest press and 70% of predicted 1-RM for the leg press and calculated as repetitions (n) × weight lifted (kg) (28).

Patient-reported outcomes. Self-reported health was assessed by asking, "In general, would you say your health is Excellent, Very Good, Good, Fair, or Poor?" Quality of life was measured using the SF-36 Version 2 (29,30). Eight dimensions on a "typical day" are aggregated to form a physical component summary and mental component summary normalized to the US adult population (30). Higher scores indicate better quality of life. Fatigue was measured using the 13-item Functional Assessment of Chronic Illness Therapy–Fatigue (FACIT-F) instrument (31). The FACIT-F assesses symptoms of fatigue in the past 7 d, and higher scores indicate less fatigue. Upper extremity limitations in the past 7 d were assessed using the 30-item Disabilities of the Arm, Shoulder and Hand scale (32). Higher scores reflect greater restriction/disability. Depression was assessed using the nine-item Patient Health Questionnaire (PHQ-9) survey that assesses symptoms of depression in the past 2 wk (33), and higher scores reflect more depressive symptoms.

Statistical analysis. We first completed descriptive analysis (mean (SD), frequency (%) of study covariates, by step count and step intensity exposures). The 20th percentile for step counts was 4859 steps per day, and we rounded up to 5000 steps per day (21.3% of participants). This step count threshold has been employed to categorize individuals as "sedentary" (34), using older terminology. The thresholds used to classify lower cadence and peak stepping were <77.66 steps per minute and <62.7 steps, respectively. Thresholds for classifying lower fitness and poorer health are presented in Supplemental Table 1 (Supplemental Digital Content, http://links.lww.com/MSS/D294, Description of health-related fitness and patient-reported health outcome thresholds classifying low fitness or poor health).

We employed a discovery-based approach to explore step-based metrics as potential clinical indicators of lower fitness and poorer health. We chose not to adjust statistical tests for multiple comparisons to minimize the exclusion of false-negative findings that could be missed with strict adjustments while acknowledging the potential for some false-positive results. To partially address this issue, our interpretation of the results emphasizes internally consistent findings within the study for measured fitness and self-reported health outcomes with logical overlap (e.g., measured upper body strength and self-reported upper extremity disability).

We adjusted all models for relevant covariates, including age (years), study location (Calgary, Edmonton), height (cm), weight (kg), and clinical factors that may impact the stepping measures including factors related to cancer diagnosis (tumor stage (I, II, or III)), type of surgery (mastectomy (yes, no)), tumor receptor status (estrogen (ER) and progesterone receptor (PR)), human epidermal growth factor receptor 2 (HER2) status (positive, negative), adjuvant treatments (chemotherapy, radiation (yes, no)), and whether adjuvant treatments started before the activPAL® monitoring period (yes, no).

At baseline, we examined cross-sectional associations between lower step counts and stepping intensity and indicators of lower health-related fitness and poorer health using logistic regression (odd ratios, 95% confidence intervals (OR (95% CI))). We examined prospective associations between the stepping metrics measured at baseline and health-related fitness and health outcomes assessed approximately 1 yr later using multinomial logistic regression. Here, we estimated associations for 1) odds of being in the lower fitness or poorer health category at baseline and remaining at that level 1 yr later (consistently low) and 2) the odds of being more fit or in better health at baseline but declining to the lower/poorer category 1 yr later (declining). The referent group included women who were either in the higher fitness or health categories at both periods or in the higher fitness/health categories only at 1 yr. To better understand the unique contribution of the cadence, peak stepping, and bout-based exposures beyond the influence of total steps counts, we also fit models without and with adjustments for step counts.

RESULTS

Of the 1528 women enrolled in the cohort, 1442 participants provided 9437 d of activPAL® data with matched wear log information. Additional quality control exclusions were applied for days with technically invalid data, <250 or >30,000 steps per day, <8 waking hours, <90% wear time in waking day, and <1-h sedentary time, and 1408 participants (n = 7582 d) remained. Of these, participants with *in situ* breast cancer (stage 0, n = 1) and no baseline patient-reported outcome information (n = 70) were excluded, leaving 1364 participants for analysis at baseline. On average, participants wore the activPAL® for 14.8 $h \cdot d^{-1}$, recorded an average of 5.5 d of wear, and 90% wore the monitor for at least 3 d. There were significant correlations among the step-based metrics (all, $P < 0.001$). Total step counts were correlated with preferred cadence (r = 0.54) and peak stepping (r = 0.75), and the correlation between preferred cadence and peak stepping was r = 0.68.

