# Postexercise Hemodynamics in Patients With Type 2 Diabetes: Effect of Exercise Intensity and Duration

Thomas K. Pellinger, PhD, ACSM-RCEP[1], Catherine B. Pearce, MS[1], Grant H. Simmons, PhD[2], Jack L. Snitzer, DO[3]




## ABSTRACT

**Background:** For individuals with type 2 diabetes (T2D), the hemodynamic response to regular exercise is critical for regulating blood glucose, protecting vascular function, and reducing cardiovascular disease risk, but the hemodynamic responses to differing doses of acute exercise in T2D are unclear. We aimed to compare postexercise (PE) hemodynamics in patients with T2D in response to 4 doses of dynamic exercise.

**Methods:** Eight subjects with well-controlled T2D (42-64 years old.; hemoglobin A1c: 6.6% ± 0.9%) participated in 4 study days, during which they exercised on a cycle ergometer at 4 different combinations of exercise duration and intensity: 30 min at 40% $\dot{V}O_{2peak}$ (30@40), 30 min at 60% $\dot{V}O_{2peak}$ (30@60), 60 min at 40% $\dot{V}O_{2peak}$ (60@40), and 60 min at 60% $\dot{V}O_{2peak}$ (60@60). Heart rate, arterial pressure, and femoral blood flow (Doppler ultrasound) were measured pre-exercise and every 15 min through 120 min PE. Femoral vascular conductance was calculated as flow/pressure.

**Results:** Compared with pre-exercise baseline, femoral blood flow and femoral vascular conductance were higher through at least 105 min of recovery in all conditions (all $P < .05$), except for the 30@40 trial. Compared with the pre-exercise measures, systolic blood pressure was lower through at least 75 min of recovery in all conditions (all $P < .05$), except for the 30@40 trial.

**Conclusion:** These results suggest that exercise must be at least moderate in intensity or prolonged in duration (>30 min) to promote sustained PE elevations in skeletal muscle blood flow and reductions in systolic blood pressure in patients with T2D.

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**Keywords:** skeletal muscle vasodilation, postexercise hypotension, blood pressure, physical activity, dose

## INTRODUCTION

It is well established that regular physical activity provides a myriad of benefits for those with type 2 diabetes (T2D), including improved blood glucose regulation (reduced hemoglobin A1c) (1,2), increased whole-body insulin sensitivity (3), and the delay or prevention of cardiovascular disease (4). In addition to these benefits of regular physical activity, research suggests that even a single bout of dynamic exercise stimulates increased insulin-mediated glucose uptake (5) and insulin sensitivity (6) in patients with T2D during the acute recovery period. Moreover, recent investigations have observed associations between the magnitude of acute exercise-induced responses and chronic training-induced adaptations (7,8), raising the possibility that acute postexercise (PE) responses—if documented—might guide practitioners to ensure that training is undertaken with sufficient intensity and duration to maximize improvements in metabolic and cardiovascular health.

Recent research indicates that in healthy individuals, elevated PE skeletal muscle blood flow plays a role in both normal glucose delivery (9,10) and insulin sensitivity (11)

[1]Department of Health Sciences, Salisbury University, Salisbury, Maryland
[2]Department of Medical Pharmacology & Physiology, University of Missouri School of Medicine, Columbia, Missouri
[3]Peninsula Regional Medical Group, Peninsula Regional Medical Center, Salisbury, Maryland

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Address for correspondence: Thomas K. Pellinger, PhD, 319-B Devilbiss Hall, 1101 Camden Avenue, Salisbury University, Salisbury, MD 21801-6860; (410) 677 0144; fax (410) 548 9185; e-mail: tkpellinger@salisbury.edu.

following dynamic exercise. These results suggest that elevated PE skeletal muscle blood flow in those with T2D may serve to circumvent insulin resistance, thereby helping improve insulin sensitivity and overall glucose regulation in this population. However, the hemodynamic responses to differing doses of acute exercise in patients with T2D have yet to be established. Therefore, our aim was to compare PE hemodynamics in individuals with T2D in response to 4 different doses of acute dynamic exercise. The goal of the current investigation was to inform exercise prescription for patients with T2D by identifying the minimum intensity and/or duration of dynamic exercise required to evoke sustained PE hemodynamic changes in this population. We tested the hypothesis that exercise must be at least moderate in intensity (60% of $\dot{V}O_{2peak}$) and/or prolonged in duration (>30 min) to promote persistent PE skeletal muscle vasodilation and decreased systolic blood pressure in those with T2D.

