Workplace Strategies to Prevent Sitting-induced Endothelial Dysfunction

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ABSTRACT

KRUSE, N. T., W. E. HUGHES, R. M. BENZO, L. J. CARR, and D. P. CASEY. Workplace Strategies to Prevent Sitting-induced Endothelial Dysfunction. *Med. Sci. Sports Exerc.*, Vol. 50, No. 4, pp. 801–808, 2018. Prolonged sitting induces endothelial dysfunction in healthy young adults, which has been demonstrated to be offset by intermittent fidgeting and standing. No information exists on the effect of sitting and endothelial dysfunction in sedentary middle-age adults, and whether common workplace counterinterventions (i.e., desk standing/desk pedaling) mitigate sitting-induced endothelial dysfunction. **Purpose**: The objective of this study was to examine whether breaking up prolonged sitting with intermittent standing or underdesk pedaling prevents sitting-induced popliteal artery endothelial dysfunction in middle-age sedentary, overweight/obese office workers. **Hypothesis**: We tested the hypothesis that sitting-induced leg endothelial dysfunction would be prevented by intermittent standing or desk pedaling. **Methods**: Thirteen middle-age, sedentary overweight/obese subjects (10 men, 3 women; age, 38 ± 3 yr; body mass index, 29.7 ± 2 $kg \cdot m^{-2}$) participated in three separate testing sessions in a randomized order: 1) 4 h of uninterrupted sitting, 2) 4 h of sitting interrupted with four 10-min bouts of standing, and 3) 4 h of sitting interrupted with four 10-min bouts of light-intensity desk pedaling. Doppler ultrasound–measured popliteal artery flow-mediated dilation and associated measures (e.g., shear rate, blood velocity) were measured immediately before and immediately after each intervention (sit, stand, and desk pedaling). **Results**: Four hours of uninterrupted sitting induced a significant impairment in popliteal artery flow-mediated dilation (baseline: 3.1% ± 0.3%, post: 1.6% ± 0.5%; $P < 0.05$). Interestingly, neither intermittent standing (baseline: 3.2% ± 0.4%, post: 1.9% ± 0.5%; $P < 0.05$) nor intermittent desk pedaling (baseline: 3.2% ± 0.4%, post: 1.9% ± 0.4%; $P < 0.05$) was effective at preventing excessive sitting–induced endothelial dysfunction. **Conclusions**: Prolonged sitting–induced leg endothelial dysfunction cannot be prevented by brief intermittent bouts of standing or desk pedaling in middle-age sedentary overweight/obese adults. **Key Words:** FLOW-MEDIATED DILATION, SEDENTARY, SITTING, STANDING, PEDALING

Prolonged sedentary behavior is associated with an increased risk for multiple chronic health diseases including cardiovascular disease (1,2), type 2 diabetes mellitus (2–4), hypertension (5), metabolic syndrome (6), and obesity (7). Importantly, adverse health outcomes as a result of sedentary behavior have been shown to be independent of leisure time physical activity (8,9). Therefore, sedentary behavior, such as prolonged sitting, may predispose individuals to cardiovascular and/or metabolic risk (8,10,11). In line with this notion, prolonged sitting (e.g., 1–6 h) and periods of reduced shear stress perturb the endothelium and render the vasculature of the lower limbs (i.e., popliteal and femoral arteries) susceptible to endothelial dysfunction (12–15). Indeed, vascular endothelial dysfunction is characterized by impairment in endothelium-dependent vasodilation in conduit and resistance arteries serving as a predictor of pathologic cardiovascular events (16). However, previous studies demonstrating that prolonged sitting induces lower limb endothelial dysfunction are restricted to young healthy individuals. Therefore, it remains unknown whether other populations prone to excessive sitting (i.e., sedentary office workers) experience a similar vascular response.

Over the past 50 yr, the work environment has become increasingly sedentary, which has contributed to declines in total physical activity levels among US adults (17). Sedentary jobs have risen 83% since 1950 and now account for 80% of all US jobs (17). Office workers spend nearly 80% of work time sitting (18). This is important because sedentary behavior is now recognized as an independent risk factor for cardiovascular disease–related mortality (9). For the average office employee who spends longer than 30 yr working, excessive amounts of sedentary time should be considered a hazardous work exposure.

