

Exercise capacity is associated with hospital readmission among patients with diabetes

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ABSTRACT

Introduction Patients with diabetes are at greater risk of hospital readmission than patients without diabetes. There is a need to identify more modifiable risk factors for readmission as potential targets for intervention. Cardiorespiratory fitness is a predictor of morbidity and mortality. The purpose of this study was to examine whether there is an association between exercise capacity based on the maximal workload achieved during treadmill stress testing and readmission among patients with diabetes.

Research design and methods This retrospective cohort study included adult patients with diabetes discharged from an academic medical center between July 1, 2012 and December 31, 2018 who had a stress test documented before the index discharge. Univariate analysis and multinomial multivariable logistic regressions were used to evaluate associations with readmission within 30 days, 6 months, and 1 year of discharge. Exercise capacity was measured as metabolic equivalents (METs).

Results A total of 580 patients with 1598 hospitalizations were analyzed. Mean METs of readmitted patients were significantly lower than for non-readmitted patients (5.7 (2.6) vs 6.7 (2.6), $p < 0.001$). After adjustment for confounders, a low METs level (< 5) was associated with higher odds of readmission within 30 days (OR 5.46 (2.22–13.45), $p < 0.001$), 6 months (OR 2.78 (1.36–5.65), $p = 0.005$), and 1 year (OR 2.16 (1.12–4.16), $p = 0.022$) compared with medium (5–7) and high (> 7) METs level. During the 6.5-year study period, patients with low METs had a mean of 3.2 ± 3.6 hospitalizations, while those with high METs had 2.5 ± 2.4 hospitalizations ($p = 0.007$).

Conclusions Lower exercise capacity is associated with a higher risk of readmission within 30 days, 6 months, and 1 year, as well as a greater incidence of hospitalization, in patients with diabetes. Future studies are needed to explore whether exercise reduces readmission risk in this population.

INTRODUCTION

Hospital readmission is an undesirable, expensive outcome used as a measure of healthcare quality.^{1–2} Patients with diabetes are more likely to be readmitted than patients without diabetes,³ and up to 20% will be readmitted within 30 days of hospital discharge.⁴ Several readmission risk factors have been identified, including repeated hospitalizations, hospital

Significance of this study

What is already known about this subject?

► Cardiorespiratory fitness is a predictor of morbidity and mortality in patients with diabetes, but associations with hospitalizations or readmissions have not been investigated.

What are the new findings?

► Relative to high exercise capacity, low exercise capacity is associated with a 2-fold to 5.5-fold higher risk of hospital readmission within 30 days, 6 months, and 1 year of discharge, as well as a greater incidence of hospitalization, in patients with diabetes.

How might these results change the focus of research or clinical practice?

► Exercise capacity is a novel predictor of readmission, and these data provide a rationale to test the hypothesis that exercise reduces readmission risk in patients with diabetes.

length of stay, sociodemographic characteristics, and comorbidities.^{4,5} However, these risk factors are largely non-modifiable. There is a need to identify more modifiable risk factors for readmission as potential targets for intervention among patients with diabetes.

A robust body of evidence indicates that cardiorespiratory fitness is a strong predictor of morbidity and mortality in patients with diabetes.^{6–8} Greater exercise capacity is associated with lower mortality and fewer diabetic complications, including cardiovascular events in patients with diabetes with and without pre-existing cardiovascular disease.^{6–11} Exercise capacity is associated with readmission/hospitalization risk in patients with other chronic conditions such as chronic obstructive pulmonary disease (COPD) and heart failure (HF).^{12–14} In these populations, exercise interventions decrease readmission/hospitalization risk. Whether exercise capacity is associated with readmission risk among patients with diabetes

is unknown. The purpose of the present study was to examine whether such an association exists. We hypothesized that lower exercise capacity based on the maximal workload achieved during treadmill stress testing is associated with a higher 30-day readmission rate in patients with diabetes.

METHODS

Study design

We retrospectively analyzed the electronic health records of patients discharged from Temple University Hospital, an urban academic medical center in Philadelphia, Pennsylvania, between July 1, 2012 and December 31, 2018. Inclusion criteria were (1) being 18 years of age or older; (2) having a diagnosis of diabetes defined by an International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) code of 249.xx or 250.xx, or ICD-10-code E08 through E013, associated with a hospital discharge in any position (primary or secondary); and (3) documentation of a treadmill stress test conducted between July 1, 2008 and December 31, 2018. Patients were excluded if they lacked a treadmill stress test before the index discharge and/or if the test was performed as part of a vascular study measuring ankle-brachial index because these tests are performed at a constant workload and not validated as a measure of cardiorespiratory fitness. Index discharges were excluded if the discharge reason was death or transfer to another hospital, or if the index discharge and subsequent admission occurred on the same day (suggesting a within-hospital transfer rather than a true discharge).

