Relation Between Sympathetic Outflow and Vascular Resistance in the Calf During Perturbations in Central Venous Pressure

Evidence for Cardiopulmonary Afferent Regulation of Calf Vascular Resistance in Humans

Susanne Fløistrup Vissing, Urs Scherrer, and Ronald G. Victor

Vascular studies in humans have advanced the concept that, during orthostatic stress, cardiopulmonary afferents reflexly regulate vascular resistance in the forearm but exert surprisingly little if any effects on vascular resistance in the calf. In contrast, neurophysiological studies have indicated that unloading of cardiopulmonary afferents during lower body negative pressure evokes comparable increases in sympathetic outflow to the muscles of both the forearm and the calf. The aim of this study, therefore, was to determine if alterations in central venous pressure over the physiological range trigger reflex changes in muscle sympathetic outflow that not only are statistically significant but also are large enough to alter vascular resistance in the calf. To accomplish this aim, we measured calf blood flow with plethysmography and simultaneously performed microelectrode recordings of sympathetic outflow to calf muscles in conscious humans during maneuvers designed to alter the loading conditions of the cardiopulmonary afferents. We found that calf vascular resistance increased by 33±7% (mean±SEM, p<0.05) during decreases in central venous pressure produced by nonhypotensive lower body negative pressure (LBNP) and decreased by 26±5% (p<0.05) during increases in central venous pressure produced by nonhypertensive infusion of normal saline. These changes in calf resistance were at least as large as the changes in forearm resistance evoked by these maneuvers and were accompanied by parallel changes in peroneal muscle sympathetic nerve activity. We performed additional experiments to determine if the increases in sympathetic vasoconstrictor outflow during LBNP were caused not only by deactivation of cardiopulmonary afferents but also by activation of venoarteriolar reflexes caused by distension of leg veins within the negative pressure chamber. Application of LBNP to only one leg caused comparable increases in sympathetic outflow to both legs. Furthermore, without LBNP, venous congestion alone (i.e., inflation of a congesting cuff on the thigh) had no effect on peroneal muscle sympathetic activity. Thus, activation of axonal or spinal venoarteriolar reflexes in the leg does not explain the observed increases in muscle sympathetic outflow during LBNP. In conclusion, the present findings strongly suggest that the stimulation of skeletal muscle sympathetic outflow caused mainly by unloading of cardiopulmonary afferents is an important autonomic adjustment to orthostatic stress. In conscious humans, this reflex sympathetic response is accompanied by vasoconstriction in all of the extremities. (Circulation Research 1989;65:1710-1717)
monary afferents in causing the reflex vascular adjustments to orthostatic stress in conscious humans remains an unsolved problem in cardiovascular physiology. In this regard, studies using direct measurements of sympathetic nerve activity and those using plethysmographic measurements of blood flow have led to opposing concepts. The neurographic studies have indicated that unloading of cardiopulmonary afferents during orthostatic stress evokes a mass sympathetic discharge to the muscles of all of the extremities. In contrast, recent plethysmographic studies have advanced the concept that, during orthostatic stress, cardiopulmonary afferents reflexly regulate vascular resistance in the forearm but exert surprisingly little if any effects on vascular resistance in the calf. Thus, the vascular studies call into question the functional importance of the muscle sympathetic nerve discharge evoked by mild orthostatic stress, a condition that mainly unloads cardiopulmonary afferents.

One possibility is that the stimulation of muscle sympathetic nerve activity (MSNA) caused by mild levels of orthostatic stress is too small to cause detectable increases in calf resistance. If the relation between sympathetic discharge and vascular response were sigmoidal rather than linear, one could hypothesize that nonhypotensive venous pooling causes increases in MSNA that fall on the initial flat portion of this sigmoid curve. The goal of this study, therefore, was to examine directly the relation between muscle sympathetic outflow and vascular resistance in the calf both at rest and during maneuvers designed to increase and decrease the stimulation of cardiopulmonary afferents in humans.

**Subjects and Methods**

**Subjects**

Eighteen subjects (16 men and 2 women) aged 23–32 years participated in this study after providing written informed consent. Two subjects were studied twice, and two other subjects were studied on three different occasions. All subjects were normotensive (supine blood pressures <140/90 mm Hg), were taking no medications, and had no evidence of cardiopulmonary disease on history or physical examination at the time of the study. The protocol was approved by the institutional review board on human investigation.

**Procedures**

All experiments were performed with the subjects supine and the lower body enclosed in a lower body negative pressure (LBNP) chamber. An opening was created on the left side of the chamber so that LBNP could be performed on the right leg and pelvis while measuring reflex changes in calf blood flow in the left leg outside of the LBNP chamber. A small opening was created on the right side of the LBNP chamber to allow performance of the microneurographic technique for recording MSNA from the peroneal nerve in the right leg. Once stable recordings were obtained, the openings were closed and sealed during the protocol.

Blood flow in the calf and forearm was measured with venous occlusion plethysmography. Blood flow was measured outside of the LBNP chamber by use of air-filled latex cuffs. The forearm and calf were elevated 10–15 cm above the level of the right atrium to collapse the veins. The circulation to the foot and hand was arrested during blood flow determinations, which were performed at 15-second intervals.

