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# Effect of physical activity breaks during prolonged sitting on vascular outcomes: A scoping review

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**Abstract:**

Emerging evidence claims the vascular benefits of varied frequency and duration of physical activity (PA) breaks, whereas the efficacy of varied intensity remains unexplored. We aimed to collate and summate the studies investigating the PA breaks at various intensities on vascular protection. Seven electronic databases were searched for potential studies till Jan 31, 2022. The eligible studies should have administered PA breaks of differing intensities in prolonged sitting postures and explored regional vascular changes [flow mediated dilation (FMD), shear stress, diameter, and blood flow] using ultrasound and novel outcome markers. Two independent reviewers assessed the studies for eligibility after abstract and full-text screen, and appropriate data were extracted to summarise vascular protective effects with PA breaks. Our findings reveal adverse regional vascular outcomes with prolonged sitting (FMD ≈ –1.5%, diameter ≈ –0.06 mm), whereas PA breaks of any intensity were found to improve endothelial functions (FMD ≈ +0.5%, diameter ≈ +0.1 mm, shear ≈ +13 $s^{-1}$) and mitigate the adverse effects associated with prolonged sitting. Compared with high-intensity activity, low-intensity PA breaks alleviate arterial stiffness and endothelial dysfunction risks.

**Keywords:**

Duplex ultrasound, endothelial function, physical activity breaks, pulse velocity, sedentary lifestyle, shear stress

## Introduction

Arterial stiffness and cardiovascular risk arterial stiffness is the reduced ability of an artery to expand and contract with changes in pressure. It is a marker of vascular aging and a predictor of cardiovascular disease (CVD).[1] Arterial stiffness is related to impaired blood flow, increased pulse pressure, and endothelial dysfunction, which are all factors that promote atherosclerosis and increase the risk of heart attack, stroke, and kidney damage.[1,2]

Sedentary behavior, physical activity, and arterial stiffness sedentary behavior (SB) are due to the lack of physical activity (PA) and is associated with higher CVD mortality.[3,4] SB can increase arterial stiffness independently of PA levels.[3,5,6] Therefore, global guidelines recommend reducing SB and increasing PA to improve vascular health.[7,8] However, many people still have high SB and low PA levels,[5] which calls for effective strategies to change their behavior and reduce their CVD risk.

SB intervention along with PA in vascular integrity regular moderate-vigorous PA (MVPA) or exercise training can protect the arteries from stiffening. However, most people spend only a small fraction of their day in MVPA.[9,10] A possible solution is to interrupt or replace SB with low-intensity PA, such as standing, walking, or light



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exercises, in different settings, such as workplaces or schools.[11–34] These PA breaks can improve vascular function by enhancing blood flow, shear stress, vasodilation, and metabolic flexibility.[9]

However, the evidence on the optimal type, duration, frequency, and intensity of PA breaks for vascular benefits is not consistent or conclusive.[35–38] Some studies suggest that high-intensity PA breaks, whether short or long, may have more advantages than low-intensity PA breaks, especially for glucose control.[39–41] More research is needed to determine the best PA break protocol for improving arterial stiffness and CVD risk.

Although an expanding body of research has delineated the advantageous impacts of interspersing sedentary behavior (SB) with multiple episodes of physical activity (PA) on glycemic outcomes such as postprandial glucose and insulin, scant attention has been paid to the effects of PA breaks on vascular outcomes such as blood pressure (BP) and flow-mediated dilation (FMD).[35–38] Recent systematic reviews have highlighted the acute vascular effects of interrupting prolonged SB but cautioned against definitive interpretations because of limited experimental studies and methodological disparities.[35–38] Moreover, investigations addressing the disparity between low- and moderate-intensity PA breaks remain scarce, hindering conclusive observations on their vascular protective effects, particularly among type 2 diabetes populations.[35] Unveiling plausible physiological mechanisms underlying prolonged sitting and interruptions, along with empirical evidence comparing the vascular impact of different PA break intensities, remains elusive. A comparison between light- and moderate-intensity activities, especially targeting older adults and individuals with chronic conditions, could offer an achievable strategy to increase PA or substitute SB, potentially informing intervention designs and policy adaptations for "dosed" exercise breaks, notably in workplace settings.[35]

## Materials and Methods

This scoping review was performed following the methodological framework provided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist. Although they share a few common characteristics, such as using a rigorous and replicable method, scoping reviews usually provide a broad overview or "map" of a topic rather than directed toward a specific question, unlike systematic reviews.[42] PRISMA-ScR checklist contains 20 essential reporting items and two optional items to include when completing a scoping review.[43] The methods and the results were presented with eight items as adapted from the PRISMA-ScR checklist as follows: (i) searching information sources based on eligibility criteria; (ii) selection of sources of evidence; (iii) data or items charting; (iv) characteristics of sources of evidence; (v) critical appraisal and results of individual sources of evidence; (vi) synthesis of results; (vii) discussion or summary of the evidence; and (viii) limitations and conclusion.[43]

**Search Strategies** We administered a comprehensive literature search for the studies that investigated the interrupted sitting with PA breaks of various intensities and measured vascular functions. The initial search was conducted on May 21, 2021, with seven electronic databases: Scopus; Web of Science (WoS); EBSCOhost (Cumulative Index to Nursing and Allied Health Sciences Library, SPORTDiscus); Embase; Ovid MEDLINE; PubMed; and Cochrane CENTRAL. The search was again updated on Jan 31, 2022. We searched with the synonyms and subject headings relating to the following Medical Subject Headings (MeSH) terms: SB, physical activity, interrupting prolonged sitting, PA breaks, movement breaks, regional vascular functions [flow mediated dilation (FMD), shear rate (SR), baseline diameter, blood flow velocity, pulse wave velocity (PWV), arterial stiffness and endothelial progenitor cells (endothelin, coagulation factors such as von Willebrand factor, other endothelial constrictor factors such as angiogenic cells)]. Appropriate search terms were identified and combined with Boolean operators (AND, OR, NOT) and appropriate wildcards (*,?) to extract the studies under the supervision of a senior librarian. The eligibility criteria for the potential studies were explicitly determined by the PICOT method, as depicted in Table 1.

### Selection of sources of evidence

After the potential studies from the databases were extracted, the citations were imported into the endnote web, and duplicates were removed. To increase the consistency among the reviews, a pilot testing of the potential studies inclusion was administered where all the authors (PS, SC, BC, and KVR) independently screened, extracted the necessary data to *a priori* extraction sheet, and discussed the initial 50 studies that were extracted for possible inclusion. Since 85% of the predetermined agreement was noted among all the authors regarding the inclusion and data charting, the two reviewers (PS and SS) independently screened the remaining articles with a collaborative Rayyan software (Rayyan Systems Inc. MI, USA) for possible inclusion of studies. In case of a split decision regarding the full-text selection, the third reviewer (BC) was contacted to solve the disagreement.