Treadmill stress testing and exercise capacity

Treadmill stress testing was used to determine exercise capacity. Patients performed standard tests using either the Bruce or modified Bruce protocols. Reasons for testing included evaluation of chest pain, ruling out of coronary artery disease (CAD), preoperative evaluation, evaluation of known CAD, evaluation of HF, and evaluation of post-organ transplant functional capacity. Tests were limited by signs and symptoms, including chest pain, shortness of breath, inability to maintain treadmill workload, or patient request to stop. According to standard procedures outlined by the American College of Sports Medicine,¹⁵ tests were terminated at maximal capacity or at the discretion of the physician for arrhythmias, abnormal hemodynamic changes, or diagnostic ST segment changes.

Exercise capacity was abstracted from the test report and expressed in metabolic equivalents (METs) based on the workload derived from maximal speed and grade achieved during treadmill testing. Values were converted using published equations for walking and running.¹⁶ The energy demand of stage 1 is equivalent to 4.6 METs, of stage 2 is 7 METs, and of stage 3 is 10.1 METs. To account for the heterogeneity in definitions of METs categories,^{17–19} exercise capacity was categorized based

on the peak workload achieved as follows: <5 METs (low), 5–7 METs (medium), and >7 METs (high). Peak heart rate achieved during the test was recorded and calculated as a percentage of the predicted maximal heart rate (220 minus age) to validate each test. In patients with multiple treadmill tests, only the test nearest the time of index discharge was used in the analysis.

Outcomes

The primary outcome was all-cause readmission within 30 days of index discharge. Secondary outcomes were all-cause readmission within 6 months (inclusive of 30 days) and 1 year (inclusive of 30 days and 6 months), as well as total hospitalizations per patient. Multiple readmissions per patient were not counted except for total hospitalizations per patient.

Other measurements

Covariates included age, sex, self-reported race/ethnicity, body mass index (BMI), indication for exercise test, peak heart rate measured as the per cent of predicted maximal heart rate, and comorbid diagnoses related to cardiovascular disease (hypertension, hyperlipidemia, CAD, chronic kidney disease (CKD), COPD, HF, and peripheral vascular disease (PVD)). All variables were abstracted or calculated at or nearest to the time of the treadmill stress test. BMI was calculated using height and weight documented within 6 months of the treadmill stress test. The presence of hypertension, hyperlipidemia, CAD, CKD, COPD, HF, and PVD was based on an ICD-9 or ICD-10 diagnosis documented on or before the date of the treadmill stress test using the following definitions: hypertension (ICD-9 401.xx–405.xx or ICD-10 I10.xx, I15.xx, or I16.xx), hyperlipidemia (ICD-9 272.0x–272.4x or ICD-10 E78.0x–E78.5x), CAD (ICD-9 410.xx–414.xx or ICD-10 I20.xx, I21.xx, I22.xx, or I25.xx), CKD (ICD-9 585.xx or ICD-10 N18.xx), COPD (ICD-9 491.2x or ICD-10 J44.x), PVD (ICD-9 250.7x, 440.xx, 443.xx, or 444.xx or ICD-10 I73.x, I74.x, I75.x, E10.51, E10.52, E11.51, or E11.52), and HF (ICD-9 428.xx or ICD-10 I50.xxx).

Analysis

Summaries of categorical variables included counts and percentages, while means and SD or medians and IQRs were used for continuous variables. Means and percentages were calculated for the study population overall, by 30-day, 6-month, and 1-year readmission, METs category, and number of hospitalizations per patient. Univariate analyses with χ^2 or independent t-tests were performed for all variables to determine those associated with 30-day, 6-month, and 1-year readmission. Differences across the three METs categories were compared using analysis of variance (ANOVA) for continuous variables. Independent t-tests, ANOVA, and Pearson's correlation coefficient were performed for all variables to determine those associated with number of hospitalizations per patient. Multinomial multivariable logistic regression models to predict 30-day, 6-month, and 1-year readmission and a linear regression

Table 1 Demographic characteristics of 580 patients with diabetes by 30-day readmission