In an effort to protect and promote the health of sedentary employees, some worksites have begun replacing traditional

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Submitted for publication August 2017.
Accepted for publication November 2017.

0195-9131/18/5004-0801/0
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DOI: 10.1249/MSS.0000000000001484

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sitting desks with activity permissive workstations (19) (standing desks or underdesk pedaling devices). A recent Cochrane review concluded that providing sedentary workers with sit–stand desks decreased sitting time between 30 min to 2 h per work day (20). This is consistent with our previous study that found that employees whom were provided sit–stand desks stood 60 min more per workday (7.5 $min \cdot h^{-1}$) compared with employees provided traditional seated desks (21). Our team has also found providing sedentary workers with underdesk pedaling devices resulted in 50 min of pedaling per work day (6.3 $min \cdot h^{-1}$) (22). Despite the growing popularity of active workstations and evidence suggesting that employees will use such devices, little is known as to whether light-intensity standing or pedaling is sufficient to reverse the negative vascular effects of prolonged sitting. Emerging evidence has demonstrated that select countermeasures, such as breaking up sitting with light-intensity walking (13,23) and leg fidgeting (24), are effective strategies to curtail the prolonged sitting–induced endothelial dysfunction in young healthy adults. Although breaking up prolonged sitting with light muscular activity attenuates the sitting-induced endothelial dysfunction in young healthy adults, this information remains unknown in populations at greater risk for sedentary-related disease such as middle-age sedentary office workers. Prolonged sitting–induced endothelial dysfunction in the lower extremities is clinically relevant in light of evidence establishing that the leg vasculature is highly vulnerable to atherosclerosis (9,16). Therefore, an investigation examining workplace physical activity strategies that may circumvent sitting-induced endothelial dysfunction within the legs of a sedentary office worker population seems highly relevant in the context of cardiovascular preventative medicine for sedentary occupations.

The primary aim of this study was to compare the effect of 4 h of uninterrupted prolonged sitting with 4 h of sitting broken up with intermittent bouts of standing or light-intensity underdesk pedaling on measures of vascular function among sedentary, overweight/obese adults working in sedentary office jobs. We hypothesized that prolonged sitting will impair endothelial function of the legs (popliteal artery) and that these impairments will be attenuated using intermittent light-intensity pedaling and standing.

METHODS

Subjects. Thirteen (3 women and 10 men) sedentary, overweight, and obese adults (age, 38 ± 3 yr (range, 35–50 yr); body mass index, 29.7 ± 1.0 $kg \cdot m^{-2}$ (range, 25.1–34.7 $kg \cdot m^{-2}$), body fat percentage, 31.7% (range, 26%–42%); via bioelectrical impedance analysis; InBody 720, Cerritos, CA) currently working in sedentary office jobs participated in the study. All participants reported working a minimum of 35 $h \cdot wk^{-1}$ and reported sitting for a minimum of 75% of their normal work day. All participants reported engaging in less than 60 min of moderate- to vigorous-intensity physical activity per week as well as not meeting the recommended physical activity guidelines (25). Exclusion criteria included the following: any history or symptoms of cardiovascular, pulmonary, metabolic, or neurological diseases; orthopedic limitations that prohibit physical activity; hospitalization from a physical or mental disorder in the past 6 months; taking medication that may influence vascular function; and/or smoking. Women recruited were considered perimenopausal and reported for study days in the early follicular phase to avoid any confounding influences that different phases of the menstrual cycle (i.e., hormonal status) are known to affect vascular measures (26). The nature, risks, and benefits of all study procedures were explained to volunteers, and their written informed consent was obtained before participation in the study. All procedures were reviewed and approved by the institutional review board at the University of Iowa.

