Hemodynamic effects of leg crossing and skeletal muscle tensing during free standing in patients with vasovagal syncope

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Van Dijk, Nynke, Ivar G. J. M. de Bruin, Janneke Gisolf, H. A. C. M. Rianne de Bruin-Bon, Mark Linzer, Johannes J. van Lieshout, and Wouter Wieling. Hemodynamic effects of leg crossing and skeletal muscle tensing during free standing in patients with vasovagal syncope. J Appl Physiol 98: 584–590, 2005. First published October 8, 2004; doi:10.1152/japplphysiol.00738.2004.—Physical maneuvers can be applied to abort or delay an impending vasovagal faint. These countermeasures would be more beneficial if applied as a preventive measure. We hypothesized that, in patients with recurrent vasovagal syncope, leg crossing produces a rise in cardiac output (CO) and thereby in blood pressure (BP) with an additional increase in BP by muscle tensing. We analyzed the age and gender effect on the BP response. To confirm that, during the maneuvers, Modelflow CO changes in proportion to actual CO, 10 healthy subjects performed the study protocol with CO evaluated simultaneously by Modelflow and by inert gas rebreathing. Changes in Modelflow CO were similar in direction and magnitude to inert gas rebreathing-determined CO changes. Eighty-eight patients diagnosed with vasovagal syncope applied leg crossing after a 5-min free-standing period. Fifty-four of these patients also applied tensing of leg muscles during leg crossing and muscle tensing reflect changes in venous pooling.

Venous pooling in dependent parts results in a rapid diminution of central blood volume with a decrease in cardiac filling pressure, stroke volume (SV), and cardiac output (CO). Unless compensatory adjustments are instituted promptly, arterial pressure falls and the subject loses consciousness. In healthy humans, orthostatic adjustments are provided by neural blood pressure (BP) regulatory mechanisms, increasing total peripheral resistance (TPR). An increase in leg and abdominal muscle tone plays a crucial adjunctive role in the compensatory adjustment, by promoting venous return when standing (22, 24).

Subjects with primary autonomic failure suffer from severe orthostatic hypotension. This is due to failure of sympathetic neural vasomotor control, with the inability to increase peripheral resistance on standing (24). Maneuvers that raise skeletal muscle tone, such as leg crossing and muscle tensing, promote venous return and increase CO in these patients (28). This results in a rise in upright BP and improvement of orthostatic tolerance (37). Instructions to cross the legs and stand firmly on both legs are an important part of the management strategy of these patients (37).

Recent reports document that physical countermeasures can also abort or delay an impending faint in patients with vasovagal syncope (2, 15). Application of these maneuvers as a preventive measure or as a remedy to combat presyncope (often as troublesome as true vasovagal syncope) would be even more beneficial to patients in giving them a sense of control over the situation.

The aim of the present investigation was to evaluate the hemodynamic effects of two of those maneuvers, i.e., leg crossing and skeletal muscle tensing, during free standing in patients with vasovagal syncope. Considering a difference in muscle mass, we expected a smaller effect of leg crossing and muscle tensing in women and in elderly patients.

We assessed whether relative changes in Modelflow [model-based measurement method to compute the aortic flow waveform from an arterial BP waveform, based on a nonlinear, 3-element (Windkessel) model of the input impedance of the aorta (Biomedical Instrumentation) (33)] CO during leg crossing and muscle tensing reflect changes in inert gas rebreathing determined CO. We analyzed the age and gender effect on the BP response, testing the hypothesis that, in patients with recurrent vasovagal syncope, leg crossing produces a rise in CO and thereby in BP, with an additional BP-raising effect from tensing the skeletal muscles during leg crossing.

METHODS

Patient selection. Eighty-eight patients, aged 16 yr or older, presenting to the syncope unit were included. A diagnosis of vasovagal syncope, based on a history of typical triggering events and prodromal symptoms, a normal physical examination, and a normal ECG, was made by the senior investigator (W. Wieling). The investigations were performed as part of our routine orthostatic stress testing protocol, including an active standing test and tilt-table test (35).