Variables	Whole sample N=580	30-day readmission n=117	No readmission n=463	P value	Effect size (CI)*
Age (years), mean (SD)	57.8 (10.6)	59.6 (10.2)	57.4 (10.7)	0.047	0.21 (0.00 to 0.41)
Sex, n (%)					
Female	230 (39.7)	36 (30.8)	194 (41.9)	0.028	0.62 (0.39 to 0.96)
Male	350 (60.3)	81 (69.2)	269 (58.1)		
Race/ethnicity, n (%)					
Black	183 (31.6)	38 (33.3)	145 (31.3)	0.970	
Hispanic	264 (45.5)	54 (46.2)	210 (45.4)		
White	99 (17.1)	19 (16.2)	80 (17.3)		
Other or not documented	34 (5.9)	6 (5.1)	28 (6.0)		
BMI, mean (SD)	31.8 (6.3)	30.2 (5.7)	32.2 (6.4)	0.016	0.32 (0.01 to 0.58)
CAD, n (%)	111 (19.1)	29 (24.8)	82 (17.7)	0.082	
Hypertension, n (%)	220 (37.9)	52 (44.4)	168 (36.3)	0.104	
Hyperlipidemia, n (%)	187 (32.2)	43 (36.8)	144 (31.3)	0.243	
CKD, n (%)	34 (5.9)	14 (12.0)	20 (4.3)	0.002	3.01 (1.47 to 6.16)
HF, n (%)	169 (29.1)	51 (43.6)	118 (25.5)	<0.001	2.26 (1.48 to 3.44)
COPD, n (%)	123 (21.2)	33 (28.2)	90 (19.4)	0.04	1.63 (1.02 to 2.59)
PVD, n (%)	130 (22.4)	29 (24.8)	101 (21.8)	0.491	
% of predicted maximal HR, mean (SD)	86.8 (11.2)	84.0 (12.6)	87.5 (10.8)	0.007	0.29 (0.08 to 0.49)
METs, mean (SD)	6.5 (2.7)	5.7 (2.6)	6.7 (2.6)	<0.001	0.36 (0.18 to 0.59)

Bold values indicate a statistically significant result.

*Effect size was calculated for significant estimates: Cohen's d was calculated for age, BMI, peak heart rate, and METs. OR was calculated for sex, CKD, HF, and COPD.

BMI, body mass index; CAD, coronary artery disease; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; HF, heart failure; HR, heart rate; METs, metabolic equivalents; PVD, peripheral vascular disease.

model to predict number of hospitalizations per patient were conducted. Variables independently associated with 30-day, 6-month, and 1-year readmission at the $p < 0.05$ level were retained in the models after enter selection. Variable selection by backward elimination, forward stepwise, and enter regression produced similar models for 30-day readmission; thus, only enter regression was used for modeling 6-month and 1-year readmission. All statistical analyses were performed using IBM SPSS Statistics V.24. P values less than 0.05 were considered statistically significant.

RESULTS

A total of 580 patients with diabetes were included (table 1). The mean age was 57.8 ± 10.6 years; 39.7% were women, 31.6% were black, and 45.5% were Hispanic. A diagnosis of CAD, hypertension, hyperlipidemia, CKD, HF, COPD, and/or PVD was common. The mean METs scores of readmitted patients were significantly lower than for non-readmitted patients ($5.7 (2.6)$ vs $6.7 (2.6)$, $p < 0.001$). In addition, readmitted patients were more likely to be male and have HF and COPD, less likely to have CKD, and had a lower BMI.

During the 6.5-year study period, patients experienced a total of 1598 hospital hospitalizations. Patients in the low METs group ($n=251$) had 803 hospitalizations (mean 3.2 ± 3.6 per patient). In the medium METs group ($n=181$), patients had 421 hospitalizations (mean 2.3 ± 2.3 per patient), while those in the high METs group ($n=148$) had 374 hospitalizations (mean 2.5 ± 2.4 per patient, $p=0.007$, $d=0.26 (0.09-0.43)$). Patients with low exercise capacity were more likely to have a 30-day, 6-month, and 1-year readmission than patients with medium and high exercise capacity (table 2).

Patients with low exercise capacity had more than five-fold greater odds of 30-day readmission (table 3) than patients with high exercise capacity after adjusting for age, sex, race, BMI, CAD, hypertension, hyperlipidemia, CKD, HF, COPD, PVD, and peak heart rate.

Patients with low exercise capacity had almost three-fold greater odds of 6-month readmission (table 4) than patients with high exercise capacity after adjusting for all covariates.

Patients with low exercise capacity had twofold greater odds of 1-year readmission (table 5) than patients with high exercise capacity after adjusting for all covariates.