## METHODS

### Ethical Approval

This study was approved by the Institutional Review Board of Salisbury University. Each subject gave his or her informed, written consent prior to participation in the study.

### Subjects

Eight nonsmoking individuals with T2D (5 men, 3 women) between the ages of 42 and 64 years participated in this study. To be included in the study, subjects had to have been diagnosed with T2D between 6 months and 15 years from enrollment, have hemoglobin A1c <9%, have a body mass index <35 $kg \cdot m^{-2}$, and be free of diabetic complications, including retinopathy, nephropathy, and autonomic and peripheral neuropathy. In addition, subjects had to be free of comorbidities, including but not limited to coronary artery disease, pulmonary disease, and cancer. Participants could be taking a maximum of 3 diabetes medications. In addition, participants were allowed to take any of the following: aspirin, dyslipidemia medications, angiotensin-converting enzyme inhibitors, ß-adrenergic blocking agents, and osteoporosis medications.

For all study visits, subjects reported to the laboratory at least 3 h postprandial, having refrained from alcohol consumption and exercise for 24 h and consumption of caffeine for 12 h. Subjects were instructed to take medications according to their normal schedule, as prescribed by their physicians. All female subjects were postmenopausal, so the potential effects of reproductive hormones on cardiovascular regulation were minimized. To confirm acceptable blood glucose levels (100-250 $mg \cdot dL^{-1}$), blood glucose was measured using a handheld glucose monitor (FreeStyle Lite, Abbott Laboratories, Abbott Park, Illinois) at the beginning and end of every study visit. If a subject had a blood glucose reading above this range, the study visit would be rescheduled; when a blood glucose reading fell below this range, the subject consumed 177 mL of apple juice and the blood glucose measurement was repeated in 15 min.

### Screening Visit

Subjects initially visited the laboratory to perform a peak aerobic power test on a cycle ergometer, in addition to self-reporting physical activity levels on a questionnaire (12). Subjects performed an incremental cycle exercise test (Lode Corival Ergometer, Groningen, The Netherlands) comprising 1-min workload increments to determine peak oxygen uptake ($\dot{V}O_{2peak}$). Specifically, after a 2-min warm-up period (20-25 W), workload was increased in a ramped manner by 10, 15, or 20 W every minute. Selection of the workload increment was based on self-reported subject activity levels, with the goal of producing exhaustion within 8 to 12 minutes. The $\dot{V}O_{2peak}$ was determined via indirect calorimetry (TrueOne 2400, ParvoMedics, Sandy, Utah) with 15 second sampling times. Peak aerobic power was determined to have been attained when 2 or more of the following criteria were met: (1) the subject was unable to maintain a cadence of 60 revolutions per minute, (2) the subject achieved a respiratory exchange ratio >1.15, or (3) the subject reached subjective exhaustion (rating of perceived exertion; score of 19 to 20 on the Borg [13] scale).

After resting for 10 min, subjects returned to the cycle ergometer to determine the workloads corresponding to steady-state oxygen consumptions of 40% and 60% of $\dot{V}O_{2peak}$. Target workloads were estimated based on each individual's $\dot{V}O_{2peak}$ and subsequently titrated until the respective target oxygen consumption was maintained for 5 min. The resulting workloads were used on subsequent study days for both the 30-min and 60-min exercise bouts. Throughout the screening visit, heart rate (HR) and rhythm were monitored via a wireless 6-lead electrocardiogram (ECG; Norav 1200W Stress ECG System, Wiesbaden, Germany). Arterial pressure during exercise was determined via manual auscultometry, by the same investigator each time.

### Experimental Protocol

Between 5 and 7 days following the screening visit, subjects reported for parallel experiments on 4 separate, randomized study days, each separated by 2 to 7 days. During the study visits, they exercised on an upright cycle ergometer at 4 different combinations of exercise duration and intensity: 30 min at 40% $\dot{V}O_{2peak}$ (30@40), 30 min at 60% $\dot{V}O_{2peak}$ (30@60), 60 min at 40% $\dot{V}O_{2peak}$ (60@40), and 60 min at 60% $\dot{V}O_{2peak}$ (60@60). All experiments were performed in a temperature-controlled laboratory with the ambient temperature maintained between 21°C and 22°C.