Experimental overview and design. A schematic of the study design is presented in Figure 1, illustrating the sequence of events that occurred during each experimental visit. Before testing sessions, subjects completed an initial screening visit to determine eligibility into the study, which was followed by meal distribution to those subjects who qualified. Subjects next attended three separate testing sessions, which were separated by at least 48 h, in a randomized order and included the following: 1) 4 h of uninterrupted

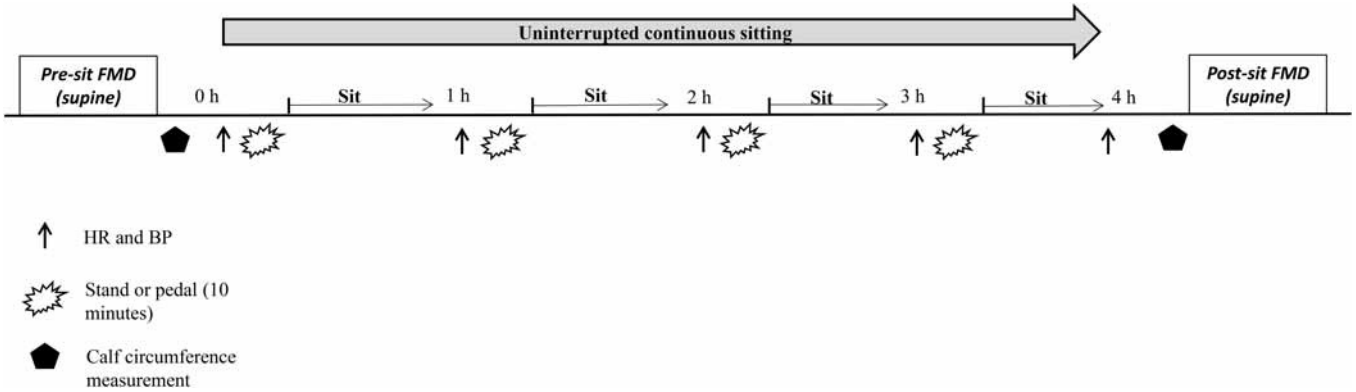

FIGURE 1—Experimental design and timeline. Subjects performed either uninterrupted continuous sitting or sitting broken up by intermittent standing or pedaling. In addition, calf circumferences were measured before each condition and immediately after each condition.

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sitting, 2) 4 h of sitting interrupted with four 10-min bouts of standing on each hour of sitting, and 3) 4 h of sitting interrupted with four 10-min bouts of light-intensity pedaling on each hour of sitting (Fig. 1). On each study day, subjects arrived at the research laboratory between 0600 and 0800 h. Subjects were instructed to consume a standardized meal (Weight Watchers Smart Ones breakfast; 210 cal, 9 g fat, 3 g fiber, 15 g protein, 22 g carbohydrate) and a 6-oz can of Dole pineapple juice (100 cal, 0 g fat, 0 g fiber, 1 g protein, 24 g carbohydrate) 2 h before arrival and baseline measures. Before consumption of the standardized meal, it was instructed that subjects fast overnight (not eating, drinking only water) not drinking alcohol and caffeine 24 h prior and no vigorous exercise for 48 h. During each testing session, participants completed desk work at a height-adjustable desk. Subjects were allowed to use a computer, read, or write during each condition; other movement not associated with the protocol was discouraged and was carefully watched by a member of the research team during each condition. Before and after each condition, subjects underwent a lower leg vascular function test that tested the vascular reactivity to a brief stimulus of limb ischemia via flow-mediated dilation (FMD) test. At the end of each hour, participant's heart rate (HR) and blood pressure (four measures) were measured (Fig. 1). In addition, calf circumferences were measured immediately before and immediately after each condition (Fig. 1).

FMD measurements: pre–sit measures. After 15 min of supine rest, the vascular reactivity of the popliteal artery was assessed on the right leg for each condition at baseline and after intervention. Popliteal artery diameter and blood velocity signals were measured with a 12-MHz linear-array Doppler probe (model M12L; Vivid 7, General Electric, Milwaukee, WI) placed over the popliteal artery just distal to the popliteal fossa with a probe insonation angle of 60°. Sample volume was adjusted to encompass the entire lumen of the vessel without extending beyond the walls, and the cursor was set at midvessel. Once satisfactory images of distal and proximal arterial walls were obtained, the FMD assessment commenced, which included the following: 1) 2 min of baseline hemodynamics followed by inflation of a rapidly inflating pneumatic cuff (Hokanson, Bellvue, WA) wrapped around the maximal circumference of the lower leg to a pressure of 240 mm Hg for 5 min, and 2) cuff inflation was released after 5 min and continuous diameter and blood velocity measures were recorded for an additional 3 min after deflation. Immediately after the baseline FMD assessment, a small mark was made on the subject's skin at the measurement site to ensure similar placement of the transducer for subsequent FMD procedures and shear rate assessments within and between conditions.