Table 2 Univariate associations with exercise capacity

Variables	Low METs (n=251)	Medium METs (n=181)	High METs (n=148)	P value	Effect size (95% CI)*
Age (years), mean (SD)	60.7 (10.4)	57.6 (10.6)	53.3 (9.6)	<0.001	0.49 (0.32 to 0.66)
Sex, n (%)					
Female	113 (45)	68 (37.6)	49 (33.1)	0.050	
Male	138 (55)	113 (62.4)	99 (66.9)		
Race/ethnicity, n (%)					
Black	83 (33.1)	59 (32.6)	41 (27.7)	0.542	
Hispanic	104 (41.4)	83 (45.9)	77 (52.0)		
White	49 (19.5)	29 (16)	21 (14.2)		
Other or not documented	15 (6)	10 (5.5)	9 (6.1)		
BMI, mean (SD)	31.9 (6.4)	32.9 (6.7)	30.1 (5.2)	0.004	0.04 (−0.17 to 0.25)
CAD, n (%)	56 (22.3)	27 (14.9)	28 (18.9)	0.156	
Hypertension, n (%)	98 (39)	64 (35.4)	58 (39.2)	0.691	
Hyperlipidemia, n (%)	83 (33.1)	53 (29.3)	51 (34.5)	0.566	
CKD, n (%)	15 (6.0)	6 (3.3)	13 (8.8)	0.110	0.15 (0.08 to 0.23)
HF, n (%)	94 (37.5)	44 (24.3)	31 (20.9)	<0.001	
COPD, n (%)	59 (23.5)	40 (22.1)	24 (16.2)	0.214	
PVD, n (%)	58 (23.1)	38 (21.0)	34 (23.0)	0.858	
% of predicted maximal HR, mean (SD)	61.2 (8.6)	64.9 (8.2)	67.4 (7.7)	<0.001	0.56 (0.37 to 0.75)
Readmission, n (%)					
30-day	67 (26.7)	29 (16.0)	21 (14.2)	0.003	0.13 (0.05 to 0.21)
6-month†	89 (35.5)	47 (26.0)	35 (23.6)	0.020	0.11 (0.03 to 0.19)
1-year‡	159 (63.3)	93 (51.4)	81 (54.7)	0.034	0.08 (0.00 to 0.16)
Hospitalizations per patient, mean (SD)	3.2 (3.6)	2.3 (2.3)	2.5 (2.4)	0.007	0.26 (0.10 to 0.47)

Bold values indicate a statistically significant result.

*Effect size was calculated for significant estimates: Cohen's d was calculated for age, BMI, peak heart rate, and hospitalizations per patient. Pearson's r correlation was calculated for HF and 30-day, 6-month and 1-year readmission.

†Readmission within 6 months of discharge inclusive of 30 days.

‡Readmission within 1 year of discharge inclusive of 30 days and 6 months.

BMI, body mass index; CAD, coronary artery disease; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; HF, heart failure; HR, heart rate; METs, metabolic equivalents; PVD, peripheral vascular disease.

Relative to high exercise capacity, low exercise capacity was associated with a greater number of hospitalizations per patient after adjustment for all covariates ($\beta=0.96$ (0.13–1.79), $p=0.024$) (online supplemental appendix table 6).

DISCUSSION

The purpose of the present study was to examine whether there is an association between exercise capacity and readmission risk among patients with diabetes. We found that lower exercise capacity based on the maximal workload achieved during treadmill stress testing was associated with a greater risk of 30-day, 6-month, and 1-year

readmission rate in patients with diabetes. We also found that low exercise capacity is associated with a greater incidence of hospitalizations per patient. These findings add to the prognostic importance of exercise capacity, an established predictor of mortality and vascular complications in patients with diabetes.^{6 9 10 20} Furthermore, the findings suggest that exercise capacity may be a modifiable risk factor for readmission up to 1 year after discharge, and suggest the hypothesis that improving exercise capacity decreases the risk of readmission for patients with diabetes.