### Data charting

The full-text articles were reviewed, and the authors extracted the following data into *a priori* designed data extraction sheet that has previously been tested in a

**Table 1: Eligibility criteria of the potential studies included**

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| The table's inclusion criteria for studies on sedentary behavior interventions among adults and adolescents aged 14 to 60 years encompassed several key aspects:<br>1. Participant Criteria:<br>Individuals displaying sedentary behavior or at risk of chronic diseases.<br>Studies involving both genders or single-gender participants.<br>2. Intervention Criteria:<br>Administering at least two bouts of physical activity breaks to interrupt sedentary time.<br>Various methods to interrupt prolonged sitting, including active breaks, workstations, policies promoting exercise, or technological prompts.<br>Conducted in either a laboratory or free-living setting, spanning acute (<7 days) or chronic (more than 7 days) time frames.<br>Any form of lifestyle behavior modification, such as interruptions using active workstations or low-dose physical activity breaks.<br>3. Measurement and Assessment Criteria:<br>- Employment of advanced physiological measures predicting vascular health risks, including ultrasound Doppler measures (FMD, shear rate, blood flow, arterial diameter, PWV, pulse wave amplitude), transcranial Doppler, blood count, and microangiogenic cells.<br>- Assessment of vascular functions in specific arteries (brachial, superficial femoral, carotid, middle cerebral, popliteal) to gauge outcomes.<br>- Studies considering vascular functions as secondary measures alongside primary measures of metabolic or cognitive functions.<br>4. Study Design Criteria:<br>- Inclusion of quasi-experimental, crossover, or randomized controlled trials. | The exclusion criteria for studies focusing on sedentary behavior interventions and their impact on vascular function among adults included several specific parameters:<br>1. Participant Exclusions:<br>- Adults with established chronic cardiometabolic diseases or disabilities that might influence vascular function or physical activity participation.<br>2. Study Design and Intervention Exclusions:<br>- Animal studies investigating sedentary behavior interventions' association with vascular function changes.<br>- Studies examining single-session exercise impacts before or after sedentary periods without interrupting the sedentary time.<br>- Multimodal interventions where interrupting prolonged sitting was only a part of the study.<br>- Workplace interventions using methods other than exercise (e.g., local heating, compression stockings) for vascular health promotion.<br>3. Lack of Specification:<br>- Studies not specifying the dose (frequency, duration, intensity) of interventions.<br>- Epidemiological studies solely exploring isotemporal substitution of sitting or detraining effects (bed rest).<br>4. Outcome Measures and Study Types:<br>- Comparisons involving modalities other than lifestyle behavior.<br>- Exclusion of outcome measures beyond basic clinical parameters such as blood pressure or heart rate, already addressed in previous systematic reviews[44] |

pilot data extraction: author, year, country, protocol registration, study participants (eligibility, recruitment), interventions (type, intensity, frequency, duration, and follow-up), regional vascular outcomes (flow-mediated dilation, shear rate, peak volume, velocity, and other advanced measures of endothelial functions such as endothelin and micro angiogenic cells), and the arteries measured [superficial femoral artery (SFA), middle cerebral artery (MCA), carotid, brachial artery (BA), and popliteal artery]. Two reviewers (SS and BC) jointly developed a data-charting form to determine which variables should be extracted. The two reviewers recorded the data independently, discussed the results, and continuously updated the data-charting form in an iterative process. Further, we have classified light-intensity or moderate-intensity physical activity breaks described in the included studies based on the compendium of physical activities or based on the rate of perceived exertion (moderate intensity ≥11 Borg's RPE) or heart rate (≥50% maximal heart rate) administered in the included studies.[44]

### Collating evidence and summary synthesis

All the authors initially screened the relevant data extracted from the included articles, and the differences in endothelial functions, the methodology used, and the dose of the PA breaks administered were charted and analyzed to provide the broad scope of the empirical evidence that investigated the differences in dose of PA breaks and their influence on endothelial function. Further, the mean differences among the low-intensity and moderate-intensity PA breaks were documented, and dose-response vascular outcome differences were documented. Nevertheless, the plausible mechanistic links for altercations in the regional vascular outcomes with the prolonged sitting and interruptions were explored. Although the formal risk of bias analysis was not performed, the individual study quality was analyzed and presented as a narrative synthesis.

## Results

### Search results

A total of 1389 citations were identified from the peer-reviewed (n = 1376) and non–peer-reviewed databases/hand search of back-references (n = 13). After duplicates removal and initial screening, 28 articles were included for the final analysis and collation of evidence. Figure 1 demonstrates the flow of the citations included in this scoping review.

### Characteristics of included studies

The analysis encompassed 28 studies, predominantly crossover studies (82.14%) and a minority being