On each study day, subjects were placed in the supine position for instrumentation. Following 10 min of quiet rest, baseline measurements of HR, arterial pressure, and femoral blood flow (FBF; discussed later) were taken in duplicate. If the 2 HR measurements varied by more than 5 beats min or the mean arterial pressure measurements varied by more than 6 mmHg, a third measurement was taken. After resting baseline measurements were obtained, subjects were moved to the upright cycle ergometer, where they exercised for that visit's predetermined duration and intensity. During

exercise, blood pressure, HR, and arterial oxyhemoglobin saturation were measured every 15 min. Subjects consumed 10 mL of water per kilogram of body weight, distributed evenly every 15 min throughout the protocol to offset volume loss during exercise.

Immediately after exercise, subjects returned to the supine position for instrumentation. Measurements of HR, arterial pressure, and FBF were taken in duplicate every 15 min through 120 min PE. Leg blood velocity and ECG data were collected in real time and saved for subsequent analysis in a data acquisition system (PowerLab 8/35 Data Acquisition System, AD Instruments, Colorado Springs, Colorado).

## Measurements

### *Heart Rate, Arterial Pressure, and Oxygen Saturation*

Throughout all study visits, HR and cardiac conduction were monitored via 6-lead ECG (Dual Bio Amplifier/ECH 12-Lead Switch Box, AD Instruments). Arterial pressure was measured with an automated oscillometric device (Welch Allyn Vital Signs Monitor, Skaneateles Falls, New York) during resting conditions. Arterial pressure during exercise was determined via manual auscultometry, and oxygen saturation was measured on the finger via pulse oximeter (Welch Allyn Vital Signs Monitor).

### *Leg Blood Flow*

Mean blood velocities and diameters of the common femoral artery were measured using a linear ultrasound probe (11-3L Ultraband trapezoidal linear-array vascular transducer, Philips, Amsterdam, The Netherlands) placed distal to the inguinal ligament, approximately 2 to 3 cm proximal to the bifurcation. The entire width of the artery was insonated with an angle of 60°, and velocity measurements were taken immediately before diameter measurements. All Doppler ultrasound measurements were conducted by the same investigator, with a coefficient of variation of 2.76% in measurements of femoral blood velocity with the system used in this investigation. A Doppler Audio Translator (Penn State Heart & Vascular Institute) was used to convert the 2 analog Doppler audio signals (Sonos 4500 ultrasound system, Philips) into a proportional time-varying flow velocity waveform that was recorded by the data acquisition system (14). Leg blood flow was calculated as artery cross-sectional area multiplied by femoral mean blood velocity, and reported as $mL \cdot min^{-1}$. Femoral vascular conductance (FVC) was calculated as leg blood flow divided by mean arterial pressure and expressed as $mL \cdot min^{-1} \cdot mmHg^{-1}$.

## Statistics

Hemodynamics were compared at rest and during exercise (for data measured during exercise) across study visits by 1-way repeated measures analysis of variance (ANOVA), and pairwise differences were evaluated using the Bonferroni method when appropriate. The PE responses in central (HR, systolic blood pressure, diastolic blood pressure, and mean arterial pressure) and peripheral (FBF, FVC) hemodynamics were the primary data of interest. For each dependent variable in this set, a 2-way repeated measures ANOVA was used to evaluate the effects of condition (4 levels: 30@40, 30@60, 60@40, and 60@60) and time (9 levels: pre-exercise and 15, 30, 45, 60, 75, 90, 105, and 120 minutes PE) on the response. When significant main or interaction effects were detected, further analysis was performed using the Holm-Sidak method. The alpha level was set at 0.05, and all values are reported as means ± standard error unless otherwise noted. Analyses were made using SigmaPlot version 12.5 (Systat Software Inc., San Jose, California) statistical software.

TABLE 1. Subject characteristics (n=8).

| | |
|---|---|
| Age (years) | 56 ± 8 |
| Sex (male/female) | 5/3 |
| Height (cm) | 170 ± 8 |
| Weight (kg) | 83 ± 18 |
| Body mass index (calculated as $kg \cdot m^{-2}$) | 28.3 ± 4.7 |
| $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) | 24.7 ± 5.6 |
| Workload at $\dot{V}O_{2peak}$ (watts) | 176 ± 59 |
| Hemoglobin A1c (%) | 6.6 ± 0.9 |
| Baecke sport index (arbitrary units) | 7.9 ± 1.2 |
| Concomitant medications (n) | |
| Metformin | 6 |
| Statins | 2 |
| Thiazolidinedione | 1 |
| Dipeptidyl peptidase-4 inhibitor | 1 |
| Angiotensin-converting enzyme inhibitor | 1 |
| ß-adrenergic blockade | 1 |

$\dot{V}O_{2peak}$ = peak oxygen consumption
Data are mean ± standard deviation of n.