Seated measures. HR and blood pressure were measured in the seated position before sitting (baseline) and during the last 5 min of each hour in all three conditions (Fig. 1). HR and blood pressure measures were taken in triplicate using an automated cuff wrapped around the upper arm (BpTRU Medical Devices BPM-200, Coquitlam, BC) and averaged together as single measurements during each time point. Work rate during the pedaling intervention was considered to be performed at a very light intensity (<2 METs), as based on recent guidelines (27) and prior work from our group demonstrating that completing sedentary work tasks at 1.7 METs on a seated active elliptical workstation significantly increased (twofold) muscle activation of the legs and energy expenditure (METs) when compared with completing tasks while sitting at a sedentary workstation (28).

Post–sit measures. To avoid leg muscle contraction and maintain sitting-induced effects on hemodynamics, subjects were carefully transferred from the chair to a padded bed after 4 h of sitting. Participants were instructed not to put any weight on their testing (right) leg when transferring from the chair to the bed. Similar to pre–sit measures, baseline resting hemodynamics, FMD, and reactive hyperemia measures were then repeated.

Calf circumference. Before each condition and immediately after FMD assessments, calf circumference was measured on the opposite leg (left) to which FMD assessments were made, as an indirect measure of venous congestion. Briefly, a Gulick measuring tape was used to measure the maximal width of the calf in centimeters, approximately one-third of the distance between the medial malleolus and medial condyle of the tibia. A mark was placed at the site and postmeasurement was done immediately after each condition.

Data analysis. Recordings of all vascular variables were analyzed offline using specialized edge-detection software (Cardiovascular Suite; Quipu, Pisa, Italy). The percent change in popliteal FMD was calculated using the following equation: %FMD (peak diameter − baseline diameter)/baseline diameter × 100. Shear rate, an indirect measurement for shear stress, is the primary stimulus that modulates FMD responses and is calculated as follows: shear rate (s^{-1}) = [4 × blood velocity ($cm \cdot s^{-1}$)]/diameter. Therefore, all FMD values were normalized to shear and measured as the hyperemic shear rate area under the curve (AUC) that was calculated up until the point of peak dilation on the basis of the following equation: normalized %FMD = %FMD/shear rate AUC × 1000. Blood flow was calculated from continuous diameter and mean blood velocity recordings at each of the experimental time points using the following equation: 3.14 × (diameter/2)^2 × mean blood velocity × 60.

Statistical analysis. Percent change in popliteal diameter (%FMD) was our primary outcome of interest. Data (%FMD, shear, blood flow, calf circumferences, and basal diameters) were analyzed by repeated-measures ANOVA for within and between condition (sit vs stand vs pedal)–time (pre vs post) effects using the SigmaPlot software version 11.0 (Systat Software Inc., San Jose, CA). Pairwise comparisons for the main effects of condition and time were made using the method of Tukey if a significant interaction was detected. All data are expressed as means ± SE, and significance was set at $P < 0.05$.

RESULTS

%FMD change. Figure 2 represents relative (Fig. 2A) and shear rate normalized (Fig. 2B) %FMD responses across conditions. There was no condition–time interaction for

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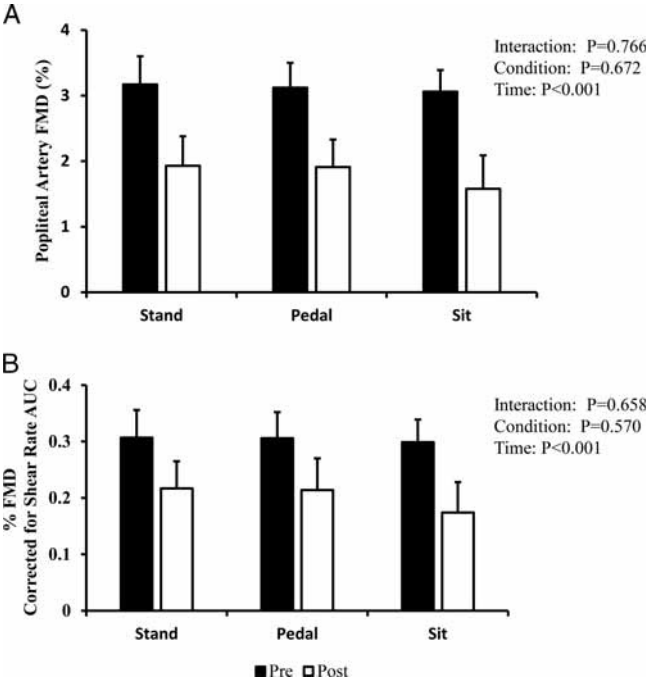