The study was approved by the Medical Ethical Committee of our institution. All participants gave informed consent.

Orthostatic stress testing. Investigations took place in the morning, at least 1 h after breakfast, in a room with a temperature of 23°C.

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After 5 min of supine rest, patients were asked to stand up and remain standing for 5 min. Patients were then instructed to cross their legs and stand firmly on both legs for 2 min. After this 2-min period, patients tensed the skeletal muscles of the legs, abdomen, and buttocks firmly for 1 more min, while in the legs-crossed position. Patients performed the maneuver once and were not given any visual feedback on their individual performance. A fall in systolic blood pressure of >20 mmHg or an excessive rise in heart rate in the first 5 min of standing were considered to be abnormal orthostatic adjustments (35).

**Measurements.** Continuous finger BP was measured noninvasively with a Finapres (11, 13) (model 5; Netherlands Organization for Applied Scientific Research, Biomedical Instrumentation). Finapres recordings accurately reflect BP changes during orthostatic stress (13). The finger cuff was applied to the midphalanx of the left middle finger. To avoid hydrostatic level differences, the hand was held at right-atrial level in the midaxillary line. All signals, including a three-lead ECG, were recorded on a personal computer and printed by a thermopaper writer (Thermal arraycorder WR 7700, Graphtec, Solingen, Germany) for direct inspection. To check whether patients were unintentionally performing a Valsalva-like maneuver, respiration was recorded in 21 patients with a thermal sensor placed in the nose. Brachial BP was obtained at regular intervals using a Dinamap (automated oscillometric BP monitor).

**Analysis.** Lean body mass (LBM) was calculated as \(1.1 \times \text{weight} - 0.0128 \times \text{body mass index} \times \text{weight for men and 1.07} \times \text{weight} - 0.0148 \times \text{body mass index} \times \text{weight for women} (8)\). For offline analysis, all signals were analog-to-digital converted by computer at a sampling rate of 100 Hz and stored on disk. Beat-to-beat systolic (SBP), mean arterial (MAP), and diastolic (DBP) BP values were derived. Pulse pressure (PP) was calculated as the SBP − DBP difference. Heart rate (HR) was the inverse of the interbeat interval. SV was determined by a three-element model of arterial input impedance that provides accurate estimates of changes in SV during postural stress (9, 33). CO was SV times HR. Model simulated CO from radial arterial pressure follows changes in thermodilution CO in direction and degree (33). Changes in Doppler echocardiography determined SV were tracked by model SV during the Valsalva maneuver, passive tilt, and exercise (21, 27, 32).

In general, where accurate absolute values are required, CO monitoring needs calibration against a gold standard such as thermodilution (12) or Fick (31). Otherwise, CO can be expressed as changes from control with the same precision in CO (9, 20). Because the Modelflow measure was not calibrated in the present study, SV, CO, and TPR were expressed as relative changes from its starting value during standing (20, 34). TPR was the ratio of BP and CO.

Circulatory effects of leg crossing during standing are presented as changes from the upright control condition. Baseline measurements are defined as averaged values over a 30-s standing period from 4.5–5 min after standing up. Hemodynamic effects of the maneuvers were averaged over the period of the maneuver. The first 10 s after the start of the maneuver were disregarded to exclude the initial transient hemodynamic effects observed at the onset of leg muscle exercise (31, 34).