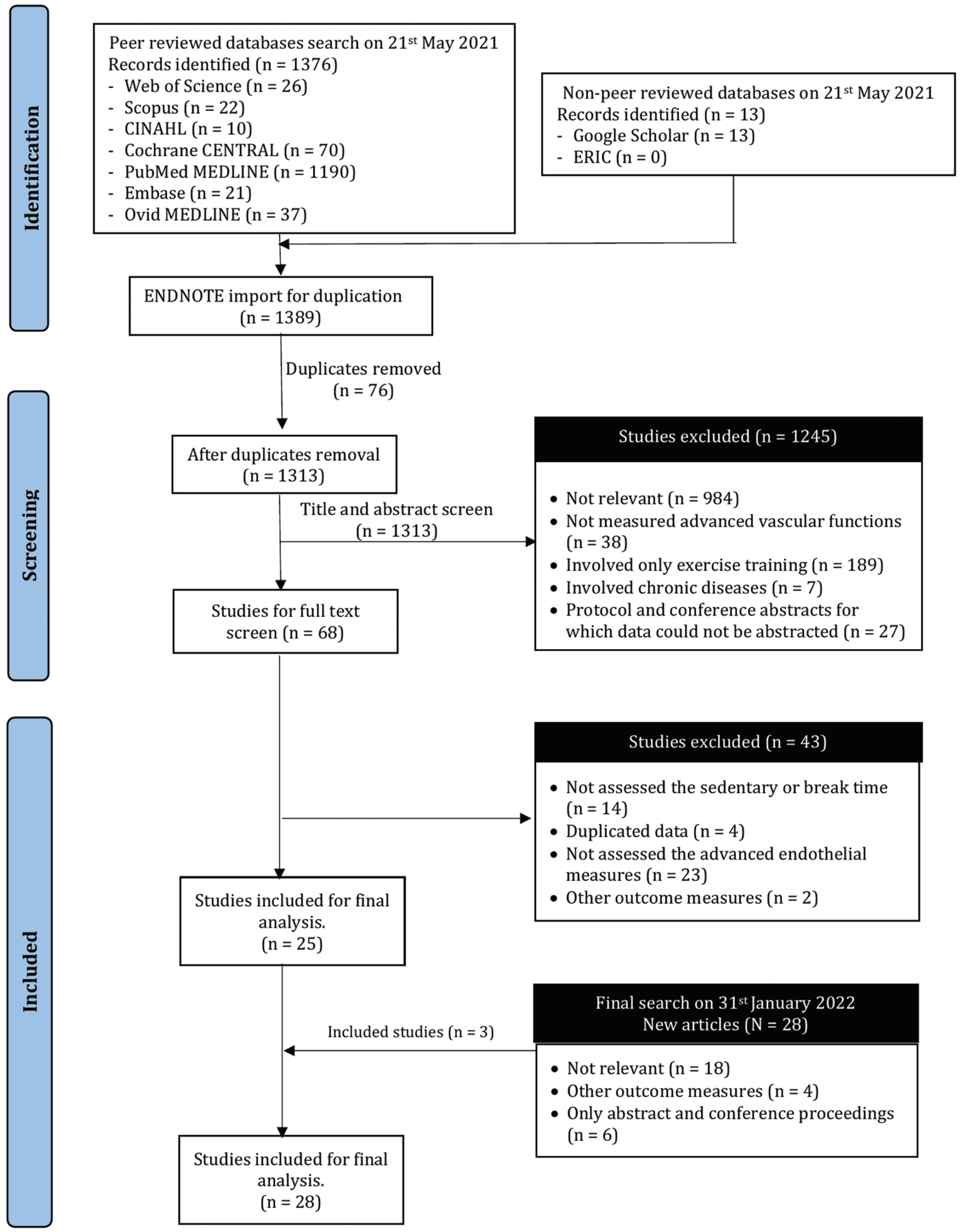


**Figure 1:** PRISMA flowchart demonstrating the inclusion and exclusion of the studies in the review

randomized controlled trials (17.86%). Merely 32.14% of studies had published protocols or registered in national registries, leaving many studies' details unaccounted for. Approximately 57.14% of studies were conducted within the past three years, all in high-income countries such as America (39.29%), Australia (17.86%), the United Kingdom (17.86%), Europe (10.71%), and a few in Japan, Korea, and Oceania (3.17%), with no representation from low-middle income countries.

These studies focused on assessing vascular function through various methodologies and parameters, employing ultrasound imaging, Doppler ultrasonography, transcranial Doppler ultrasound, NIRS, tonometry, and biochemical markers to evaluate parameters such as flow-mediated dilation (FMD), shear rate (SR), blood flow, diameter, pulse wave velocity (PWV), and endothelial markers. For example, Bodker *et al*. (2021)[29] used ultrasound to observe improvements in FMD, diameter, and blood flow in arteries after nitro-glycerine administration. Carter *et al*. (2020)[14] found changes in FMD, velocity, and shear rate in different arteries using Doppler sonography. Duvivier *et al*. (2018)[23] focused on endothelial markers, revealing changes associated with endothelial dysfunction.

The scoping review incorporated 27 studies by various authors in diverse locations and populations. These investigations underscore the potential cardiovascular benefits of interrupting sedentary behavior, especially

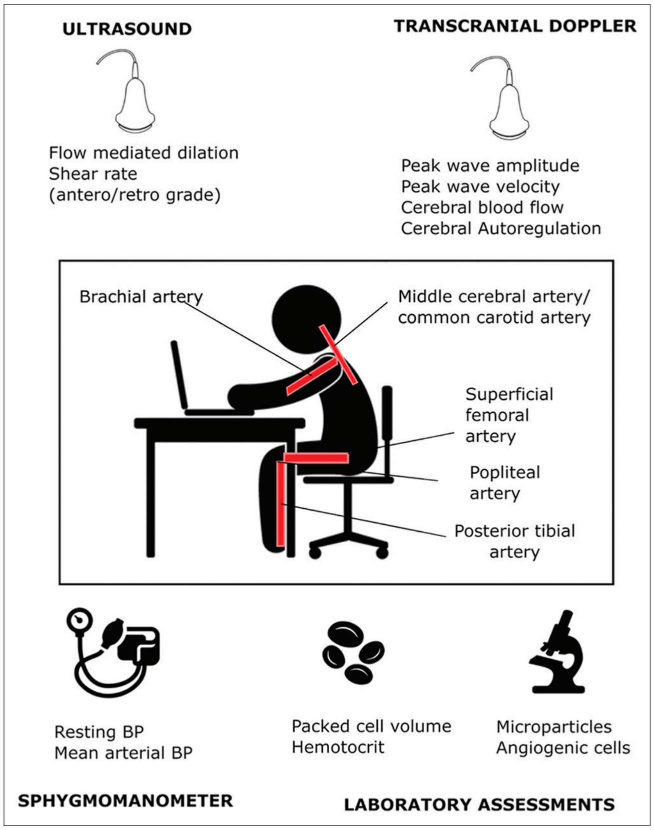


**Figure 2:** Measures used to quantify the vascular functions in the included studies

in office settings, indicating positive impacts on cardiovascular health, metabolic rates, and overall well-being across diverse populations. Studies emphasized the value of incorporating breaks, even low-intensity ones, in prolonged sitting, shedding light on various aspects of vascular function and responses under different conditions and interventions[11–14,16–24,26–33,39,45–48] Table 2. Dose of the physical activity microbreaks and its influence on advanced measures of endothelial functions

*Participants:* A total of 537 participants were studied from 28 trials with a wider range of sample sizes (9 – 61). The majority of studies included sedentary office workers as participants (κ = 16; 57.14%), whereas few studies attempted to investigate the role of PA breaks in elderly[33] and young girls.[19] The majority of the studies have administered PA breaks in healthy participants (κ = 15; 53.57%) and are fairly equal in the "at-risk" population (κ = 13; 46.43%). Ten studies have investigated on clinical population: Diabetes (κ = 2; 7.14%), obese (κ = 4; 14.29%), and cardiovascular risk (κ = 4; 14.29%), whereas one study investigated the vascular effects of PA breaks in women with polycystic ovarian syndrome.[12]

