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The effect of sitting and calf activity on leg fluid and snoring

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ABSTRACT

Prolonged sitting may promote leg fluid retention that redistributes to the neck during sleep and contributes to snoring. This could be attenuated by calf activity while sitting. In 16 healthy non-obese subjects we measured leg fluid volume (LFV) below the knees using bioelectrical impedance while sitting for 4 h, snoring using a portable BresoDx™ device, and Mallampati grade. Using a double cross-over study design, subjects were randomized to one of two arms and crossed-over one week later: control arm – no calf exercise while sitting; intervention arm – calf contraction against a pedal resistance while sitting. The effects of sitting ± calf activity on LFV and snoring were compared. We found that LFV increased by 216 ± 101.0 ml ($p < 0.0001$) after sitting. Calf activity while sitting attenuated LFV by 53.8 ml ($p < 0.0001$) and, in all five subjects with severe upper airway narrowing (Mallampati grade IV), reduced snoring duration (from 357 ± 132.9 to 116.2 ± 72.1 s/h, $p = 0.02$) suggesting reduced overnight rostral fluid shift to the neck.

1. Introduction

Modern technological advances have led to more sedentary lifestyles and this trend is expected to rise (Ng and Popkin, 2012). This has important ramifications because a sedentary lifestyle and prolonged sitting are associated with many adverse health outcomes including increased risks for type II diabetes mellitus, cardiovascular disease, cancer and mortality (Biswas et al., 2015; Hupin et al., 2015). A sedentary lifestyle is also associated with obstructive sleep apnea (OSA) independently of body habitus (Peppard and Young, 2004; Simpson et al., 2015). For example, a recent Western Australian study of more than 2000 patients referred for investigation of OSA found that, compared to those in physically demanding occupations, men and women in sedentary occupations were at increased risk of moderate-severe OSA (odds ratios 1.8 and 3.5 respectively), independently of body mass index (BMI) (Simpson et al., 2015).

A possible mechanism for the association between a sedentary lifestyle and OSA is that prolonged sitting promotes fluid retention in the legs because of high capillary hydrostatic pressure, low tissue pressure from reduced muscle tone and absence of calf muscle pump activity. The latter is the main mechanism for augmenting venous outflow from the legs. Fluid retained in the legs caused by sitting may then redistribute to the neck while recumbent during sleep and exacerbate snoring and OSA. Indeed, Redolfi and colleagues (Redolfi et al., 2009) found that in 23 non-obese men suspected of OSA, overnight rostral fluid shift from the legs to the neck correlated with the severity of OSA, as assessed by the frequency of apneas and hypopneas per hour of sleep (apnea-hypopnea index, AHI), and time spent sitting during the day. Further, the application of lower body positive pressure using anti-shock trousers to displace fluid from the legs to the neck has been shown to increase upper airway resistance (Chiu et al., 2006; Shiota et al., 2007) and collapsibility (Su et al., 2008, 2009).

Few studies have examined the effect of sitting on fluid retention in the legs, and existing studies have measured this indirectly by estimating changes in leg volume (V_L) using methods such as water

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displacement (Noddeland and Winkel, 1988; Pottier et al., 1969) and air plethysmography (Goddard et al., 2008; Mittermayr et al., 2007). These studies indicate that V_L usually increases after sitting. There has been no previous study of fluid retention in the legs during sitting using more direct measures of fluid such as bioelectrical impedance analysis (BIA).

Activation of the calf muscle pump augments venous outflow from the leg so this may be an effective method to attenuate fluid retention in the legs during prolonged sitting required for most office work. However activation of the calf muscle pump also causes a rise in muscle temperature (Kenny et al., 2003; Winkel and Jorgensen, 1986), and the associated vasodilatation could increase leg fluid.

Thus the aims of this study were to test the hypotheses that, in healthy subjects, (1) sitting causes fluid retention in the legs, (2) calf activity while sitting will reduce fluid volume of the legs, and (3) in those with a narrow pharynx, calf activity will reduce snoring at night presumably due to reduced overnight rostral fluid shift from the legs to the neck.

2. Methods

2.1. Subjects

Inclusion criteria were non-obese (BMI <30 kg/m^2) men or women aged 40–70 years. Exclusion criteria were conditions that could cause fluid retention in the legs (pregnancy, hypertension, cardiac failure and renal failure), use of prescribed medications for these conditions, and subjects with peripheral (pitting) edema. Only non-obese subjects were included to avoid the potential confounding effects of obesity on leg fluid retention and snoring. Subjects were asked to refrain from caffeinated and alcoholic drinks on the days they attended the laboratory. The study protocol was approved by the University of Toronto Health Network Research Ethics Board. Subjects were recruited by advertisement and provided written informed consent prior to participation.

