Journal of the American Society of Hypertension 8(6) (2014) 388–393

Research Article

The effect of lower body weight support on arterial wave reflection in healthy adults

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Manuscript received December 20, 2013 and accepted March 13, 2014

Abstract

Body weight support (WS) during treadmill exercise is used to rehabilitate orthopedic/neurological patients. WS lowers musculoskeletal strain and load. It compresses the lower body and increases intrathoracic volume. We studied short-term effects of WS on wave reflection indices using applanation tonometry during progressive WS of 25%, 50%, and 75% of body weight in 25 healthy men. WS decreased mean heart rate from 79 to 69 beats/min ($P < .001$). Peripheral and central mean arterial, systolic, and pulse pressures (PP) remained unchanged. There was a trend toward lower peripheral and central diastolic pressure. PP amplification ratio decreased significantly ($P = .005$). Reflected wave characteristics: Augmented pressure and index increased in a stepwise manner with WS (both $P < .001$). Both ejection duration and systolic duration of the reflected pressure wave ($\ddot{A}t_r$) increased progressively (both $P < .001$). The round-trip travel time (Δt_p) was unchanged. Left ventricular workload and oxygen demand: Left ventricular wasted pressure energy increased ($P < .001$), and the subendocardial viability ratio decreased ($P = .005$), whereas the tension time index remained unchanged. In normal men, WS acutely decreases the PP amplification ratio, increases the amplitude and duration of the reflected aortic pressure wave, and increases measures of wasted left ventricular pressure energy and oxygen demand. J Am Soc Hypertens 2014;8(6):388–393. Published by Elsevier Inc. on behalf of American Society of Hypertension.

Keywords: Aortic stiffness; applanation tonometry.

Introduction

Weight support (WS) treadmill exercise has been advocated for rehabilitation of patients with orthopedic and neurological conditions.[1–5] This method lowers the strain on joints and impact on muscles during treadmill exercise and allows for training in patients with acute and chronic disorders. WS treadmill systems have been used to simulate microgravity conditions and are commercially available.[6,7] In general, such systems consist of a computer-controlled treadmill equipped with a pressurized air chamber that generates a vertical upward force directly opposing the force of gravity and effectively decreasing body weight. The airtight chamber is formed by neoprene shorts that zip around the waist, and form a kayak type skirt from the waist down. This chamber suspends the subject over the treadmill surface upon inflation. Variable degrees of WS can be achieved by pumping greater air pressure as WS is proportional to the level of lower body positive pressure. WS evokes a number of cardio-respiratory changes as a consequence of increased intrathoracic blood volume and lower extremity compression, including augmenting venous return, increasing stroke volume, and baroreceptor activation.[6–15]

Applanation tonometry is an increasingly utilized technique to noninvasively measure arterial stiffness, arterial wave reflection, and central aortic (CA) blood pressure (BP). CA-BP and brachial artery (BA) BP may differ substantially because of pressure wave amplification.[16–18]

Conflict of interest: None.

Financial support: None.

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1933-1711/$ - see front matter Published by Elsevier Inc. on behalf of American Society of Hypertension.
http://dx.doi.org/10.1016/j.jash.2014.03.004

Greater arterial wave reflection is an independent predictor of adverse cardiovascular events.[19,20] Higher CA pressures are due to higher reflected wave amplitude as well as to earlier arrival of the reflected pressure wave from the periphery back to the aortic root in a stiffer vasculature. This augmented pressure increases left ventricular (LV) afterload and adversely impacts ventricular-arterial coupling.[21] The augmentation index (AI), which is the most commonly used measure of wave reflection, is the ratio of augmented pressure due to wave reflection to the CA pulse pressure (PP).[17]

Although widely viewed as a measure of afterload, AI appears to be related to LV contractile performance, as patients with depressed LV systolic function have lower AI values.[22,23] Results from use of maneuvers to increase venous return suggest LV preload is an important determinant of wave reflection properties.[24,25] However, the effects of increasing venous return on AI appear to depend on the specific technique used to vary preload. Water immersion increases the amplitude and duration of the reflected aortic pressure wave, whereas passive leg raising decreases the amplitude and delays the onset of the reflected wave.[24,25]

Inflation of the pressurized lower body air chamber of the WS treadmill while stationary provides an opportunity to vary intrathoracic loading conditions and study the effects on arterial wave reflection. Although WS-induced heart rate (HR) and BP changes have been studied, graded lower body compression has not been used to assess arterial functional properties. The objectives of this study were to characterize acute changes in noninvasive measures of arterial stiffness and wave reflection using applanation tonometry during WS in healthy male subjects.