*Interventions:* Of 28 full-text articles included for the review, 26 studies investigated short-term vascular effects of PA breaks (4.98 ± 2.88 hrs, 95% CI 1.26 – 14 hr), whereas two studies investigated for 28 ± 28.28 weeks (95% CI 8 – 48 weeks).[18,29] The mean duration of PA breaks observed was 6.32 ± 10.25 minutes (95% CI 0.2 – 45 minutes). The majority of the studies have standardized the tasks (κ = 27; 96.43%) and meals (κ = 22; 78.57%) during the control or the intervention period in crossover trials. The majority of studies have administered low-intensity PA breaks (κ = 19; 67.86%), whereas few studies attempted for moderate-intensity (κ = 7; 25%) and high-intensity (κ = 2; 7.14%) PA breaks.[23,26]

Commonly, PA breaks were used for 3 minutes (κ = 9; 32.14%) every 30 minutes (κ = 8; 28.57%); however, heterogeneity was observed in the break duration and frequency across the majority of the studies. Callisthenics was administered commonly used modality for PA breaks (κ = 6; 21.43%), followed by treadmill (κ = 5; 17.86%), sit-stand work stations (κ = 4; 14.29%), cycling (κ = 4; 14.29%), and seated calf raise (κ = 3; 10.71%). Rarely PA breaks were administered in the form of stair climbing,[26] computer-based prompts[16], and isometric bilateral leg extension using a leg extension machine.[30]

*Outcome measures:* The majority of the studies measured FMD using ischemia and hyperemia method by cuff inflation method (κ = 19; 67.86%) followed by NIRS (κ = 2; 7.14%), cold water immersion (κ = 1; 3.57%), $CO_2$ mixture method for cerebrovascular reactivity (κ = 1; 3.57%).[14,17,21,48] Right side was chosen for measurement in most of the studies (κ = 17; 60.71%), whereas four studies chose the left side for the vascular assessments. Supine position (κ = 15; 53.57%) was adapted to measure FMD and other vascular functions, whereas few attempted to measure in seated positions (κ = 9; 32.14%). All the studies have adapted manual or mechanical transitions from the intervention positions for FMD measurements. Common regional vascular measurements administered in the empirical studies are illustrated in Figure 2.

## Appraisal of individual sources of evidence

Because of limited data on high- and moderate-intensity PA breaks across different sites (PA, SFA, BA, and MCA), regional vascular outcome variables (FMD, PWV, shear stress, flow, and diameter) could not be pooled. We have presented descriptive statistics for baseline to endpoint changes, yet have not statistically analyzed or established significance.[26,27,30,46] Uninterrupted sitting reduced SFA and popliteal artery FMD by -0.43 ± 0.59% and -1.43 ± 0.66% respectively, whereas light-intensity PA breaks improved SFA and popliteal artery FMD by +2.07 ± 0.61% and +0.20 ± 0.79%. However, high-intensity PA breaks showed no change in FMD of lower limb arteries. Light-intensity PA breaks increased FMD by +1.07 ± 1.32% and +1.84 ± 1.13%

**Table 2: Charting of the data**

| Author, year | Objective of the study | Quantification and comparison of the activities | | | Key findings |
|---|---|---|---|---|---|
| | | Control period/group | Low-intensity exercise breaks | Moderate-/high-intensity breaks | |
| Bodker *et al*., 2021[29] | To assess the impact of reducing sedentary time with standing desks on FMD and other markers of cardiometabolic health | Controlled sitting period for six weeks monitored through accelerometers (ActivPAL) | • Replacing sitting with sit-stand workstations using it ad libitum for 24 weeks<br>• Encouraged to use the sit-stand workstations most of the time of their typical workday | Not administered | • SFA-FMD increased from baseline (4.9±1.7%) to 12 weeks (6.4±2.3%) and continued to increase by 24 weeks (8.1±3.2%) compared with baseline); BA no change.<br>• No change in the SFA diameter across three study visits. |
| Carter *et al*., 2020[16] | To explore the effect of using e-health interventions on markers of health and work performance. | • Routine work period for eight weeks<br>• Software usage data was matched with the ActivPAL data | • E-health intervention for eight weeks (computer-based prompts - only walking selected, self-selected walking speed).<br>• Every 45 min, the prompts popup. | Not administered | • Large effects were observed for the change in absolute (d=0.88) and relative (d=1.06) SFA FMD in favour of Intervention.<br>• E-health may positively influence vascular function as following the intervention femoral artery FMD increased by 4.8%. |
| Carter *et al*., 2019[39] | To assess the effect of breaking up sitting with different PA break strategies on lower limb endothelial function | • Uninterrupted sitting<br>• performed desk-based activities (reading, working on a computer) | • Two dose interruptions: High frequency (2 min every 30 min for 4 hrs=16 min) and low frequency (8 min every 120 min for 4 hrs)<br>• Self-selected level walking on treadmill. | Not administered | • No significant main effect on HR BP.<br>• No significant effect on FMD% or SR neither the correlation between them.<br>• Greater reduction in SFA blood flow and conductance during SIT compared with low frequent walk but not high frequent walk<br>• No significant main effect on HR and BP |
| Carter *et al*., 2018[15] | To explore the acute CBF and cerebrovascular function responses to uninterrupted sitting and interruptions with short bouts of light-intensity PA. | • Uninterrupted sitting for 4 h.<br>• low cognitively demanding desk-based activities (watching television, surfing the internet, or completing simple work tasks on a computer) | • Two dose interruptions: high frequency (2 min every 30 min for 4 hrs=16 min) and low frequency (8 min every 120 min for 4 hrs=16 min)<br>• Self-selected level walking on treadmill. | Not administered | • A greater change in MCAv during prolonged sitting compared with high frequent walk but not during prolonged sitting and low frequent walks.<br>• No significant main effects for $CO_2$ reactivity across conditions.<br>• Cerebrovascular autoregulation better in high frequent walk breaks |
| Carter *et al*., 2016[14] | To assess changes in BA endothelial function with callisthenics | Uninterrupted sitting for 1 hour 26 min. | Callisthenics (five body-supported exercises) for 2 min every 20 minutes for 1 hour 26 min | Not administered | • Use of calisthenics did not increase the endothelial function.<br>• BA endothelial function is resistant to the negative effects of 1 h of sitting. |
| Cho *et al*., 2020[26] | To evaluate the acute effects of interrupting prolonged sitting with stair climbing on vascular and metabolic function after a high-fat meal. | • Uninterrupted sitting for four hours<br>• Participants were allowed to do light activities (e.g., using smartphone or laptop and reading materials) | Not administered | • Stair climbing bouts for 5 min every hour for 4 h | • BA FMD decreased prolonged sitting (9.65±2.63% to 7.84±2.36%) but not stair (9.41±2.61% to 10.34±3.30%). |