Table 1 outlines the demographic and clinical covariates along with activPAL® summary metrics based on the primary step-based metrics examined. The average age at diagnosis was 55 yr; 92% of participants had stage I or II breast cancer, and approximately 40% underwent a mastectomy (Table 1). Participants with lower levels of the stepping metrics tended to be older and heavier. They were also more likely to have worn the activPAL® after beginning chemotherapy and were more sedentary and less physically active (Table 1).

Health-related fitness: lower step counts. At baseline, taking fewer than 5000 steps per day was cross-sectionally

TABLE 1. Description of study participants by step count and step-based metrics, AMBER study (N = 1364).

	Step Counts (Per Day)				Cadence 1–10 m (Steps per Minute)				Stepping Bouts 10+ min			
	<5000 (n = 291)		5000+ (n = 1073)		<77.66 (n = 263)		≥77.66 (n = 1101)		No (n = 592)		Yes (n = 772)	
	Freq/Mean	SD/%	Freq/Mean	SD/%	Freq/Mean	SD/%	Freq/Mean	SD/%	Freq/Mean	SD/%	Freq/Mean	SD/%
Study site												
Calgary	167	22%	607	78%	148	19%	626	81%	425	55%	349	45%
Edmonton	124	21%	466	79%	115	19%	475	81%	347	59%	243	41%
Age (yr)	56.1	11.7	55.3	10.4	56.3	11.3	55.3	10.5	55.8	11.2	55.3	10.2
Height (cm)	163.6	6.6	163.7	6.4	163.8	6.7	163.6	6.3	163.3	6.5	164.0	6.3
Weight (kg)	81.7	18.1	71.6	14.4	78.9	18.0	72.5	15.0	77.4	16.8	70.9	14.4
BMI >30 kg·m^{-2}	142	49%	237	22%	109	41%	270	25%	233	39%	146	19%
AJCC stage												
I	121	42%	499	47%	100	38%	520	47%	272	46%	348	45%
II	142	49%	488	46%	139	53%	491	45%	274	46%	356	46%
II	28	10%	86	8%	24	8%	90	8%	46	8%	68	9%
Surgery type												
Mastectomy (yes)	126	43%	425	40%	121	46%	430	39%	242	41%	309	40%
Tumor receptors												
ER positive	250	86%	965	90%	230	87%	985	89%	525	89%	690	89%
PR positive	209	72%	840	78%	185	70%	864	78%	448	76%	601	78%
HER2 positive	63	22%	142	13%	47	18%	158	14%	98	17%	107	14%
Radiation												
No	204	70%	736	69%	188	71%	752	68%	402	68%	538	70%
Yes: activPAL before	74	25%	265	25%	69	26%	270	25%	152	26%	187	24%
Yes: activPAL after	13	4%	72	7%	6	2%	79	7%	38	6%	47	6%
Chemotherapy												
No	120	41%	414	39%	102	39%	432	39%	222	38%	312	40%
Yes: activPAL before	107	37%	469	44%	97	37%	479	44%	252	43%	324	42%
Yes: activPAL after	64	22%	190	18%	64	24%	190	17%	118	20%	136	18%
activPAL												
Valid days	5.0	1.9	5.5	1.7	5.2	1.8	5.4	1.7	4.9	1.9	5.8	1.4
Wear time (h·d^{-1})	14.3	1.4	15.0	1.1	14.6	1.4	14.9	1.2	14.7	1.4	14.9	1.1
Sedentary (h·d^{-1})	10.1	1.8	8.8	1.6	9.7	1.9	8.9	1.6	9.3	1.8	8.9	1.6
Standing (h·d^{-1})	3.0	1.3	4.0	1.3	3.4	1.5	3.9	1.3	3.7	1.4	3.9	1.3
Stepping (h·d^{-1})	0.9	0.2	1.7	0.5	1.1	0.4	1.7	0.5	1.3	0.5	1.7	0.6
Steps (per day)	3792	935	8379	2665	4761	1992	8031	2920	5797	2306	8630	2981
Cadence <1 m (steps per minute)	75.3	5.9	77.7	5.5	73.6	5.5	78.0	5.4	76.7	6.0	77.5	5.4
Cadence 1–10 m (steps per minute)	73.1	21.8	93.3	12.5	62.2	15.7	95.4	9.5	83.4	19.6	93.3	13.4
Peak 2 min (no. of steps)	172.5	33.3	221.9	28.5	167.3	33.5	221.9	27.3	191.5	35.1	226.6	28.0
Peak 6 min (no. steps)	352.1	103.3	551.2	126.1	359.9	126.1	544.3	127.3	409.0	119.5	585.1	116.1
No bouts 10+ m (%)	234	80%	358	33%	172	65%	420	38%	—	—	—	—