**CO measurements.** In two healthy subjects (2 men, age 31 and 27, length 188 and 192 cm, and weight 84 and 76 kg), echocardiographic changes were assessed during standing and additional muscle tension (VIVID 7; General Electronics). To confirm that during the maneuvers CO as calculated by Modelflow changes in proportion to actual CO, 10 healthy subjects (6 men, age 26–31, length 170–194 cm, and weight 59–91 kg) performed the same study protocol with CO evaluated simultaneously by Modellflow and by inert gas rebreathing (Innocor model: \(S_\text{pa}\), and \(O_2\) options) (5, 6) giving two estimates of CO: inert gas rebreathing CO (IGRCO) and Modellflow CO (MFCO). IGRCO was measured at three instances: one in the free-standing position before the maneuvers, and again during leg crossing and additional muscle tension. IGRCO during standing was used to calibrate MFCO. MFCO during standing was multiplied by the ratio of standing IGRCO to MFCO. IGRCO and calibrated MFCO changes during leg crossing and additional muscle tension became available for comparison. Calibrated MFCO was expressed as the average value of 30-s periods and was compared with the corresponding IGRCO during leg crossing (0.5–1.0 min after start of the maneuver) and additional muscle tension (0.5–1.0 min after start of the maneuver).

**Statistical analysis.** All variables were checked for normal distribution by use of the Kolmogorov-Smirnov test and Q-Q plots. When normally distributed, changes are expressed as mean and SD, otherwise as median and range. Changes in the hemodynamic variables during the maneuvers were tested by paired t-test. The influence of age, gender, height, and weight on the effects of the maneuvers on the hemodynamic variables was analyzed by multiple linear regression. The relation between MFCO and IGRCO was analyzed by Pearson’s correlation. A P value of <0.05 was considered to indicate a statistically significant difference.

**RESULTS**

**Patient characteristics.** Forty-two of the 88 patients (48%) were male. Patients had a median age of 38.5 (range 16–85) yr. Men had a median height of 180 (range 165–199) cm and weight of 77 kg (range 60–106). Median LBM was 62 (range 50–80) kg. Women had a median height of 167 (153–184) cm and weight of 63 kg (range 47–91). Median LBM was 47 (range 38–58) kg.

With a little support of the noninstrumented arm by one of the investigators, all but two patients could perform the maneuvers. The cause of inability to perform the maneuvers was marked obesity in one patient and standing instability due to old age in the other.

**Baseline hemodynamic characteristics.** Average BP, measured by Dinamap, in the supine position was 125 (SD 17) mmHg systolic and 74 (SD 10) mmHg diastolic with a HR of 70 (SD 12) beats/min. In men, supine blood pressure was higher (130/77 vs. 120/71 mmHg) and HR lower (66 vs. 74 beats/min). After 3 min of standing, average SBP was 125 (SD 19) mmHg, with a DBP of 80 (SD 10) mmHg and HR of 80 (SD 14) beats/min. Three patients showed a fall of SBP of >20 mmHg after standing up (−21 to −23 mmHg). No patient showed an excessive increase in heart rate. No patient expressed symptoms of orthostatic intolerance or presyncope during standing. In elderly patients, supine BP was higher. The BP change after standing was not different for older vs. younger subjects.

**Circulatory effects of leg crossing and additional muscle tensing during standing.** Figure 1 shows the hemodynamic changes during leg crossing in a single patient. In all patients the typical hemodynamic transient was observed with an instantaneous rise in SV, CO, and arterial BP and a drop in TPR followed by a slightly elevated BP due to an increase in SV and CO (Table 1).

SBP, MAP, DBP, and PP increased during leg crossing, whereas HR remained stable. No hemodynamic differences were observed between the first and second minute of leg crossing. The frequency distribution of the individual changes in BP during leg crossing is given in Fig. 2: SBP, MAP, and DBP increased in, respectively, 84, 77, and 69% of the patients. There was no difference in age, gender, height, weight, or LBM between responders (patients with a rise in BP during the maneuver) and nonresponders.
Fifty-four patients performed skeletal muscle tensing in the leg-crossed position. Gender, age, and physical characteristics were comparable for the entire group of patients.

Table 2 shows the effects of leg crossing combined with skeletal muscle tensing on BP.

Skeletal muscle tensing during leg crossing caused an additional rise in SBP, MAP, DBP, and PP related to an increase in HR and CO in 90% of the patients. There was no difference in age, gender, weight, or LBM between responders and nonresponders, except for median height (175 vs. 165 cm).