FIGURE 2—Popliteal artery relative %FMD (A) and FMD-corrected for shear rate AUC (B) presit and postsit versus stand versus pedal conditions. There was a similar reduction in %FMD between each condition.

%FMD; however, there was a main effect of time such that %FMD was significantly reduced among conditions (pre vs post; $P < 0.05$). There was no significant main effect of condition for %FMD. Similar to %FMD responses, there was no significant condition–time interaction; however, there was a significant main of effect of time (preintervention vs postintervention) such that each condition produced a marked reduction in leg blood flow and shear rate (Table 1). There was no main effect of condition, and therefore, resting leg blood flow and shear rate (preintervention vs postintervention) remained similar between conditions. In a similar manner, %FMD corrected for hyperemic shear rate AUC did not affect the interpretation of the main findings, because the results were similar (no time–condition interaction, no main effect of condition, significant main effect of time) to the relative values (Figs. 2A, B). There was no condition–time interaction for resting baseline diameter values before and after sitting, such that resting baseline diameters (pre vs post) were similar among conditions (Table 1).

Central hemodynamic responses. There was no significant condition–time interaction for central hemodynamic parameters of systolic blood pressure (SBP), diastolic blood pressure (DBP), and HR. However, there was a significant main effect of time for HR such that HR was elevated during sitting, pedaling, and standing periods (Table 2). There was no significant main effect of condition for HR, SBP, and DBP, respectively.

Calf circumferences. There was no significant condition–time interaction for calf circumferences. However, there was a significant main effect of time such that there was an increase in calf circumference (pre vs post; $P < 0.05$). There was no significant main effect of condition for calf circumference.

DISCUSSION

To date, experimental studies investigating the acute effects of prolonged sitting on endothelial function have focused exclusively on healthy, young individuals. This is the first study to investigate whether sitting-induced endothelial function is altered among middle-age, overweight/obese sedentary office workers. Furthermore, we have examined whether two common workplace health protection/promotion strategies might serve to protect the vasculature during prolonged, uninterrupted sitting. Our findings show that prolonged sitting (4 h) induces endothelial dysfunction in a cohort of sedentary, middle-age, overweight/obese adults. In addition, we present novel evidence demonstrating that breaking up prolonged sitting with 10 min of intermittent standing or pedaling each hour is not sufficient for protecting the vasculature from sitting-induced endothelial dysfunction within this population. Collectively, our findings suggest that workplace strategies, such as standing or light-intensity pedaling breaks, are not sufficient at attenuating the prolonged sitting–induced leg endothelial dysfunction occurring in middle-age, sedentary, overweight/obese adults.

FMD and hemodynamic stimuli associated with uninterrupted sitting. The primary objective of the present study was to explore the vascular effects that accompany prolonged sitting in middle-age, sedentary overweight/obese adults. Furthermore, we sought to explore whether interrupting prolonged seated work with brief bouts of light-intensity, intermittent physical activities (standing and seated pedaling) is sufficient to attenuate endothelial dysfunction resulting from prolonged sitting. Our selection of interventions was based on previous data demonstrating both standing desks and seated active desks to be acceptable and effective strategies for reducing occupational sedentary time (21,28). We further based our hypothesis on recent evidence demonstrating that prolonged sitting (1–6 h) reduces shear stress and induces endothelial dysfunction in young healthy adults (12,13,15,23,24,29).

TABLE 1. Baseline popliteal artery hemodynamics in a prone resting period before (pre) and after (post) sitting versus standing versus pedaling conditions.