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**Table 2: Contd...**

| Author, year | Objective of the study | Quantification and comparison of the activities | | | Key findings |
|---|---|---|---|---|---|
| | | Control period/group | Low-intensity exercise breaks | Moderate-/high-intensity breaks | |
| | | • no or minimal movement in the lower extremity. | | • A bout of stair climbing involved climbing up and down indoor staircase of a six-story building twice | • Increase in PA flow and shear after stair climbing.<br>• Peak diameter increased in both but low in prolonged sitting but significant difference in diameters or SR AUC between the trials. |
| Climie *et al.*, 2018[24] | To explore the effects of interrupted sitting with resistance activities on arterial function in at CVD risk individuals (obese/overweight) | Sitting for five hrs and asked to minimize the excessive movement. | • SRA: Light-intensity, body weight-resisted exercises.<br>• Each exercise was performed for 20 s at a tempo of 1 repetition every 2 s, 3 times, for a total of 3 min every 30 min | Not administered | • Sitting SFA FMD significantly lower at 1 and 2 h of prolonged sitting compared with SRA (3.3±0.6% vs. 9.3±0.6%, and 5.4±0.8% vs. 8.9±0.8%,) but were the same at 5th h.<br>• No significant differences between conditions were observed for BA FMD at either the 0 or 5 h<br>• Mean resting SFA shear rate was lower during prolonged sitting condition relative to SRA, (23.1±9.7/s vs. 45.7±9.6/s, *P*=0.052).<br>• Five hours of prolonged sitting, relative to regular interruptions to sitting time, impaired SFA vasodilator function and increased circulating ET-1 in overweight/obese adults |
| Duvivier *et al.*, 2018[23] | To explore whether reducing sitting time by light- or high-intensity exercise affects the endothelial markers compared with uninterrupted sitting in free living conditions | Uninterrupted sitting for 14 h in free living environment for four days | Substituting the 5-6 h sitting with walking and 2-3 h by standing | Substituting one hour sitting with cycling for four days | • Compared with prolonged sitting and sit less groups, exercise group resulted in a significantly lower endothelial markers (sICAM1 and sE-selectin).<br>• Intermittent increases in shear stress during MVPA more important for endothelial function |
| Evans *et al.*, 2020[25] | To answer two questions: in young, healthy adults 1) does prolonged sitting (3 h) lead to increased aortic stiffness, and 2) do intermittent calf raise exercises to prevent pooling prevent aortic stiffening. | • Uninterrupted sitting for three hours<br>• Participants remained seated watching a nonstimulatory television program<br>• Movements monitored by accelerometer | • 10 seated calf raises every 10 minutes directed by metronome (20 beats/min; Pro Metronome Xiao Yixiang) for 3 hours<br>• Movements monitored by accelerometer | Not administered | • No interaction for angiogenic cells: CD34+, CD3+/31+, orCD14+/31+ cell frequency<br>• No interaction effect for Endothelin-1 and VEGFR mediators.<br>• Prolonged sitting found to decrease annexin V+/CD34+MPs, annexin V+/CD62E+MPs, and annexin V+/CD31+/42b–MPs.<br>• Main effect of condition for ET-1 to be greater in prolonged sitting |

*Contd...*

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|---|---|---|---|---|---|
| | | Control period/group | Low-intensity exercise breaks | Moderate-/high-intensity breaks | |
| Evans *et al*., 2019[21] | To answer two questions: in young, healthy adults 1) does prolonged sitting (3 h) lead to increased aortic stiffness, and 2) do intermittent calf raise exercises to prevent pooling prevent aortic stiffening. | • Uninterrupted sitting for three hours<br>• Participants remained seated watching a nonstimulatory television program)<br>• Movements monitored by accelerometer | • 10 seated calf raises every 10 minutes directed by metronome (20 beats/min; Pro Metronome Xiao Yixiang) for 3 hours<br>• Movements monitored by accelerometer | Not administered | • No differences in HRV.<br>• PWV significantly increased from pre to post (6±6%) in sitting (aortic stiffness).<br>• Sitting increases aortic stiffness in young, healthy individuals, a process that may be influenced by lower extremity blood pooling.<br>• Calf raises alone do not appear to provide sufficient stimulus for maintaining central cardiovascular health |
| Gibbs *et al*., 2017[28] | To examine BP and PWV responses across a simulated workday of prolonged sitting according to currently recommended (seated BP and supine PWV) and alternate postures (supine BP and seated PWV) | Uninterrupted sitting (3 hr 40 min morning and 3 hr 40 min afternoon). Mean breaks 3.7±1.3 breaks | Replacing sitting with 30 min every 30 min for 8 hours | Not administered | • Females had higher BP responses than males in seated position and lower with sit stand transition visit period.<br>• Carotid–femoral PWV did not differ between condition during the workday (β=-0.03 m/s, *P*=0.831, d=0.02).<br>• Standing breaks likely have a smaller effect on BP than more active breaks.<br>• 0.27 m/s reduction was observed in carotid–ankle PWV during frequent postural transition |
| Graves *et al*., 2015[18] | To evaluate the impact of a sit-stand workstation on sitting time, vascular, metabolic and musculoskeletal outcomes in office workers | Routine work practises and received no intervention | Sit-stand workstations were installed at respective workplaces and online support (Ergotron) was given | Not administered | • Nonstatistical improvement for FMD, cIMT and SBP [−1.6 mmHg (−7.0 to 3.7)] among active work station and control groups<br>• No significant differences in the vascular functions |
| Hartman *et al*., 2020[22] | To examine the acute and long-term effect of reduced sitting intervention on vascular and cerebrovascular function | Lab-based: Uninterrupted sitting for 3 hours<br>Field-based: Controlled period for 16 weeks | light-intensity walking for 2 min every 30 min for 3 h<br>Sitting time monitored using the activity monitor<br>Vibrotactile feedback from mobile device | Not administered | • SFA blood flow did not change significantly after the 16-wk intervention.<br>• A significant increase in FMD was found when corrected for baseline diameter (3.1% ± 0.3% to 3.8% ± 0.4%) in intervention groups<br>• In lab lab-based study, a small decline in FMD after uninterrupted sitting, whereas FMD improved when sitting was interrupted.<br>• Although no change in FMD, CBFv and CVCi are reduced after uninterrupted sitting, which was prevented by physical activity breaks |