In 21 patients, respiration was recorded during the maneuvers. An example is given in Fig. 3. Average breathing frequency was 17 breaths/min before the maneuvers and 18 breaths/min during leg crossing and additional muscle tensing. No patient showed breath holding during the maneuvers.

**CO measurements.** In two healthy subjects, echocardiographic assessment during standing and additional muscle tensing in the leg-crossed position showed a large increase in SV and CO (Fig. 4). In 10 healthy subjects, MFCO during leg crossing and additional muscle tensing changed in proportion to IGRCO ($r^2 = 0.82; P < 0.01$; Figs. 5 and 6).

**Influence of age, gender, height, weight, and LBM on BP changes during leg crossing and additional muscle tensing.** Age was positively related to the rise in SBP, MAP, DBP, and PP during leg crossing, with an additional rise in SBP of 0.9 mmHg during leg crossing for every additional 5 yr of age. All other variables did not affect BP. The rise in SBP (13.5 vs. 6.7 mmHg; $P < 0.01$) and PP (6.6 vs. 2.4 mmHg; $P < 0.01$) during muscle tensing was larger in men, when corrected for age, height, and weight. Otherwise, gender, height, weight, and LBM did not predict the effects of the maneuvers on BP.

**DISCUSSION**

This study tested the hypothesis that physical countermaneuvers produce a rise in BP in patients prone to posture-related vasovagal syncope. The principal findings are as follows: 1) Leg crossing produces a rise in CO, BP, and PP in patients prone to vasovagal syncope. TPR actually decreased slightly. 2) Skeletal muscle tensing during leg crossing further increases CO, with an additional rise in BP and a drop in TPR. We also found that increasing age positively correlates with the BP effects of leg crossing and that the increase in SBP and PP during muscle tensing is larger in men. These results are in concordance with the large effects on BP observed when countermaneuvers are applied during a vasovagal response (2, 15).

**Hemodynamics.** Leg crossing involves tensing and compression of the skeletal muscles in the legs, which raises intramuscular pressure. The consequent mechanical compression of the venous vascular beds in the legs, into which blood pools during standing, translocates blood back to the chest with an increase in cardiac filling pressure, SV, and CO and thereby a rise in systemic BP (28, 31, 37). The rise in BP induced by the maneuvers is explained solely by an increase in CO, whereas TPR actually decreased (Tables 1 and 2). A similar observation has been reported by Smith et al. (26). In that study, sustained muscle tension of the lower limbs significantly attenuated the fall in BP, induced by progressive lower body negative pressure, because of maintenance of CO by compression of the vascular tree (26). Preliminary data also suggest that the

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Table 1. Hemodynamic effects of leg crossing during standing in 88 patients with vasovagal syncope

<table>
<thead>
<tr>
<th></th>
<th>Standing</th>
<th>Crossed Legs</th>
<th>% Change From Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic BP, mmHg</td>
<td>125.3±16.1</td>
<td>130.9±16.9</td>
<td>4.5%†</td>
</tr>
<tr>
<td>Mean arterial pressure, mmHg</td>
<td>89.9±11.1</td>
<td>92.9±11.6</td>
<td>3.3%†</td>
</tr>
<tr>
<td>Diastolic BP, mmHg</td>
<td>73.8±10.3</td>
<td>75.0±10.7</td>
<td>1.6%†</td>
</tr>
<tr>
<td>Pulse pressure, mmHg</td>
<td>51.5±11.3</td>
<td>55.9±11.9</td>
<td>8.5%†</td>
</tr>
<tr>
<td>Heart rate, beats/min</td>
<td>82.8±15.3</td>
<td>82.2±14.9</td>
<td>-0.7%</td>
</tr>
<tr>
<td>Stroke volume</td>
<td>100%</td>
<td>107.7%</td>
<td>7.7%†</td>
</tr>
<tr>
<td>Cardiac output</td>
<td>100%</td>
<td>95.9%</td>
<td>4.9%†</td>
</tr>
<tr>
<td>Total peripheral resistance</td>
<td>100%</td>
<td>95.1%</td>
<td>5.1%†</td>
</tr>
</tbody>
</table>

Values are means ± SD; n = 88 patients. BP, blood pressure. *P < 0.01; †P < 0.001.
abortion of a vasovagal faint by leg crossing and skeletal muscle tensing is mediated solely by an increase in CO (14).