Methods

We prospectively studied a convenience sample of 25 healthy men, age 31 ± 9 years (range, 22–59 years). The body mass index (BMI) was 24.5 ± 3.6 kg/m^2 (range, 18.6–30.5 kg/m^2), and body surface area (BSA) was 1.96 ± 0.21 m^2 (range, 1.58–2.36 m^2). Participants were without cardiovascular risk factors or disease via history. All subjects had adequate pulses and were in sinus rhythm. The institutional review board approved this study, and participants provided written consent. Baseline measurements (100% body weight) were recorded after 2 minutes of standing on the WS treadmill (AlterG Anti-Gravity Treadmill, Alter G, Fremont, CA, USA). Systolic (BA-SBP) and diastolic (BA-DBP) BA blood pressure was measured using an automated blood pressure cuff (Omron HEM-780) placed around the left arm. The weight of the subject was covertly measured by the treadmill. Baseline radial artery tonometry using SphygmoCor (AtCor Medical, Sydney, Australia) was performed to obtain the aortic waveform and baseline pulse wave analysis measurements.[16,17] Then 25%, 50%, or 75% of body weight was supported. After 2 minutes, BP and arterial tonometry measurements were repeated on the same outstretched arm resting on the treadmill rail. The degree of WS was adjusted to study levels in random order immediately after the measurements were obtained, without a rest period. BA mean arterial pressure (MAP) was calculated as diastolic pressure + 1/3 pulse pressure (PP).

Pulse Wave Analysis

Radial artery pressure waveforms were recorded at the wrist with the applanation tonometer according to previously published methods.[17] In brief, the aortic pressure waveform was derived from the radial artery waveform by a previously validated generalized transfer function.[26,27] The following parameters were obtained: augmentation pressure or reflected wave amplitude ($P_s - P_i$), defined as the difference between peak systolic pressure (P_s) and pressure at the inflection point (P_i), which is the merging point of incident and reflected waves, incident (or forward) wave amplitude ($P_i - P_d$), and AI, defined as reflected wave amplitude divided by PP and expressed as percentage ($AI = [P_s - P_i]/[P_s - P_d]$). P_d is central diastolic pressure. AI was also normalized to a HR of 75 bpsm (AI75) since AI is heart-rate dependent.[28] The round-trip travel time (Δt_p) of the pressure wave to and from the major reflecting sites in the lower body was determined from the aortic pressure waveform.[29] The systolic duration of the reflected pressure wave (Δt_r) was determined from the inflection point to the incisura.[17] ($\Delta t_p + \Delta t_r$) represents LV ejection duration (ED). ED was corrected for heart rate (ED_c) according to the previously reported formula.[30]

Indices of LV workload and myocardial oxygen demand were also derived from the pressure waveform using the technique of pulse wave analysis.[17,31] Wasted LV pressure energy (ΔEw) is defined as the extra energy that the LV must generate to overcome the augmented pressure. Wasted energy (ΔEw) is the area under the systolic portion of the reflected wave and is estimated from the equation $\Delta Ew = 1.05 \Delta t_r (P_s - P_i)$.[32] The tension time index (TTI) was obtained as the area under the systolic (AS) portion of the aortic pressure wave and that is related to work of the heart and to myocardial oxygen consumption.[33] The ratio of the areas under the diastolic portion (AD) and systolic portion (AS) of the aortic waveform is associated with the perfusion pressure and time to coronary perfusion, and is therefore an approximation of energy supply of the heart. This ratio of supply and demand is termed the subendocardial viability ratio (SEVR) or Buckberg index (SEVR = AD/AS).[32–34]

Statistical Methods

All continuous data were expressed as mean ± standard deviation. A one-way repeated measures analysis of