## RESULTS

Subject characteristics are presented in Table 1. Table 2 displays resting and exercise (where available) values for HR, FBF, FVC, arterial pressures, and blood glucose on each of the study days. Exercise values are all taken from minute 30 of the exercise bout.

## Effect of Exercise Dose on PE Arterial Pressures

The PE changes in systolic, diastolic, and mean arterial pressure following 4 different doses of aerobic exercise are displayed in Figure 1. We observed a significant main effect of time on each of these responses ($F$ = 10.274, 3.036, and 6.176 for systolic, diastolic, and mean arterial pressures, respectively; all $P < .05$). Systolic pressure was lower after exercise in each condition except the lowest exercise dose (30 min at 40% $\dot{V}O_{2peak}$) and remained depressed through at least 75 minutes PE. In contrast, diastolic pressure was no different from pre-exercise baseline at any time point, and thus, responses in mean arterial pressure were less pronounced and persisted for a shorter duration. The exception

TABLE 2. Resting and exercising hemodynamics and blood glucose.

| Study Day: | 30 min at 40% $\dot{V}O_{2peak}$ | | 30 min at 60% $\dot{V}O_{2peak}$ | | 60 min at 40% $\dot{V}O_{2peak}$ | | 60 min at 60% $\dot{V}O_{2peak}$ | |
|---|---|---|---|---|---|---|---|---|
| **Measures** | **Rest** | **Exercise** | **Rest** | **Exercise** | **Rest** | **Exercise** | **Rest** | **Exercise** |
| Heart rate (beats×min-1) | 64±2.8 | 102±4.9 | 64±2.7 | 125±5.8* | 63±2.6 | 102±4.6 | 62±2.7 | 124±6.8* |
| Systolic blood pressure (mmHg) | 118±4.7 | 137±3.6 | 118±4.6 | 147±4.6* | 118±5.1 | 139±5.1 | 117±5.0 | 148±3.9* |
| Diastolic blood pressure (mmHg) | 71.0±3.2 | 75.3±2.2 | 70.0±2.9 | 77.7±1.3 | 69.4±2.8 | 76.3±1.4 | 69.6±3.2 | 76.5±1.5 |
| Mean arterial pressure (mmHg) | 87±3.2 | 96±2.0 | 86±3.2 | 101±2.3† | 86±3.2 | 97±2.3 | 86±3.5 | 100±1.6 |
| Femoral blood flow ($mL \times min^{-1}$) | 324.6±63.7 | – | 305.5±55.3 | – | 305.2±38.7 | – | 291.8±54.6 | – |
| Femoral vascular conductance ($mL \times min^{-1} \times mmHg^{-1}$) | 3.79±0.80 | – | 3.52±0.58 | – | 3.57±0.44 | – | 3.45±0.66 | – |
| Blood [glucose] ($mg \times dL^{-1}$) | 124.1±8.3 | – | 118.6±6.2 | – | 128.6±12.0 | – | 123.1±12.3 | – |

[a]Values are means ± standard error (n = 8). Exercise values were obtained at 30 min of each exercise bout.
*$P < .05$ vs. 30 min at 40% $\dot{V}O_{2peak}$ and 60 min at 40% $\dot{V}O_{2peak}$ exercise trials; †$P < .05$ vs. 30 min at 40% $\dot{V}O_{2peak}$ exercise trial.

to this was the 30 min at 60% $\dot{V}O_{2peak}$ condition in which reductions in mean arterial pressure were sustained through 75 min PE ($P < .05$ vs. baseline for each time point).