The marked initial increase in SV, CO, and BP (Fig. 1) observed in all subjects is a characteristic finding at the onset of whole body exercise (34). After the initial large increase, BP returned to the previous level. We consider this a reflex effect and attribute this change in BP to the fact that the arterial baroreflex is not reset, because the level of muscular activity has not changed importantly during leg crossing. In the present study, the steady-state circulatory adjustment induced by leg crossing consists of a small increase in SV, CO, and PP and a decrease in TPR. An identical hemodynamic pattern during leg crossing was observed in a previous study in six healthy young adults without a history of vasovagal fainting (28).

Active tensing of leg and abdominal muscles reinforced the mechanical effects on the circulation induced by leg crossing. The increase in HR during muscle tensing indicates that reflex effects are involved. First, tensing of the skeletal muscles is associated with activation of the central nervous drive from higher brain centers (central command) that stimulate the brainstem cardiovascular centers, with an instantaneous increase in HR resulting from a withdrawal of vagal outflow to the heart (29). Second, feedback from the contracting skeletal muscles due to mechanoreceptor activation can raise HR by reducing vagal outflow to the heart (muscle-heart reflex) (7, 10). Muscle tensing is also known to activate the muscle chemoafferents, resulting in a reflex increase in sympathetic outflow and thereby in TPR. However, muscle chemoafferents are activated only after 1 min of sustained muscle contractions, rendering involvement of the muscle chemoreflex in the instantaneous rise in BP caused by the physical countermaneuvers therefore less likely. In the present study, TPR actually decreased slightly (23).

The greater effect of leg crossing on BP in the elderly was unexpected, when the age-related reduction in muscle mass and strength is considered (17). Although supine BP in older patients was higher, the change in BP after standing was not different from younger subjects. We therefore speculate that this effect is due to the age-related reduced baroreceptor buffering (3) and steeper rises in BP due to a less compliant venous vascular system (19). An alternative explanation for the

Table 2. Hemodynamic effects of skeletal muscle tensing during standing in leg-crossed position in 54 patients with vasovagal syncope

<table>
<thead>
<tr>
<th></th>
<th>Standing</th>
<th>CROSSED LEGS</th>
<th>% CHANGE FROM BASELINE</th>
<th>CROSSED LEGS + TENSING</th>
<th>% CHANGE FROM BASELINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic BP, mmHg</td>
<td>126.1±15.9</td>
<td>132.0±16.1</td>
<td>4.8%‡</td>
<td>142.2±18.1‡</td>
<td>12.8%‡</td>
</tr>
<tr>
<td>Mean BP, mmHg</td>
<td>90.8±11.4</td>
<td>94.0±11.4</td>
<td>3.5%‡</td>
<td>101.1±12.6‡</td>
<td>11.3%‡</td>
</tr>
<tr>
<td>Diastolic BP, mmHg</td>
<td>74.9±10.6</td>
<td>76.1±10.5</td>
<td>1.6%§</td>
<td>81.8±11.4‡</td>
<td>9.2%‡</td>
</tr>
<tr>
<td>Pulse pressure, mmHg</td>
<td>51.2±10.8</td>
<td>56.0±11.3</td>
<td>9.4%‡</td>
<td>60.4±12.8‡</td>
<td>18.0%‡</td>
</tr>
<tr>
<td>Heart rate, beats/min</td>
<td>86.3±15.7</td>
<td>85.4±15.7</td>
<td>-1.0%</td>
<td>90.0±16.0‡</td>
<td>4.3%†</td>
</tr>
<tr>
<td>Stroke volume</td>
<td>100%</td>
<td>100%</td>
<td>12.7%‡</td>
<td>100%</td>
<td>14.0%‡</td>
</tr>
<tr>
<td>Cardiac output</td>
<td>100%</td>
<td>100%</td>
<td>11.3%§</td>
<td>100%</td>
<td>19.6%‡</td>
</tr>
<tr>
<td>Total peripheral resistance</td>
<td>100%</td>
<td>100%</td>
<td>-6.5%§</td>
<td>100%</td>
<td>-5.2%†</td>
</tr>
</tbody>
</table>