	Precondition	Postcondition	RM ANOVA
Basal diameter, cm			
Sit	0.664 ± 0.02	0.664 ± 0.02	Interaction: P = 0.874
Stand	0.654 ± 0.02	0.654 ± 0.02	Condition: P = 0.920
Pedal	0.662 ± 0.02	0.669 ± 0.02	Time: P = 0.887
Resting mean shear rate, s^{-1}			
Sit	47.1 ± 6.1	31.0 ± 4.7	Interaction: P = 0.421
Stand	44.0 ± 6.1	31.7 ± 4.5	Condition: P = 0.904
Pedal	48.7 ± 6.4	33.2 ± 4.3	Time: P < 0.001
Resting blood flow, $mL \cdot min^{-1}$			
Sit	132.3 ± 13.3	91.2 ± 13.0	Interaction: P = 0.491
Stand	129.0 ± 14.1	92.7 ± 13.2	Condition: P = 0.930
Pedal	136.9 ± 11.0	100.7 ± 11.9	Time: P < 0.001
Resting hyperemic shear rate AUC, a.u.			
Sit	11282 ± 979	8995 ± 1106	Interaction: P = 0.673
Stand	10701 ± 751	8960 ± 701	Condition: P = 0.838
Pedal	11165 ± 1102	9579 ± 910	Time: P < 0.001

Data are reported as mean ± SE.
RM, repeated-measures.

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TABLE 2. Central hemodynamic responses before (baseline) and during sit, stand, and pedal conditions.

	Baseline	1-h Sit	2-h Sit	3-h Sit	4-h Sit	RM ANOVA
SBP, mm Hg						
Sit	114 ± 4	114 ± 2	114 ± 2	115 ± 3	114 ± 3	Interaction: P = 0.962
Stand	116 ± 3	112 ± 3	115 ± 4	117 ± 4	114 ± 3	Condition: P = 0.102
Pedal	112 ± 4	109 ± 4	111 ± 3	112 ± 3	110 ± 2	Time: P = 0.117
DBP, mm Hg						
Sit	77 ± 2	74 ± 2	77 ± 2	79 ± 2	77 ± 3	Interaction: P = 0.909
Stand	77 ± 3	77 ± 3	77 ± 3	78 ± 4	78 ± 3	Condition: P = 0.133
Pedal	75 ± 2	76 ± 2	78 ± 2	75 ± 2	75 ± 3	Time: P = 0.358
HR, bpm						
Sit	73 ± 2	70 ± 3	70 ± 2	68 ± 3	70 ± 3	Interaction: P = 0.422
Stand	72 ± 3	70 ± 2	68 ± 2	68 ± 2	68 ± 2	Condition: P = 0.780
Pedal	73 ± 3	71 ± 2	68 ± 2	68 ± 3	69 ± 3	Time: P = 0.001

Data are reported as mean ± SE.
RM, repeated-measures.

Nevertheless, the application of intermittent light muscular activity interventions (e.g., leg fidgeting and walking) (13,23,24) has been shown to be an effective substitute to attenuate the prolonged sitting–induced endothelial dysfunction in young individuals. The findings of the present study corroborate prior work (13–15,23,24,29), as we demonstrate that uninterrupted prolonged sitting for 4 h attenuates shear rate, blood flow, and %FMD in sedentary, middle-age, overweight/obese adults. However, our findings contrast prior work (14,23,24), as we found hourly 10-min bouts of standing and seated pedaling to be ineffective strategies for preventing the sitting-induced endothelial dysfunction in this specific population.

Population differences in sitting-induced endothelial function. The discrepancy in findings of previous research and the present study may be related to the physiological nature of the sample we investigated. We specifically chose a sample that is exposed to excessive amounts of prolonged sitting time (e.g., middle-age office workers). Accordingly, the transition into older age and/or obesity poses several serious metabolic and cardiovascular complications (30). This may also be exacerbated when individuals are consistently exposed to sedentary behaviors, such as those office workers who spend more than 80% of their time sitting during a typical work day, as represented in the present study. For example, Boyle et al. (31) found that exposure to a sedentary lifestyle for just 5 d impairs popliteal artery FMD (from 4.5% to ~2%) in young healthy men. Therefore, chronic prolonged occupational sitting (>30 $h \cdot wk^{-1}$ for several years) may progressively deteriorate lower extremity endothelial dysfunction, rendering it less responsive to light-intensity muscular activity regiments. Indeed, the present study found similar baseline %FMD between each condition, yielding ~3.1% change and this decreased to 1.6% to 1.9% after each sitting condition. In addition, baseline %FMD assessments seem to be lower within our cohort than baseline values of what has previously been published in young healthy adults (~4% to 8% difference) (12,13,24,29). Thus, these findings corroborate with widely known evidence that FMD progressively decreases across the life span (32) and may be one reason for the lack of vascular responsiveness as a result of intermittent light-intensity bouts of pedaling and standing within our cohort of the present study (15).