### Effect of Exercise Dose on PE HR and Perfusion

The PE changes in HR, FBF, and FVC following 4 different doses of aerobic exercise are displayed in Figure 2. We observed a significant dose-by-time interaction effect on each of these responses ($F = 4.365$, 1.898, and 1.948 for HR, FBF, and FVC respectively; all $P < .05$). The PE HR was significantly higher in the 60 min at 60% $\dot{V}O_{2peak}$ exercise condition than in both conditions carried out at 40% $\dot{V}O_{2peak}$ throughout the entire PE period with the exception of 2 time points (all $P < .05$). A similar separation was observed when contrasting the 30 min at 60% $\dot{V}O_{2peak}$ responses to both 40% $\dot{V}O_{2peak}$ workload trials (both $P < .05$), but only at the first time point measured after exercise. Consistent with these between-condition differences, when compared with pre-exercise baseline, HR was elevated PE only in the conditions characterized by the higher exercise workload, and PE HR increases were more sustained in the longer duration exercise condition (60 min at 60% $\dot{V}O_{2peak}$; see Figure 2).

Post hoc analysis of the exercise dose effects revealed that PE FBF and FVC responses were similar between conditions except for the first time point immediately following exercise. At this time point (15 min) the higher exercise intensity (60% $\dot{V}O_{2peak}$) elicited a greater FBF and FVC compared with the lower-intensity bout when exercise was 30 min in duration ($P < .05$ between conditions). Also, and consistent with the statistically significant dose × time interaction noted previously, the decays in FBF and FVC after exercise were faster in the 30 min at 40% $\dot{V}O_{2peak}$ condition compared with the other conditions. Whereas elevated FBF and FVC were sustained for only 30 min PE in this condition (lowest exercise dose), each of the other exercise conditions evoked persistent elevations in FBF and FVC that were sustained for at least 105 min following exercise (see Figure 2).

## DISCUSSION

The aim of this study was to compare PE hemodynamics in individuals with T2D in response to 4 different doses of acute dynamic exercise. The primary outcomes are that all exercise conditions, except for the 30 min at 40% of $\dot{V}O_{2peak}$ trial, evoked sustained PE elevations in FBF and FVC, as well as sustained PE reductions in systolic blood pressure. To our knowledge, this study is the first to describe the relationship between exercise dose and PE hemodynamics in patients with T2D. Consistent with our hypothesis, these findings suggest that exercise must be at least moderate in intensity (60% of $\dot{V}O_{2peak}$) or prolonged in duration (>30 min), to promote persistent PE skeletal muscle vasodilation and decreased systolic blood pressure in those with T2D.

Following an acute bout of dynamic exercise, humans experience PE hypotension (PEH), which is characterized by sustained PE skeletal muscle vasodilation that is not completely offset by a still elevated cardiac output (15,16). Multiple mechanisms appear to be responsible for the sustained PE vasodilation of the previously active skeletal muscle vascular beds. The baroreflex is reset to defend a lower pressure following exercise (17), which results in a reduction in PE muscle sympathetic outflow in humans (17). Moreover, for a given level of sympathetic nerve activity, there is reduced vascular resistance in the previously active skeletal muscle vascular beds following exercise (17,18). Finally, PE skeletal muscle vasodilation is mediated locally by activation of the histamine $H_1$ and $H_2$ receptors, as combined $H_1$- and

FIGURE 1. Time-course of postexercise changes in systolic (SBP; panel A), diastolic (DBP; panel B), and mean arterial pressure (MAP; panel C) compared with pre-exercise baseline values. Responses to 4 different doses of cycling exercise are shown (30 min at 40% $\dot{V}O_{2peak}$, 30 min at 60% $\dot{V}O_{2peak}$, 60 min at 40% $\dot{V}O_{2peak}$, and 60 min at 60% $\dot{V}O_{2peak}$). * $P < .05$ vs. pre-exercise baseline time point within exercise dose (n = 8). Symbols indicating statistical significance are color coded to match the relevant exercise dose.