2.2. Baseline assessments

At the initial visit to the laboratory, height, weight, heart rate and blood pressure were measured, and the Epworth Sleepiness Scale assessed. Upper airway size was assessed using the Mallampati grades I–IV, with grade IV being the narrowest (Samsoon and Young, 1987). High Mallampati grades are associated with OSA (Nuckton et al., 2006). Neck circumference was measured while supine.

2.3. Leg fluid volume (LFV)

Fluid volumes of both legs were measured using a bioelectrical impedance analysis (BIA) device (MP150, Biopac Systems Canada Inc., Montreal, Canada) as previously described (Lyons et al., 2015; White et al., 2015a, 2015b; Yadollahi et al., 2014, 2015). This technique uses impedance to electric current within a body segment to measure its fluid content (Kyle et al., 2004). The distal sensing electrodes were placed just above the lateral malleolus. The proximal sensing electrodes were placed below the knee at the level of the tibial tuberosity to avoid potential changes in segment length when the knee was flexed while sitting and extended in the erect and supine postures. The length of each segment was measured at the beginning of the first study. To measure the circumferences of the segment consistently during the study, a pen was used to mark the proximal and distal ends of the segment and the level at which the calf circumference was greatest. The segment was treated as a single truncated cone where the proximal circumference was a mean of circumferences at the tibial tuberosity and the largest circumference of the calf, and the distal circumference was that measured at the ankle. Circumferences of the segment were measured while supine at the beginning and end of the study, and every 30 min while sitting. To electrically isolate each leg we used different injecting frequencies for each leg (25 and 50 kHz). Tissue resistance is frequency-dependent because the cell membrane acts as an insulator at low frequencies. At frequencies up to 100 kHz, measured resistance is believed to represent primarily extra-cellular fluid (De Lorenzo et al., 1997). We assumed a resistivity of 99 and 98 Ω cm for women and men, respectively, as these are the only published data on specific segmental resistivity of the legs (Zhu et al., 2006).

We also measured LFV in the same segment of the left leg with a validated commercially available BIA device (Xitron 4200, Hydra ECF/ICF, Xitron Technologies Inc., San Diego, CA) (XITRON, 2007). This device measures multi-frequency bioelectrical impedance (up to 1 MHz) to estimate both intra- and extra-cellular fluid volumes but does not allow continuous measurements. Measurements were obtained while supine before and after sitting, and every hour while sitting.

2.4. Leg volume

Leg volumes (V_L) in the same segments were calculated from the length of the segment, circumferences at the proximal and distal ends of the segment and at the level of the segment with the widest circumference, all assessed by tape measure, and assuming the shape of a truncated cone.

2.5. Gastrocnemius electromyography

To quantify muscle activation during calf activity, electromyography of both gastrocnemii muscles (EMGgas) was measured by bipolar surface electrodes placed over the belly of the gastrocnemii and referenced to ground electrodes placed above the knee. The signal was band pass filtered (high pass 1 Hz, low pass 500 Hz), amplified, collected and displayed continuously on the MP150 (Biopac Systems). Muscle activation was quantified by measuring the root mean square (RMS) of the signal.

2.6. Leg position

Two 3d accelerometers (Dimension Engineering, DE-ACCM3D Buffered ±3 g Tri-axis Accelerometer) were applied to each leg midway along the tibia and femur to assess leg position and ensure that it remained constant while sitting.

2.7. Snoring and sleep apnea

Snoring and sleep apnea were quantified by automated acoustic analysis of breath sounds during sleep at home using a portable, battery-operated, wireless device (BresoDx™, BresoTec Inc., Toronto, Ontario, Canada). The device consists of a light loose fitting face frame with an embedded unidirectional condenser microphone in the centre at a fixed distance (approximately 3 cm) in front of the subject's face, and an electronic module containing a pre-amplifier, microprocessor, analog-to-digital converter and a microSD memory card. Digitized sound is captured at a sampling frequency of 16 kHz, and later transferred to a computer for offline analysis. The detection of snoring and sleep apnea are automated using highly accurate algorithms that have been validated during polysomnography and in the unattended home setting (Alshaer et al., 2013a; Alshaer et al., in press; Alshaer et al., 2016, 2013b, 2014). The analysis of snoring is illustrated in an accompanying supplement. In brief, each audio file was segmented into 64 ms