associated with an elevated body mass index (BMI), lower cardiorespiratory fitness, less sit and reach flexibility, and lower muscular strength and endurance (Table 2). For example, taking fewer steps was associated with nearly fourfold greater odds of having lower cardiorespiratory fitness (OR, 3.82 (95% CI, 2.36–6.19)) and twofold greater odds of having low upper body strength (OR, 2.02 (1.24–3.29)).

Prospectively, taking fewer steps at baseline was associated with remaining in the low category for several health-related fitness measures 1 yr later (Table 2), including cardiorespiratory

TABLE 2. Associations between lower step counts (<5000 per day) at baseline and lower health-related fitness at baseline and 1 yr, AMBER cohort study.

	Cross-Sectional		Prospective			
	Low at Baseline		Consistently Low[a]		Declining[b]	
Health-Related Fitness	N/Cases[c]	OR (95% CI)	N/Cases[c]	OR (95% CI)	N/Cases[c]	OR (95% CI)
BMI >30 kg·m^{-2}	1364/379	**3.46 (2.62–4.58)**	1166/284	**3.72 (2.70–5.13)**	1166/42	1.71 (0.79–3.71)
$\dot{V}O_2$ peak (L·min^{-1})	1063/213	**3.82 (2.36–6.19)**	787/92	**5.17 (2.45–10.90)**	787/49	**2.64 (1.10–6.34)**
$\dot{V}O_2$ ventilatory threshold (L·min^{-1})	1118/226	**4.25 (2.73–6.61)**	843/74	**7.63 (3.76–15.50)**	843/56	1.58 (0.67–3.70)
$\dot{V}O_2$ ventilatory threshold (% peak)	1040/229	1.22 (0.82–1.83)	768/27	0.71 (0.20–2.56)	768/76	1.05 (0.50–2.19)
RPE at ventilatory threshold	1098/105	0.97 (0.56–1.69)	810/71	0.98 (0.46–2.06)	810/135	1.01 (0.59–1.74)
Sit and reach	1297/259	**1.58 (1.13–2.20)**	1052/130	**1.87 (1.19–2.92)**	1052/43	1.88 (0.89–3.96)
Curlups	1257/293	1.11 (0.77–1.59)	1006/146	1.45 (0.88–2.38)	1006/113	**1.84 (1.10–3.05)**
Grip strength (kg)	1316/267	**1.89 (1.32–2.71)**	1084/143	**1.74 (1.05–2.89)**	1084/91	1.46 (0.81–2.65)
Chest strength (predicted 1-RM, kg)	868/174	**2.02 (1.24–3.29)**	563/47	2.37 (0.96–5.86)	563/23	2.44 (0.79–7.58)
Leg strength (predicted 1-RM, kg)	905/186	**2.16 (1.36–3.42)**	581/65	**3.40 (1.50–7.68)**	581/38	1.00 (0.32–3.06)
Chest endurance (total kg)	867/173	**1.66 (1.05–2.63)**	561/49	2.34 (0.99–5.50)	561/50	**2.38 (1.05–5.42)**
Leg endurance (total kg)	903/185	**2.53 (1.60–4.00)**	578/40	**3.78 (1.54–9.25)**	578/70	0.89 (0.37–2.17)

OR (95%CI) values in bold are statistically significant ($P < 0.05$).
Adjusted for study location, age, height, weight, cancer stage, ER, PR, HER2, surgery type, and receipt (yes, no) and timing of radiation and chemotherapy relative to activPAL® measurements.
[a]Consistently Low = lower health status at baseline and 1 yr.
[b]Declining = Movement into the lower health status category/quintile.
[c]Cases = number of participants in the lower category/quintile.

fitness (OR, 5.17 (2.45–10.90)), sit and reach flexibility (OR, 1.87 (1.19–2.92)), grip strength (OR, 1.74 (1.05–2.89)), and lower body muscular strength (OR, 3.40 (1.50–7.68)) and endurance (OR, 3.78 (1.54–9.25)). Taking fewer steps at baseline was also associated with reduced health-related fitness and declines into the lower quintile of cardiorespiratory fitness (OR, 2.64 (1.10–6.34)), abdominal endurance (curlups) (OR, 1.84 (1.10–3.05)), and upper body endurance (OR, 2.38 (1.05–5.42)) 1 yr later (Table 2).