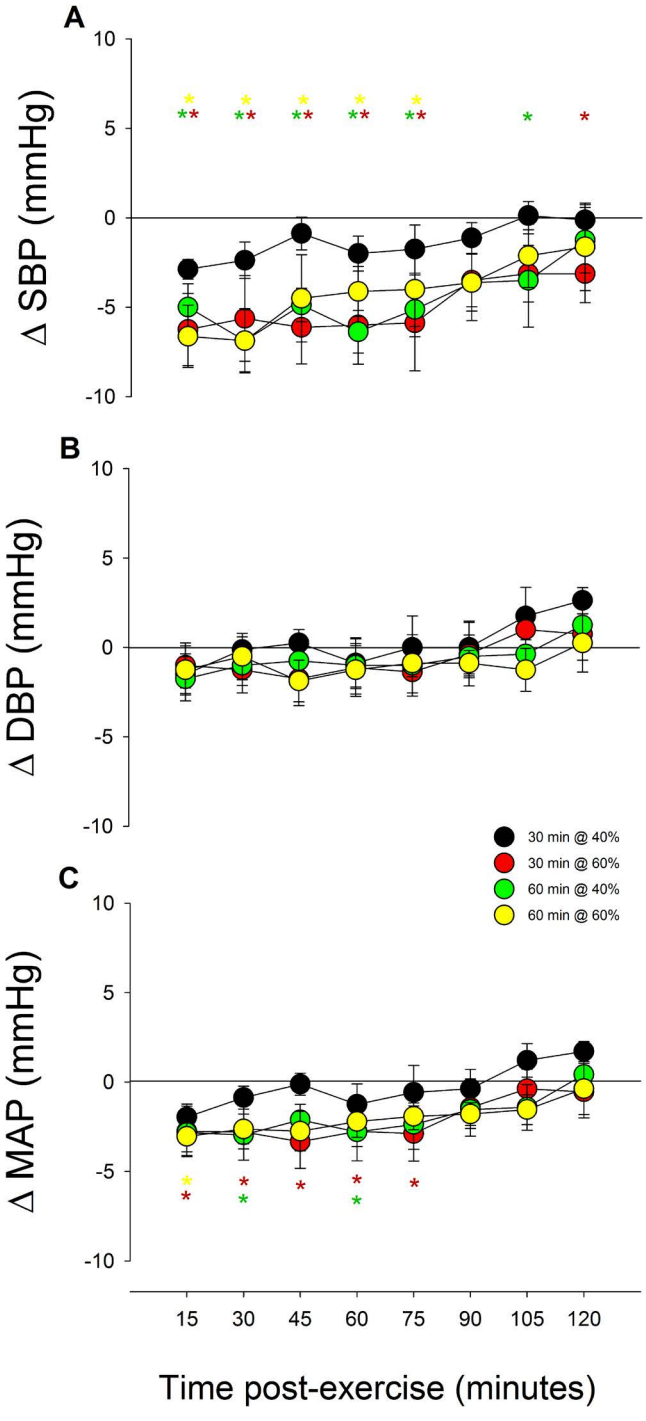
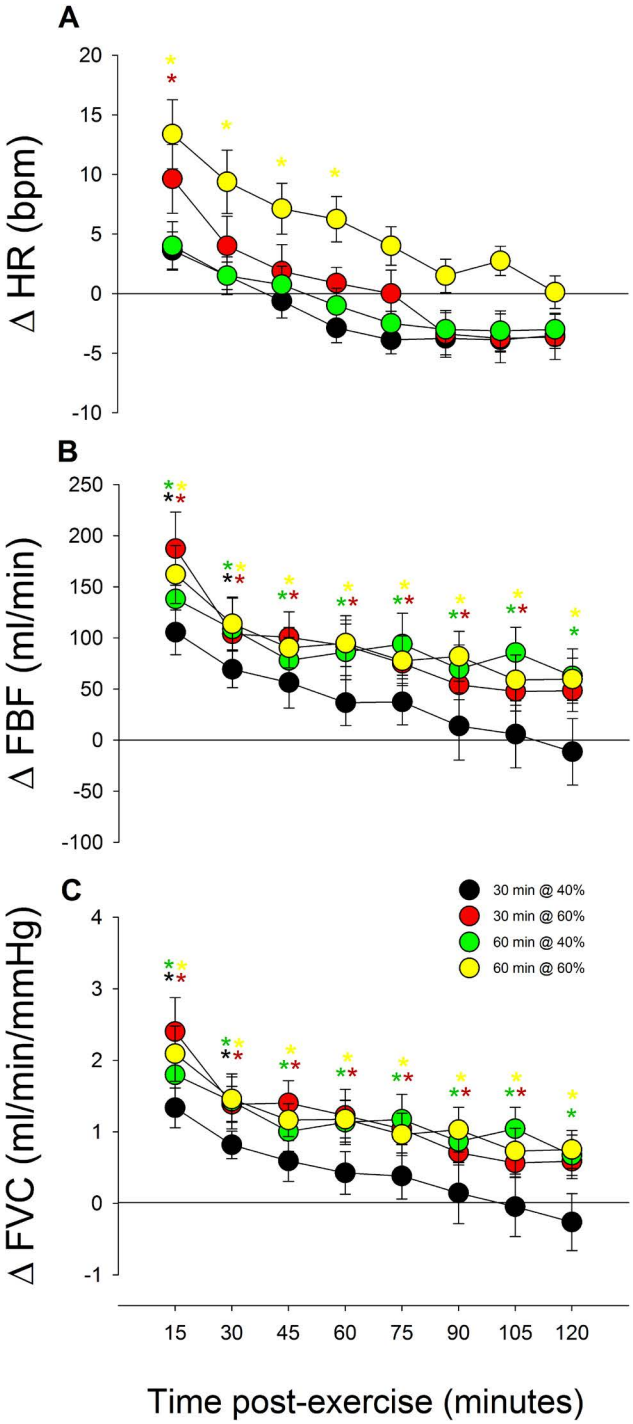