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**Table 2: Contd...**

| Author, year | Objective of the study | Quantification and comparison of the activities | | | Key findings |
|---|---|---|---|---|---|
| | | Control period/group | Low-intensity exercise breaks | Moderate-/high-intensity breaks | |
| Horiuchi, 2021,[31] | To investigate the macrovascular and microvascular responses to 3 h of sitting that was (i) uninterrupted sitting and (ii) interrupted every 20 min with 1-min light-intensity exercise (half squats). | • Uninterrupted sitting for 3 h<br>• watched a nonstimulatory television program | Light-intensity squats (90°) for one minute every 20 minutes for 3 hours | Not administered | • Arterial stiffness increased by 18.7 during prolonged sitting visit whereas reduced by –11.9 during microbreaks visits<br>• BA PWV did not significantly change with time or by condition<br>• Gastrocnemius tissue oxygen saturation AUC decreased by 18% during prolonged sitting visit while increased by 32% during microbreaks visit |
| Howard *et al*., 2013[20] | To examine the effects of interrupting sitting time on blood coagulation and blood volume parameters in sedentary, middle-age, overweight/obese adults | Uninterrupted sitting for 5 hours | Sitting interrupted by light-intensity treadmill walk (speed 3.2 kmph) for 2 minutes every 20 minutes for five hours | Sitting interrupted by moderate-intensity incremental treadmill walk (speed 5.8 and 6.4 kmph; increment 0.1 kmph every 30 sec) for 2 minutes every 20 minutes for five hours [RPE – 12-14] | • Fibrinogen increased with sitting and moderate-intensity breaks.<br>• aPTT decreased significantly in the sitting interrupted with moderate-intensity activity condition only<br>• activity breaks attenuated increases seen in plasma fibrinogen (light-intensity only), Hct, Hb, and RBC and the reduction in plasma volume with uninterrupted sitting. |
| Kerr *et al*., 2017[33] | To compare the acute metabolic and vascular endothelial function outcomes of prolonged sitting condition with three different active conditions | Uninterrupted sitting for 5 hours. performed following conditions: read books, magazines, or newspapers, performed light paperwork, or worked on a laptop computer | Interrupting sitting with three measures: (1) sit stand prompts every 20 minutes 15 reps; (2) walking breaks for 2 minutes every one hour; (3) with standing every 10 minutes every one hour for 5 hours. | Not administered | Both 2-minute walking and 10-minute standing every hour condition resulted in an improved FMD response, which was significantly greater than the control. |
| Kowalsky *et al*., 2019[34] | To investigate the effects of hourly SRA breaks on acute cardiometabolic health outcomes | • Uninterrupted sitting for 4 h<br>• Instructed to complete their own work in a seated position | Not administered | • SRA with body supported exercise<br>• 2-4 minutes RE, 10-15 Reps, 2 sets hourly, RPE – 12 | SRA breaks can potentially improve 1-hour postprandial glucose, but may not acutely benefit other cardiometabolic outcomes. |
| Kruse *et al*., 2019[45] | To examine whether breaking up prolonged sitting with intermittent standing or under desk pedalling prevents sitting-induced PA endothelial dysfunction in middle-age sedentary, overweight/obese office workers. | Four hours of uninterrupted sitting | Two light-intensity microbreaks: (1) using standing desk for 10 minutes every one hour for four hours; (2) Pedalling on a seated elliptical workstations (>1.7 METS) for 10 minutes every one hour for four hours | Not administered | Prolonged sitting–induced leg endothelial dysfunction cannot be prevented by brief intermittent bouts of standing or desk pedalling in middle-age sedentary overweight/obese adults |

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**Table 2: Contd...**

| Author, year | Objective of the study | Quantification and comparison of the activities | | | Key findings |
|---|---|---|---|---|---|
| | | Control period/group | Low-intensity exercise breaks | Moderate-/high-intensity breaks | |
| McManus *et al.*, 2015[19] | To examine the SFA FMD changes with acute bout of uninterrupted sitting and its interruptions in young girls | • A 3-h uninterrupted period of sitting on bean bags watched movies, played iPads, read, or coloured books.<br>• Accelerometers for lower limb movement | Not administered | • Cycling breaks for 10 minutes every 1 h for 3 h<br>• Individualized moderate intensity based on maximal test | • SFA FMD decreased significantly during uninterrupted sitting but not during interrupted sitting visit<br>• No significant change in shear rates during reactive hyperaemia<br>• 3 h period of uninterrupted sitting causes a profound (33%) reduction in vascular function in young girls. |
| Morishima *et al.* 2017[32] | To examine whether previous aerobic exercise will nullify the ill-effects associated with excessive sitting | • Three hour sitting period without previous exercise<br>• No leg movement allowed | • Three hour standing period without previous exercise<br>• Minimal movement (shifting) allowed<br>• No stepping permitted | • Three hour sitting previous aerobic cycling for 45 minutes at intensity of 11-13<br>• Intensity >70% HRmax (moderate to vigorous activity) | • Uninterrupted sitting produced a marked reduction in leg blood flow and shear, independent of exercise<br>• With previous exercise, the above effects nullified<br>• Blood flow was low in standing but higher than sitting |
| Morishima *et al.* 2016[46] | To examine whether the fidgeting during prolonged sitting bouts would avert the hemodynamic dysfunction | • Seated position for 3 h<br>• The control leg remained still for 3 hrs | • Contralateral leg (experimental) was subjected to intermittent fidgeting<br>• 1 min on/4 min off<br>• Heel taps 248±6 taps/min | No applicable | • Significant reduction in blood flow and shear rate during the 3-hr sitting however the fidgeting leg showed higher blood flow and shear rate<br>• Impaired FMD after 3 h of sitting in the control leg (presit, 4.5±0.3% to postsit: 1.6±1.1%) |
| Peddie *et al.*, 2021[27] | To compare acute effects of prolonged sitting, prolonged standing and sitting interrupted with regular activity breaks on vascular function | • Uninterrupted sitting for 6 h<br>• Two-bathroom breaks 20 m down the hall<br>• To read or use their laptop | • Prolonged standing for 6 h<br>• Dimension (type, frequency) not specified | • Treadmill walk (5 kmph; 10% incline) for 2 minutes every 30 minutes<br>• Intensity not specified | • No change in SFA FMD during sitting or breaks<br>• Regular activity breaks resulted in a net shear rate that was 72% higher than prolonged sitting and maintained at 240 and 360 min.<br>• Prolonged standing improved 80% SR than prolonged sitting.<br>• During activity breaks, blood flow increased by 56% when compared with prolonged Standing. |
| Perdomo *et al.*, 2019[11] | To evaluate the effects of alternating standing and sitting vs prolonged sitting on CBFv | Uninterrupted sitting for 8 hours (3 hrs 40 min morning and 3 hrs 40 min evening) | • Sit stand work stations<br>• standing for 30-min and sitting for 30-min for 8 hrs | Not administered | Increased systolic CBFv (β=0.98 cm/s) with breaks compared with sitting |