It is also reasonable to speculate that a higher dose (volume or intensity) of physical activity might be necessary to prevent the sitting-induced vascular endothelial dysfunction in our cohort of middle-age, sedentary overweight/obese individuals. For example, previous evidence has shown that light-to-mild intensity physical activities, such as intermittent leg fidgeting (24) and intermittent 10-min bouts of self-selected pace walking (23), can attenuate the prolonged sitting–induced endothelial dysfunction, at least in young healthy men. The intermittent pedaling intervention used within our present study design was likely performed at a similar "light" intensity to previous study designs (23,24); however, this was not capable of reducing the sitting-induced endothelial dysfunction within our cohort. Thus, given that light-to-mild intermittent interventions (i.e., leg fidgeting, walking) does seem effective at mitigating the sitting-induced endothelial dysfunction in young, healthy individuals (23,24), it can be speculated that 1) using a greater volume and/or pedaling workload to break up prolonged sitting may provide a more potent stimulus to attenuate the prolonged sitting–induced endothelial dysfunction and/or 2) factors related to aging, obesity, and sedentary lifestyle may have contributed to the lack of effect of standing and pedaling strategies in the current sample of middle-age obese, sedentary office workers, although future research is warranted to directly confirm this hypothesis.

Mechanistic contributors to sitting-induced endothelial dysfunction. The mechanisms by which sitting increases leg vascular resistance and contributes to subsequent reductions in shear stress and endothelial function have been highlighted in a recent review (15) and therefore warrant brief consideration. One hypothesis proposes that the increased hydrostatic pressure in combination with little-to-no lower body muscular activity within the leg vasculature during sitting elicits venous congestion, which may be one reason for the observed increases in calf circumference (13,15). Mechanistically, venous congestion (venous distension) evokes increases in muscle sympathetic nervous system activity (33). This elicits adrenergic vasoconstriction, contributing to the elevated leg vascular resistance and reduced shear stress and blood flow. The present study adds to previous evidence by showing that calf circumference and presumably venous congestion are increased after 4 h of uninterrupted sitting relative to baseline in a cohort of middle-age sedentary, overweight/obese adults. Somewhat surprisingly, near identical increases in calf

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circumference were observed in the stand versus sit and pedal vesus sit conditions within our cohort, suggesting that the level of venous congestion occurred to a similar degree across each condition. However, given that we did not directly assess the extent of venous congestion and its association to an elevated muscle sympathetic nervous system activity, further research is needed to verify this running hypothesis in both young and middle-age adults.

Second, angular variations in muscle length distort the tortuous (i.e., curving and bending) arrangement of arteries, arterioles, and microvessels and thus may also be mechanistically linked to sitting-induced endothelial dysfunction. Sarcomere and whole muscle lengthening has been shown to increase vascular resistance, reduce red blood cell–myocyte flux (34,35), and bulk blood flow across the vasculature (36–38). As hypothesized in recent work (15,29), the nature of sitting predisposes the musculature to fixed lengthened positions which may distort the arterial angulations, thus predisposing the vasculature to an altered resting hemodynamic environment. Given that the resistance vessels and microcapillary network is tethered to adjacent connective/muscular tissues, and muscle fascicle lengthening reduces blood flow and shear rate in humans (36–38), it is possible that sitting and the associated increases in muscle length are important mechanistic contributors to the purported reductions in shear stress and endothelial function in young and middle-age adults.