FIGURE 2. Time-course of postexercise changes in heart rate (HR; panel A), femoral blood flow (FBF; panel B), and femoral vascular conductance (FVC; panel C) compared with pre-exercise baseline values. Responses to 4 different doses of cycling exercise are shown (30 min at 40% $\dot{V}O_{2peak}$, 30 min at 60% $\dot{V}O_{2peak}$, 60 min at 40% $\dot{V}O_{2peak}$, and 60 min at 60% $\dot{V}O_{2peak}$). * $P < .05$ vs. baseline time point within exercise dose (n = 8). Symbols indicating statistical significance are color coded to match the relevant exercise dose.



$H_2$-receptor antagonism reduces PEH by ~65% and PE vasodilation by ~80% following 60 min of moderate-intensity exercise in both sedentary and endurance-trained individuals (19–21).

The results of the current study provide insight into the effect of exercise dose on PE blood pressure responses in patients with T2D. Specifically, all exercise conditions, except for the lowest exercise dose (30 min at 40% of $\dot{V}O_{2peak}$) evoked reductions in systolic blood pressure through at least 75 min PE. These findings are similar to findings of previous laboratory investigations of the effects of exercise intensity (22,23) and duration (24) on PE blood pressure in healthy people and people with hypertension, which indicated that PEH can be induced by varying doses of exercise (22–24), yet the magnitude and duration of PEH is somewhat exercise dose-dependent with regards to exercise intensity (25,26) and duration (27,28). In contrast to the current study, MacDonald et al. (24) found a similar magnitude of PEH in normotensive and borderline hypertensive individuals for 60 minutes following moderate intensity (70% $\dot{V}O_{2peak}$) exercise ranging from just 10 to 45 minutes.

Investigators have also utilized ambulatory blood pressure monitors to examine the effect of different exercise intensities (29,30) and durations (31) on PE blood pressure responses in individuals with hypertension. Pescatello et al. (29) found that light (40% $\dot{V}O_{2peak}$) and moderate (60% $\dot{V}O_{2peak}$) intensity exercise evoked similar PEH versus control trials over the 9 h following exercise. Conversely, Eicher et al. (30) found a dose-response antihypertensive effect over 9 h following exercise bouts performed by persons with hypertension at low (40% $\dot{V}O_{2peak}$), moderate (60% $\dot{V}O_{2peak}$), and vigorous (graded exercise test to 100% $\dot{V}O_{2peak}$) intensities. In studying the effect of exercise duration on PEH, Guidry et al. (31) found that both short (15 min) and long (30 min) duration exercise lowered ambulatory blood pressure for 9 h PE in men with hypertension.

It is worth noting that 2 recent investigations suggest that, in populations at risk of developing hypertension, the degree of PEH is highly correlated with long-term blood pressure reductions in response to aerobic exercise training (7,8). Since hypertension is a component of metabolic syndrome, characterizing blood pressure responses in individuals with T2D following dynamic exercise may inform exercise prescriptions for this population at increased risk for developing cardiovascular disease.