Health-related fitness: lower stepping intensity and duration. The cadence, peak steps, and the absence of stepping bouts lasting over 10 min metrics were often associated with lower fitness before adjusting for total step counts. However, these associations diminished after adjustment—particularly for the prospective outcomes. Therefore, we provide only a brief summary here. After adjusting for total steps, baseline cross-sectional associations remained statistically significant for preferred cadence and cardiorespiratory fitness and leg strength (Supplemental Table 2, Part A, Supplemental Digital Content, http://links.lww.com/MSS/D294, Associations between preferred cadence (1–10 m)* and indicators of lower health-related fitness and patient-reported poor health). Steps taken in peak 6 min of activity remained associated with curlups, grip strength, and lower body muscular strength and endurance (Supplemental Table 3, Part A, Supplemental Digital Content, http://links.lww.com/MSS/D294, Associations between peak steps in most active 6-min periods* and indicators of lower health-related fitness and patient-reported poor health). The absence of 10+-min stepping bouts remained cross-sectionally associated with an elevated BMI, lower ventilatory threshold (%), curlups, and upper and lower body muscular strength (Supplemental Table 4, Part A, Supplemental Digital Content, http://links.lww.com/MSS/D294, Associations between no 10+-min stepping bouts and indicators of lower health-related fitness and patient-reported poor health).

Fewer prospective associations were observed with health-related fitness after adjustment for total steps. Lower cadence remained associated with a decline in abdominal endurance/curlups (OR, 2.16 (1.26–3.71)), but peak steps had no prospective associations with any health-related fitness measures. The absence of 10+-min stepping bouts was prospectively associated with consistently elevated BMI (OR, 2.02 (1.47–2.78)), consistently lower sit and reach flexibility (OR, 1.65 (1.06–2.57)), upper body muscular endurance (OR, 2.36 (1.14–4.87)), and a decline in upper body muscular endurance 1 yr later (OR, 2.64 (1.30–5.34)) (Supplemental Tables 2, 3, and 4, Part A, Supplemental Digital Content, http://links.lww.com/MSS/D294, ST2 Associations between preferred cadence (1–10 m)* and indicators of lower health-related fitness and patient-reported poor health; ST3 Associations between peak steps in most active 6-min periods* and indicators of lower health-related fitness and patient-reported poor health; ST4 Associations between no 10+-min stepping bouts and indicators of lower health-related fitness and patient-reported poor health).

Patient-reported health outcomes: lower step counts. At baseline, taking fewer than 5000 steps per day was cross-sectionally associated with virtually all of the patient-reported outcomes for poor health (Table 3). Prospectively, associations were noted for reporting consistently low physical function (OR, 2.25 (1.54–3.30)), persistent fatigue (OR, 2.21 (1.61–3.03)), and continued upper extremity disability (OR, 1.58 (1.15–2.18)). Taking fewer steps at baseline was associated with a decline in self-reported health (OR, 2.37 (1.42–3.93)) and physical function (OR, 2.13 (1.30–3.49)), and increased fatigue (OR, 1.81 (1.07–3.06)) 1 yr later (Table 3).

Patient-reported health: lower stepping intensity and duration. For these metrics, most associations were attenuated and no longer statistically significant after adjustment for total steps (Supplemental Tables 2, 3, and 4, Part B, Supplemental Digital Content, http://links.lww.com/MSS/D294, ST2 Associations between preferred cadence (1–10 m)* and indicators of lower health-related fitness and patient-reported poor health; ST3 Associations between peak steps in most active 6-min periods* and indicators of lower health-related fitness and patient-reported poor health; ST4 Associations between no 10+-min stepping bouts and indicators of lower health-related fitness and patient-reported poor health). Each of the step intensity and duration metrics remained associated with upper extremity disability at baseline (e.g., preferred cadence: OR, 1.47 (1.02–2.11)). The absence of extended stepping bouts was also cross-sectionally associated with lower physical function (OR, 2.06 (1.36–3.11)) and greater fatigue (OR, 1.51 (1.10–2.06)) at baseline. Prospective associations were noted between lower stepping cadence and consistently low mental component scores (OR, 1.85 (1.00–3.43)) and new moderate–severe depression (OR, 2.23 (1.11–4.48))

TABLE 3. Associations between lower step counts (<5000 per day) at baseline and poorer patient reported at baseline and 1 yr.