Methodological considerations. Although all subjects completed the same pedal workload during sitting, the exact muscular work and metabolic equivalents were not directly measured. Recent work from our group has demonstrated that completing sedentary work tasks while pedaling at a light intensity (1.7 METs; similar to our pedaling condition) on a seated active elliptical workstation significantly increased (twofold) muscle activation of the legs and energy expenditure (METs) when compared with completing tasks while sitting at a sedentary workstation (28). Nevertheless, although muscular activity and metabolic work can be nearly doubled during light-intensity pedaling, this seems not to be a sufficient stimulus to circumvent sitting-induced endothelial dysfunction in the specific cohort of the present study.

Previous evidence has shown that 1 h of uninterrupted sitting sufficiently reduces shear rate and impairs leg endothelial function in young healthy individuals (23). In light of this evidence, it is possible that the last hour of sitting may have masked the potential beneficial effects of standing and pedaling. That is, more recurrent bouts of pedaling or standing may be needed throughout the sitting period to prevent endothelial dysfunction within our specific cohort. It should also be noted that shear rate and blood flow were not assessed during each "sitting" intervention (only measured in a resting prone position, preintervention vs postintervention) of the present study, and therefore, it remains unknown whether actual low levels of shear rate during 4 h of sitting may have precipitated the observed decrease in endothelial function. However, we believe that our basal levels of shear rate in the immediate post–sit intervention prone position likely reflect the effect of prolonged sitting, as previous evidence has shown similar decreases in shear rate during sitting and immediately after sitting (13). Lastly, although we provide a variety of subject characteristics (i.e., activity levels, work habits, body mass index, and age) to label our specific cohort, we did not obtain a full blood panel (i.e., blood lipid, glucose, cholesterol, triglycerides, etc.) from each participant, which may also provide additional important information toward our study population and overall interpretation of the findings.

Perspectives and significance. Although sedentary desk employees are often encouraged to be more active (i.e., walking) as part of a workplace wellness program, this is not always feasible because of space constrains and/or work obligations (10). As an alternative approach to protect employees from highly sedentary work, employers have begun introducing activity permissive workstations such as standing desks and seated pedaling desks to mitigate excessive sitting. Until the present study, it was yet to be determined whether such approaches are effective at preventing sitting-induced changes in endothelial function in middle-age sedentary office workers. Thus, our finding that regular intermittent bouts of standing and pedaling do not protect the lower leg vasculature from sitting-induced endothelial dysfunction is novel and adds to our understanding of sitting-induced endothelial dysfunction beyond a young healthy population.

It should also be noted that although light-intensity muscular work strategies such as intermittent fidgeting and walking can offset the decay in endothelial function in young healthy adults, prolonged standing (3 h) has additionally been shown to be an effective stimulus to ameliorate leg endothelial dysfunction when compared with prolonged sitting of a similar duration (29). However, continuous standing for 3 h may not be a feasible approach within the context of workplace strategies to circumvent sitting-induced endothelial dysfunction. Although these prior findings lend credence to the "something is better than nothing" notion (39), the present study's findings suggest that a light-intensity muscular activity stimulus to break up prolonged sitting was not an effective strategy to overcome the sitting-induced endothelial dysfunction within our specific cohort.

CONCLUSIONS

The findings of the present study revealed that 4 h of uninterrupted sitting induced endothelial dysfunction in middle-age, sedentary overweight/obese adults. Furthermore, hourly 10-min bouts of light-intensity standing and/or pedaling were not a sufficient stimulus to reverse the negative effect on endothelial dysfunction as a result of prolonged seated work. Given that mild intermittent activity effectively mitigates the sitting-induced endothelial dysfunction in young, healthy individuals, it seems that factors related to aging, obesity, and sedentary lifestyle may contribute to the lack of effect of standing and pedaling strategies in the current sample of middle-age obese, sedentary office workers, although future research is warranted to directly confirm this hypothesis.

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The authors thank the volunteers for their time and Katie Hosteng for technical assistance. No conflicts of interest, financial or otherwise, are declared by the authors. This research was supported (in part) by a pilot project research training grant from the Heartland Center for Occupational Health and Safety at the University of Iowa. The Heartland Center is supported by Training Grant No. T42OH008491 from the Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health.

The results of our study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The findings of the present study do not constitute endorsement from the American College of Sports Medicine.

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