To the best of our knowledge, this study is the first to evaluate the association between exercise capacity and

Table 3 Association of exercise capacity and other factors with 30-day readmission in multivariable logistic regression model*

Predictor	OR (95% CI)	P value
Low METs	5.46 (2.22 to 13.45)	<0.001
Medium METs	1.85 (0.71 to 4.81)	0.21
Sex (male)	0.41 (0.21 to 0.79)	0.008
BMI	0.93 (0.88 to 0.98)	0.01
CKD	2.47 (1.00 to 6.05)	0.049

Bold values indicate a statistically significant result.
 *Only statistically significant covariates are presented in the table. BMI, body mass index; CKD, chronic kidney disease; METs, metabolic equivalents.

readmission in patients with diabetes. Although there are no other studies with which we can directly compare these results, our findings are consistent with studies showing similar associations in patients with COPD and HF.^{21 22} For example, Chawla *et al*²¹ found that patients with COPD with lower levels of physical activity over the first week after hospital discharge were more likely to have all-cause 30-day readmission. In a recent review article, Aronow and Shamliyan²² reviewed 7 meta-analyses and 48 randomized controlled trials, and recommended exercise interventions to improve exercise capacity for adults with HF in order to reduce hospitalization risk and improve the quality of life. It is plausible that exercise capacity serves as a marker for cardiopulmonary function and metabolism that is broadly applicable to patients with chronic conditions such as diabetes, COPD, and HF. Lower exercise capacity may also be associated with depression, a risk factor for readmission among patients with diabetes.⁵ In the Look AHEAD (Action for Health in Diabetes) study, participants with type 2 diabetes who received the intensive diet and exercise intervention had a lower incidence of depression symptoms and fewer hospitalizations.^{23 24}

Although improving exercise capacity is important, it is a challenging endeavor for many patients to engage in physical activity. Good patient–clinician health

Table 4 Association of exercise capacity and other factors with 6-month readmission in multivariable logistic regression model*

Predictor	OR (95% CI)	P value
Low METs	2.78 (1.36 to 5.65)	0.005
Medium METs	1.37 (0.66 to 2.85)	0.403
Sex (male)	0.32 (0.18 to 0.56)	<0.001
BMI	0.94 (0.89 to 0.98)	0.006
HF	1.81 (1.06 to 3.08)	0.030

Bold values indicate a statistically significant result.
 *Only statistically significant covariates are presented in the table. BMI, body mass index; HF, heart failure; METs, metabolic equivalents.

Table 5 Association of exercise capacity and other factors with 1-year readmission in multivariable logistic regression model*

Predictor	OR (95% CI)	P value
Low METs	2.16 (1.12 to 4.16)	0.022
Medium METs	1.24 (0.64 to 2.38)	0.527
Age	0.95 (0.92 to 0.97)	<0.001
BMI	0.91 (0.87 to 0.95)	<0.001
HF	2.70 (1.54 to 4.74)	0.001

Bold values indicate a statistically significant result.
 *Only statistically significant covariates are presented in the table. BMI, body mass index; HF, heart failure; METs, metabolic equivalents.

communication guided by the use of shared decision making (SDM) approach during and after hospitalization has the potential to help patients increase their physical activity. SDM studies in general,^{25 26} and particularly in diabetes,^{27–29} indicate promising engagement outcomes for treatment uptake. However, most SDM studies in diabetes targeted treatment-related decisions, and tools for motivating patient engagement in physical activity are lacking. Studies developing and testing SDM and health communication tools to support physical activity engagement are needed.

Our study has several limitations that warrant discussion. First, the association of low exercise capacity with readmission in this retrospective observational study does not establish causation. Furthermore, the mechanisms by which lower exercise capacity may have contributed to readmission risk cannot be established. Second, the data were drawn from electronic health records not designed for research. This precludes definitive assessment of diabetes type, although it is very likely that the vast majority of patients had type 2 diabetes, consistent with the general population. Similarly, exercise tests were administered for diagnostic purposes rather than to assess fitness. In addition, exercise capacity could have changed during the study period after the baseline assessment. However, we and others believe fitness measured at one time to be informative of fitness throughout many years.³⁰ Third, data on deaths after hospital discharge were not available, so only inpatient deaths were excluded. Finally, we cannot rule out residual confounding from unmeasured variables, including secular trends related to changes in practice that occurred during the study.

Despite these limitations, our study has several strengths. We analyzed objectively measured functional data on exercise capacity obtained through the commonly performed treadmill stress test rather than relying on subjective questionnaires of physical activity.³¹ Our cohort was ethnically diverse and 45% female, suggesting some degree of generalizability.

In summary, lower exercise capacity is associated with a higher risk of hospital readmission in patients with diabetes. Future studies are needed to explore whether

exercise reduces readmission risk in this population and how behavioral health communication tools may motivate physical activity engagement among patients with diabetes.

Contributors DJR was responsible for study concept and design. YZ-I was responsible for analysis, and DJR and YZ-I were responsible for interpretation of data. YZ-I, KF, and DJR drafted the manuscript versions. MW provided access to all the data. KF prepared the data for analysis.

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Competing interests None declared.

Patient consent for publication Not required.

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Data availability statement Data are available upon reasonable request.

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