	Cross-Sectional: Baseline			Prospective: 1 yr		
	Low at Baseline			Consistently Low[a]		Declining[b]
Patient-Reported Outcomes	*N*/Cases	OR (95% CI)	*N*/Cases	OR (95% CI)	*N*/Cases	OR (95% CI)
Self-reported health (fair/poor)	1364/91	**2.06 (1.28–3.31)**	1189/33	2.05 (0.94–4.47)	1189/83	**2.37 (1.42–3.93)**
SF-36 Physical component score	1364/156	**2.25 (1.54–3.30)**	1189/52	**2.33 (1.24–4.37)**	1189/89	**2.13 (1.30–3.49)**
SF-36 Mental component score	1364/295	**1.71 (1.24–2.36)**	1189/79	1.57 (0.90–2.74)	1189/59	1.58 (0.84–2.99)
Fatigue	1363/270	**2.21 (1.61–3.03)**	1188/85	**2.11 (1.26–3.54)**	1188/86	**1.81 (1.07–3.06)**
Disability arm, shoulder, hand	1363/268	**1.85 (1.33–2.57)**	1186/120	**1.88 (1.19–2.97)**	1186/143	1.06 (0.67–1.68)
PHQ-9 Depression (total)	1363/264	**2.27 (1.64–3.13)**	1188/122	1.56 (0.98–2.48)	1188/92	1.63 (0.96–2.74)
PHQ-9 Moderate–severe depression	1363/144	**1.88 (1.26–2.82)**	1188/43	1.98 (0.99–3.97)	1188/60	0.98 (0.50–1.93)

OR (95%CI) values in bold are statistically significant ($P < 0.05$).
Adjusted for study location, age, height, weight, cancer stage, ER, PR, HER2, surgery type, and receipt (yes, no) and timing of radiation and chemotherapy relative to activPAL measurements.
[a]Consistently Low = lower health status at baseline and 1 yr.
[b]Declining = reduced health status at 1 yr.

(Supplemental Table 4, Part B, Supplemental Digital Content, http://links.lww.com/MSS/D294, ST2 Associations between preferred cadence (1–10 m)* and indicators of lower health-related fitness and patient-reported poor health; ST3 Associations between peak steps in most active 6-min periods* and indicators of lower health-related fitness and patient-reported poor health; ST4 Associations between no 10+-min stepping bouts and indicators of lower health-related fitness and patient-reported poor health). Prospective associations also remained between the absence of extended stepping bouts and consistently greater upper extremity disability (OR, 1.99 (1.26–3.14)), a decline in this outcome (OR, 1.86 (1.23–2.80)), and a decline in mental health (OR, 2.08 (1.13–5.34)) 1 yr later (Supplemental Table 4, Part B, Supplemental Digital Content, http://links.lww.com/MSS/D294, ST2 Associations between preferred cadence (1–10 m)* and indicators of lower health-related fitness and patient-reported poor health; ST3 Associations between peak steps in most active 6-min periods* and indicators of lower health-related fitness and patient-reported poor health; ST4 Associations between no 10+-min stepping bouts and indicators of lower health-related fitness and patient-reported poor health).

DISCUSSION

In this large prospective study of newly diagnosed breast cancer patients, we explored associations between lower step counts and stepping intensity in relation to lower fitness and poorer health status. We found that taking fewer than 5000 steps per day was cross-sectionally associated with several indicators of health-related fitness and patient-reported health outcomes close to the time of diagnosis. Importantly, taking fewer steps near the time of diagnosis was prospectively associated with remaining in lower categories of health-related fitness and poorer health outcomes, as well as a decline in cardiorespiratory fitness, abdominal endurance, upper body muscular endurance, self-reported physical function, and self-rated health 1 yr later. Notably, the stepping cadence, peak stepping, or the absence of extended stepping bouts was not associated with any outcomes that were not also related to total daily steps. These findings support the notion that step count measures gathered close to the time of diagnosis could serve as a useful indicator of current and future health status.

Several smaller cross-sectional studies have examined the relationship between physical activity and health-related fitness and self-reported health outcomes among those diagnosed with nonmetastatic cancer (6,18,35–37), including reports from this cohort (15–17). These results are broadly consistent with our cross-sectional findings, which demonstrate that lower activity levels and/or greater sedentary time are associated with a range of health-related fitness and patient-reported health outcomes. Bachman and colleagues (6) examined activPAL®-measured step counts and step-based metrics in 86 cancer survivors in the posttreatment period and found that step counts and peak stepping rates were associated with higher cardiorespiratory fitness, but preferred cadence was not. They also reported that measures of "real-world physical activity" were mainly associated with cardiorespiratory fitness rather than self-reported well-being or physical function. In contrast, in our larger cross-sectional and prospective analysis, we found that lower daily step counts were associated with cardiorespiratory fitness and physical function. We also noted associations with several health outcomes that are less obviously related to stepping, such as upper body strength and endurance and limitations of the upper extremities. Therefore, daily step counts appear to provide additional insights into whole-body fitness and health status beyond lower extremity functioning.