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**Table 2: Contd...**

| Author, year | Objective of the study | Quantification and comparison of the activities | | | Key findings |
|---|---|---|---|---|---|
| | | Control period/group | Low-intensity exercise breaks | Moderate-/high-intensity breaks | |
| | | | | | Pulsatility index significantly increased from morning to midday<br>Sleepiness, mental effort, mental fatigue, and bathroom breaks were not significantly associated with cerebrovascular hemodynamics |
| Silva *et al*., 2021[30] | To analyze the acute effects of breaking up prolonged sitting with isometric leg extension exercise on the cardiovascular health indicators | • Uninterrupted sitting for three hours<br>• Allowed to freely move their upper limbs<br>• Go for bathrooms at ad libitum | • Two low-intensity breaks<br>• Self-paced walk breaks for 2 min every 30 min for 2 h<br>• Isometric leg extension (30% MVC) for 2 min every 30 min | Not administered | • No significant differences in FMD across conditions.<br>• Increased SR was evident before and after prolonged and interrupted sitting<br>• No significant differences in cardiac autonomic function between conditions<br>• No significant deterioration in vascular functions after prolonged sitting for 3 hours |
| Stoner *et al*., 2019[17] | To explore whether (a) prolonged sitting lead to decreased cerebral perfusion and executive function? and (b) breaking up prolonged sitting, using intermittent calf raise exercises, prevent changes in cerebral perfusion and executive function? | Uninterrupted sitting (motionless) watching nonstimulated TV series “Graphic design” for 3 hours | • Calf raises at 0.33 hz set from Pro Metronome<br>• 3 h sitting with 10 calf raises every 10 min for 170 min | Not administered | • Elevated parasympathetic activity with prolonged sitting.<br>• Decreased prefrontal cortex tHb in intervention compared with control [−2.1 μM, Reduction in TSI (−1.5%) in sitting group compared with fidgeting.<br>• Exercise during microbreaks decreased cerebral perfusion and executive function. |
| Taylor *et al*., 2020[12] | To explore the change in endothelial functions while interrupting prolonged sitting with brief activity in women with PCOS | Uninterrupted sitting for 3.5 hours | • SRA: light-intensity body weight exercises.<br>• Each exercise was performed for 20 s and repeated three times in a sequential order<br>• RE for 3 min every 30 min | Not administered | • No significant within or between-condition (7.31%±0.61% vs 7.40%±0.63%)<br>• Mean resting SFA shear rate was significantly higher in the SRA condition compared with prolonged sitting groups (62.8±6.1 vs 40.1±6.1 $s^{-1}$) |
| Taylor *et al*., 2021[13] | To examine the acute effects on vascular function in T2D of interrupting prolonged sitting with SRA at different frequencies. | • Uninterrupted sitting for 7 h<br>• Reading a book, use of phone | Two dose of SRA interruptions: high frequency (3 minutes every 30 minutes) and low frequency (6 minutes every 60 minutes | Not administered | • FMD increased by 1.4% in calisthenics group<br>• SR reduced in SIT group by 12.2 $s^{-1}$<br>• Blood flow ↓ 25.3 ml/min in SIT compared with calisthenics<br>• PLASMA ET ↓ 4% in SIT (0.4 pg.hr.$ml^{-1}$) |
| Thosar *et al*., 2015[47] | To examine the effects of breaking sedentary time on SFA endothelial function | Uninterrupted sitting for 3 h (not permitted lower limb movements) and typing computer tasks allowed | Treadmill walk breaks at 2 mph for 5 minutes every one hour | Not administered | • Prolonged sitting: significant reduction in FMD (η2=0.481).<br>• Anterograde and mean SR also decreased (η2=0.209). |

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**Table 2: Contd...**

| Author, year | Objective of the study | Quantification and comparison of the activities | | | Key findings |
|---|---|---|---|---|---|
| | | Control period/group | Low-intensity exercise breaks | Moderate-/high-intensity breaks | |
| Wanders *et al*., 2020[48] | To investigate whether meal composition alters how sedentary behavior and PA breaks affect these acute health outcomes | • Two conditions of uninterrupted sitting for four hours: high protein/low fat diet or the westernised diet<br>• The participants were asked to watch the nature documentary | Not administered | Two conditions of cycling (moderate intensity 50 – 70% max. heart rate) for five minutes every 30 minutes for four hours: one with high protein/low fat diet or western diet | • Meal composition did not alter the effects of PA breaks on any of the outcomes of cognitive performance, vascular function, BP, perceivable benefits or metabolic health.<br>• Compared with uninterrupted sitting, PA breaks resulted in less sleepiness, a better mood, less fatigue.<br>• No significant change in vascular outcomes with prolonged sitting or its interruptions |

in SFA and popliteal artery compared with prolonged sitting. Vascular diameter reduced with uninterrupted sitting in SFA, popliteal artery, and BA, whereas moderate-intensity PA breaks improved popliteal artery diameter by +0.15 ± 0.05 mm. Shear rate in SFA increased during both sitting and interruptions, whereas popliteal artery shear rate reduced in both scenarios. Low-intensity PA breaks increased the shear rate in both arteries, whereas moderate- to high-intensity PA breaks notably increased popliteal artery shear rate. MCA velocity decreased with sitting but increased with low-intensity PA breaks compared with baseline. PA breaks increased SFA blood flow substantially, with light-intensity breaks improving SFA and popliteal artery blood flow. Endothelin-1 increased marginally after uninterrupted sitting and more prominently with low-intensity PA breaks.

## Discussion

Our scoping review explored the breadth of the literature investigating the vascular effects of prolonged sitting and their interruptions. We found several regional vascular functions (FMD, shear rate, and blood flow) of lower limbs are adversely affected by prolonged sitting. In contrast, low to moderate-intensity PA breaks mitigate the vascular ill-effects associated with prolonged sitting. However, evidence remains mixed to draw definite conclusions on the vascular impact (peak velocity, angiogenic regulation) of prolonged sitting and its interruptions with PA breaks. The plausible physiological and mechanistic pathways underpinning the vascular effects of prolonged sitting and their interruptions are illustrated in Figure 3.