Recent research on healthy individuals suggests that sustained PE vasodilation subserves normal glucose regulation following exercise. Pellinger et al. (9) utilized skeletal muscle microdialysis following 60 min of moderate-intensity cycling exercise to demonstrate that glucose delivery to previously active skeletal muscle is supported by PE vasodilation, as interstitial glucose concentration was reduced when PE hyperemia was blunted by local histamine receptor blockade. Subsequently, Emhoff et al. (10) found that oral histamine receptor antagonism reduced both FVC and leg glucose delivery after 60 min of cycling exercise. Moreover, Hamrin et al. (32) found, via skeletal muscle microdialysis, that increased tissue perfusion was associated with enhanced glucose uptake for 12 h following moderate-intensity 1-legged cycling. And finally, Pellinger et al. (11) observed that oral histamine antagonism reduced both FVC and whole-body insulin sensitivity following 60 min of moderate-intensity cycling exercise, which suggests that histaminergic skeletal muscle vasodilation plays a key role in PE glucose regulation in healthy humans. Taken together, these investigations highlight the importance of elevated PE skeletal muscle blood flow in normal glucose regulation.

Although the aforementioned studies were conducted on healthy subjects, their findings suggest a beneficial role of sustained PE vasodilation for patients with T2D who employ exercise to help manage their blood glucose levels. That is, the role of PE skeletal muscle vasodilation in PE glucose regulation suggests that, in those with T2D, persistent elevations in limb perfusion may serve as a barometer for the efficacy of an exercise bout from a metabolic regulation standpoint. In this context, the present findings demonstrate that all exercise conditions, except for the lowest exercise dose (30 min at 40% of $\dot{V}O_{2peak}$), evoked increases in FBF and FVC through at least 105 min PE. Thus, as long as exercise is at least moderate in intensity and/or prolonged in duration, patients with T2D will exhibit sustained PE vasodilation in the previously active muscle. This PE vasodilation appears to be an important mechanism by which to increase nutritive blood flow and counteract insulin resistance in patients with T2D (33) and likely contributes to the increased insulin-mediated glucose uptake (5) and insulin sensitivity (6) following a single bout of dynamic exercise in this population. Importantly, Hecksteden et al. (34) found an association between the magnitude of acute exercise-induced and chronic training-induced changes in indicators of metabolic health, which suggests that tailoring the exercise prescription in individuals with T2D based on acute PE hemodynamic responses may guide patients toward beneficial chronic adaptations to exercise. Further research is needed to determine the relationship between PE skeletal muscle blood flow and glucose regulation in patients with T2D in response to differing doses of dynamic exercise.

### Methodologic Considerations

In an effort to minimize the effect of confounding variables, the subjects recruited to participate in this study had relatively well-controlled diabetes and minimal comorbidities. This selectivity contributed to the relatively small sample size in the current investigation. In addition, while subjects performed 2 different durations of exercise at low and moderate intensities, this study did not include a vigorous exercise-intensity condition, which has been recommended for those with T2D who are able to tolerate high-intensity exercise. Finally, 2 of the subjects were taking antihypertensive medication during the study (see Table 1), which may have blunted the degree of PEH in these subjects (35). However, given the within-subjects design of the investigation, this

would not be expected to affect the differences in hemodynamic responses between the exercise conditions.

### Clinical Implications

It has been recommended that patients with T2D exercise at a moderate intensity for at least 150 min per week or perform at least 60 min of more vigorous physical activity per week (36,37). However, for individuals with T2D who do not tolerate moderate- to high-intensity exercise, lower-intensity dynamic exercise may be an appealing option. Therefore, the current investigation employed 2 durations of exercise performed at low and moderate intensities. Although physical activity of any intensity is encouraged in patients with T2D, the results of the current investigation suggest that low-intensity exercise must be performed for longer durations in this population, in order to promote sustained hemodynamic changes. These acute hemodynamic changes appear to contribute to PE glucose regulation, in addition to being correlated with chronic adaptations to exercise; thus, clinicians can factor these study results into their exercise prescription design to address the metabolic and cardiovascular challenges associated with T2D.

In conclusion, consistent with our hypothesis, the results of this study indicate that, in patients with T2D, dynamic exercise must be at least moderate in intensity and/or prolonged in duration to promote sustained elevations in skeletal muscle blood flow and reductions in systolic blood pressure during recovery. Thus, it appears that individuals with T2D may reap comparable PE hemodynamic benefits from either short-duration, moderate-intensity exercise or long-duration, low-intensity exercise. Given the emerging role of PE skeletal muscle vasodilation in PE glucose regulation, as well as the association between acute and chronic responses to dynamic exercise, these findings can be used to inform future research and refine exercise prescriptions for this growing population.

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