A distinctive aspect of our study was the examination of prospective associations between a single measure of step counts collected near the time of diagnosis with health-related fitness and self-reported health outcomes assessed approximately 1 yr later. Several studies have used continuous measures of daily physical activity to identify adverse reactions during treatment (19–21) and risk for hospitalization (22). For example, Wood and colleagues (21) found that continuous longitudinal measures of step counts were inversely associated with symptom burden during chemotherapy. Friesner and colleagues (22) utilized continuous daily step counts during chemoradiotherapy to predict the risk of hospitalization. Schulte and colleagues (38) examined self-reported physical inactivity and found associations with a higher risk of poorer physical and mental quality of life several years later among adult survivors of childhood cancer. We found low step counts to be prospectively associated with an increased risk of remaining in many lower fitness and poorer health categories 1 yr later and an increased risk of declines into the lower categories of fitness and self-reported physical function and greater fatigue 1 yr later. Our finding that a one-time measurement of average step counts near the time of diagnosis is associated with multiple measures of health-related fitness and patient-reported health outcomes may be significant because this relatively simple measure can be shared with health care providers by self-report during clinic visits or by linking data captured via wearable devices to electronic medical records.

An unexpected observation was the limited number of associations between stepping intensity and health status after controlling for total daily step counts. We analyzed preferred cadence (steps per minute) during stepping bouts lasting 1 to 10 min and the peak number of steps taken in the most active 6-min period of the day as indicators of stepping intensity. We observed several cross-sectional associations with these indicators after adjusting for total step counts, but none were associated with a health outcome that was not also associated with step counts, and significant prospective associations were limited. The cross-sectional associations between lower preferred cadence and self-reported SF-36 Mental Component Score and moderate to severe depression also suggest that poorer mental health may be associated with lower stepping intensity and fewer total steps taken each day.

Associations observed with a lack of extended walking bouts lasting 10 or more minutes were striking and deserve additional study. The absence of extended stepping bouts, found in 46% of participants, was prospectively associated with remaining in lower categories of flexibility (sit and reach), upper body endurance, self-reported physical function, and limitations of

the upper extremity after 1 yr. In addition, it was associated with declines in upper body muscular endurance, self-reported mental health, and upper extremity limitations after 1 yr. This more restricted pattern of ambulatory activity may indicate reduced mobility outside of the home, which has been associated with lower cardiorespiratory fitness (6-min walk test) and executive functioning measures in older adults (39). Further study using context-specific measures of daily activities via self-report will contribute to understanding these relationships more completely to then target future intervention efforts if warranted.

Strengths and limitations. This study has several strengths, including the use of objective measures of daily step counts and other metrics through a device that has demonstrated strong measurement performance (24,25). We also had a large sample size and employed direct measures of health-related fitness, examining both cross-sectional and prospective outcomes. There are also limitations that should be considered. Several outcomes we examined did not have specified thresholds to define the measure's lower or "at-risk" levels, so we used the quintile values as proxy indicators for analysis. Results from other study populations with different thresholds may produce different results. In addition, we focused solely on dichotomous associations to identify factors linked to greater risk. Future studies should investigate predictors of decline in these outcomes over the full range of their distribution (e.g., declining from higher to intermediate fitness). The potential for false positives (type I errors) is acknowledged, given the number of associations examined. We chose a discovery-oriented analytic approach that favored minimizing false-negative findings (type II errors) while emphasizing the internally consistent results in this initial study.

CONCLUSIONS

Lower daily step counts measured shortly after a breast cancer diagnosis were associated with both lower aerobic fitness and muscular strength and several indicators of poorer patient-reported health outcomes in cross-sectional and prospective analyses. Step counts from wearable sensors, a simple measurement that can be easily obtained near the time of cancer diagnosis, could facilitate health and wellness planning across the treatment timeline and into survivorship for women with breast cancer. Further studies to confirm these results and refine step count thresholds that best identify at-risk individuals who could benefit from enhanced supportive care services appear warranted.

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