### Dose-response relationship between PA breaks and vascular functions

#### *Flow-Mediated Dilation (FMD)*

The impact of physical activity (PA) breaks on vascular functions revealed reduced lower limb FMD during prolonged sitting, notably in the SFA and popliteal artery.[36,38] Although upper-limb FMD remained stable, light-intensity activities showed improved or sustained lower limb FMD.[26,49] However, high-intensity PA breaks lacked consistent improvements in SFA FMD but indicated increased popliteal artery FMD. Each ≈ 1% increase in FMD was associated with a 13% reduction in cardiovascular disease risk.[38,50]

#### *Shear rate and diameters*

Prolonged sitting compromised shear in SFA and popliteal artery, alleviated by PA breaks. Low-intensity PA breaks increased cerebral blood flow velocities[47,51,52] but high-intensity breaks require further exploration for their potential endothelial alterations.[21,25,53]

#### *Flow velocity*

PA breaks significantly impacted cardiometabolic diseases of vascular origin.[54] Yet, studies focused primarily on break frequency and duration, overlooking the intensity's pivotal role.[23,26,47]

#### *Methodological concerns*

Methodological concerns, including sitting duration and outcome timing, demand attention. Future investigations should delve into varying intensities' effects, especially in high-risk populations[55] conducting comprehensive, long-term studies in free-living settings to generalize recommendations.[15,38] Limitations in study heterogeneity, language restrictions, and outcome variability necessitate cautious interpretation,

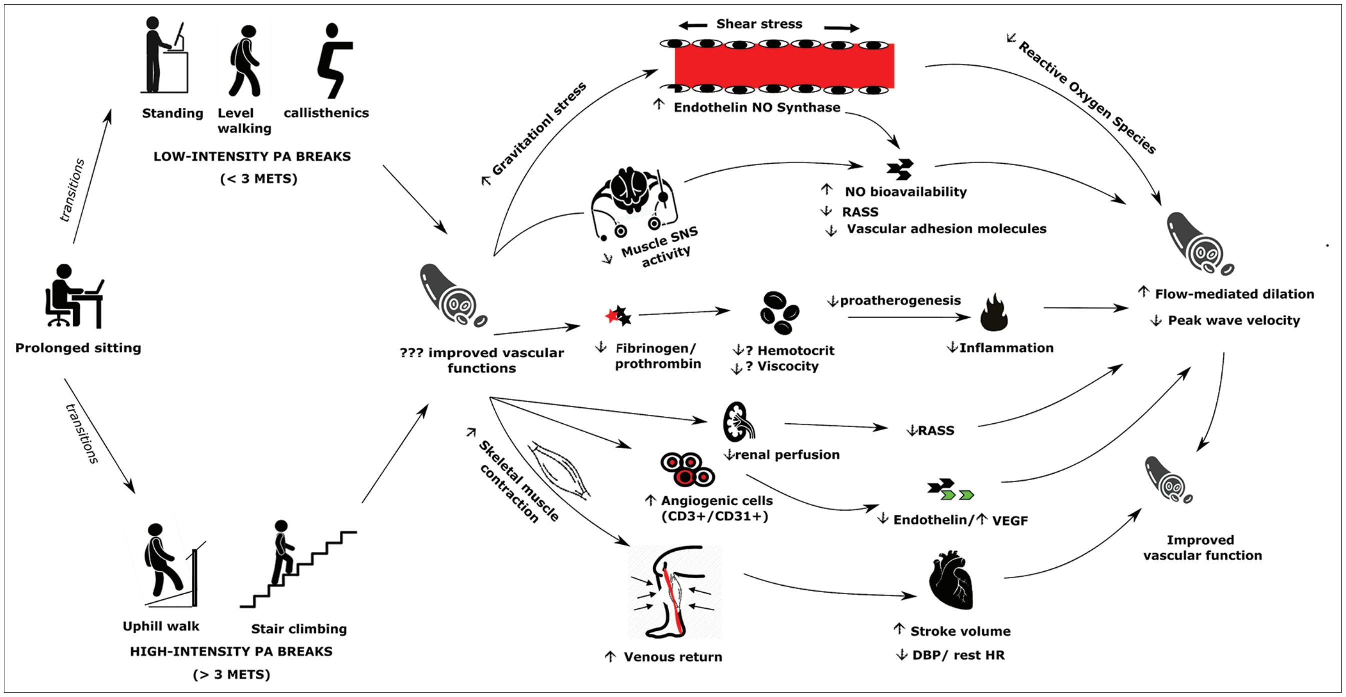


**Figure 3:** Infographics show the plausible physiological and mechanistic pathways underpinning the vascular effects of prolonged sitting and their interruptions

stressing the need for thorough, unbiased, and quality assessments.[16,19,39]

### *Clinical significance*

Although highlighting favorable vascular effects,[21,25] the clinical significance of these findings warrants extensive exploration through robust, long-term investigations into the vascular benefits of PA breaks.

## Conclusion

To conclude, our study findings demonstrated a potential reduction in regional vascular functions with prolonged sitting with interruptions of any intensity that may alleviate those adverse vascular effects. Nevertheless, the current evidence favors low-intensity PA breaks in protecting vascular integrity rather than the high-intensity PA breaks. To strengthen the existing evidence, short- and long-duration studies using high-intensity PA breaks should be advocated.

### Clinical relevance

Vascular dysfunction has propensity toward early cardiometabolic disease risk. High sedentary behaviors such as prolonged sitting is found to mediate the vascular dysfunction. This review has elaborated the clinical role of interrupting the prolonged sitting with physical activity breaks in mitigating the adverse vascular effects associated with the high sedentary behaviors. The review may aid the public health experts and the primary care providers to adapt and prescribe low-moderate physical activity breaks for their clients to ameliorate the vascular dysfunction and cardiometabolic protection.

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### Ethical approval

As this manuscript is a scoping review, the ethical approval was not needed.

### Availability of data and materials

All the data are presented in the manuscript are published online Shruthi, Poovitha, 2023, “Effect of physical activity breaks during prolonged sitting on vascular outcomes: A scoping review”, https://doi.org/10.7910/DVN/SZHVG4, Harvard Dataverse, V1.

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### Conflicts of interest

There are no conflicts of interest.

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