Values are means ± SD; n = 54 patients. *P < 0.05; †P < 0.01; ‡P < 0.001.
larger rise in BP in elderly subjects is the age-associated reduction in blood volume (4). If so, performance of a physical countermaneuver would give way to a relatively larger rise in central blood volume, with a larger effect on BP. In this study, these effects were, however, not reflected in a larger rise in SV and CO in elderly patients.

Clinical relevance. Leg crossing and muscle tensing are safe maneuvers, easy to apply and cheap, and are able to increase standing BP (30; present study) and to abort an impending faint under laboratory conditions (2, 15). We consider that these observations support that patients with posture-related vasovagal (pre)syncope are advised to apply physical countermaneuvers in daily life.

In the present study, patients were not trained in performing the maneuvers. Training of the physical counterpressure maneuvers might enhance their effectiveness (1). The changes in BP can be demonstrated to a patient immediately by showing the continuous BP tracing on a video screen while the patient performs the maneuver. Resistance exercise to prevent a reduction in muscle mass should be advised to all people and
especially those prone to vasovagal syncope (36). Physical counterpressure maneuvers may be of assistance in preventing recurrent episodes of vasovagal syncope and the consequent impairment in quality of life that can accompany this common clinical syndrome (18).

In our current practice, patients are advised to apply leg crossing as a preventive measure to improve orthostatic tolerance during prolonged upright standing. During presyncopal symptoms, they should combine leg crossing with tensing of the leg, abdominal, and buttocks muscles to prevent an impending vasovagal reaction. When the mentioned measures appear ineffective, or when presyncopal symptoms develop rapidly, patients are advised to apply squatting as an emergency measure to prevent loss of consciousness (16).

Fig. 5. Changes in cardiac output (CO) during standing, leg crossing, and additional muscle tensing in 10 healthy volunteers measured simultaneously using Modelflow and the inert gas rebreathing (IGR) technique. A: HR changes during maneuvers. B: CO changes measured by IGR (IGRCO). C: CO changes measured by Modelflow (MFCO; calibrated with IGR during standing). Additional muscle tensing produces a significant rise in CO from standing (*P < 0.05).

Fig. 6. Pooled data for IGRCO and calibrated MFCO measurements during leg crossing (○) and additional muscle tensing (●). A: correlation between both methods. Line: regression for pooled data points. B: differences between IGRCO and MFCO against their means. Horizontal lines indicate means ±1.96 SD of pooled data. Note the significant correlation between the IGR and Modelflow measurements.

Fig. 6. Pooled data for IGRCO and calibrated MFCO measurements during leg crossing (○) and additional muscle tensing (●). A: correlation between both methods. Line: regression for pooled data points. B: differences between IGRCO and MFCO against their means. Horizontal lines indicate means ±1.96 SD of pooled data. Note the significant correlation between the IGR and Modelflow measurements.
In conclusion, leg crossing produced a 9.5% rise in CO and thereby in MAP (+3%), with an additional 8.3% increase in CO and 7.8% rise in MAP by skeletal muscle tensing. TPR thereby in MAP (Grant 2003B156) and Space Research Organization Netherlands project MG-052 and MG-020.

REFERENCES