Multunit recordings of postganglionic sympathetic nerve activity were obtained with unipolar tungsten microelectrodes inserted into muscle nerve fascicles of the peroneal nerve posterior to the fibular head by microneurography; the details of this technique have been described extensively in previous publications. Briefly, the neural signals recorded by microelectrodes were amplified, filtered (bandwidth of 700–2,000 Hz), rectified, and integrated to obtain a mean voltage display of MSNA. A recording of MSNA was considered acceptable when the neurograms revealed spontaneous pulse-synchronous bursts that increased during the Valsalva maneuver but not during arousal stimuli (loud noise, skin pinch).

Sympathetic bursts were detected by inspection of the filtered and mean voltage neurograms; the interobserver and intraobserver variability in identifying bursts is less than 10% and less than 5%, respectively. Nerve traffic was expressed both as bursts per minute, an index of the frequency of activity, and as bursts per minute times mean burst amplitude, an index of integrated (total) nerve activity.

Heart rate was measured from the continuous electrocardiogram. Blood pressure was measured in the right arm by sphygmomanometry with an automated system (Dinamap, Critikon, Tampa, Florida) that recorded arterial pressure once every 30 seconds. Respiratory excursions were monitored with a strain gauge pneumograph. Central venous pressure was measured directly. After local anesthesia, a venous catheter was inserted percutaneously into an antecubital vein and advanced into an intrathoracic vein; central venous pressure was used as an index of the mechanical stimulus to the cardiopulmonary afferents. Pressure inside of the LBNP chamber was measured with a Statham transducer (Gould, Cleveland, Ohio).

Mean arterial pressure was calculated as diastolic pressure plus one-third pulse pressure. Vascular resistance in the forearm and calf was calculated as mean arterial pressure in millimeters of mercury divided by blood flow in milliliters per minute per 100 ml tissue.

**Specific Protocols**

**Protocol 1: Relation between MSNA and vascular resistance in the calf.** In eight subjects, we measured blood flow in the left calf and simultane-
uously recorded MSNA from the right peroneal nerve 1) at rest, 2) during decreases in central venous pressure produced by LBNP, and 3) during increases in central venous pressure produced by saline infusion. These interventions were designed to alter central venous pressure, an index of cardiopulmonary afferent stimulation, without altering arterial pressure or heart rate, indexes of arterial baroreflex stimulation.

Subjects rested quietly for 15 minutes before beginning the experimental interventions. Calf flow and peroneal MSNA were recorded during 6 consecutive minutes of rest. After control measurements, graded LBNP was performed for 2 minutes at −5 mm Hg followed directly by 2 minutes at −10 mm Hg followed by recovery.

After an additional 2 minutes of control, 1,000 ml normal saline was infused into a forearm vein as rapidly as possible (over about 20 minutes). Measurements were recorded after 500 and after 1,000 ml saline had been infused.

| TABLE 1. Effects of Lower Body Negative Pressure and Infusion of Saline on Muscle Sympathetic Nerve Activity, Blood Flow, and Vascular Resistance in the Calf |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Mean arterial pressure (mm Hg) | Pulse pressure (mm Hg) | Heart rate (beats/min) | Central venous pressure (mm Hg) | Muscle sympathetic nerve activity (bursts/min x amplitude) | Calf blood flow (ml/min/100 ml) | Calf vascular resistance (units) |
| LBNP            |                 |                 |                 |                            |                        |                          |                                |
| Control         | 92±1            | 38±3            | 59±4            | 5.9±1.2                    | 18±2                   | 233±46                    | 2.9±0.2                        | 32.7±2.2                      |
| −5 mm Hg        | 91±1            | 36±3            | 58±4            | 4.4±1.2*                   | 22±3*                  | 290±55*                   | 2.5±0.2*                       | 37.4±3.3*                     |
| −10 mm Hg       | 91±1            | 39±2            | 57±4            | 2.9±1.4*                   | 27±3*                  | 399±65*                   | 2.2±0.2*                       | 42.3±4.4*                     |
| Recovery        | 91±1            | 40±4            | 61±6            | 6.0±1.4                    | 17±2                   | 206±39                    | 2.9±0.2                        | 32.7±2.5                      |
| Saline infusion |                 |                 |                 |                            |                        |                          |                                |                                |
| Control         | 92±2            | 40±3            | 62±4            | 6.2±1.0                    | 23±4                   | 324±72                    | 2.5±0.2                        | 38.9±3.4                      |
| 500 ml          | 93±2            | 42±3            | 64±6            | 9.0±1.3*                   | 19±4                   | 260±71*                   | 3.0±0.2*                       | 32.4±2.6*                     |
| 1,000 ml        | 93±2            | 42±4            | 68±7            | 10.4±1.3*                  | 17±4                   | 200±46*                   | 3.2±0.2*                       | 30.6±3.2                      |

Values are mean±SEM for seven subjects during lower body negative pressure (LBNP) protocol and for eight subjects during saline infusion.

*p<0.05 vs. control.
In six of the subjects, we examined the correlation between spontaneous fluctuations in MSNA and in calf vascular resistance during 6 minutes of rest. For each flow determination, calf resistance was calculated, and the corresponding value of MSNA was determined for the preceding 15-second interval.

Protocol 2: Effects of increasing transmural pressure in calf veins on sympathetic discharge to calf muscles. The purpose of this protocol was to determine if the MSNA response to LBNP was due in part to reflexes elicited by venous distension in the leg inside of the LBNP chamber. We performed simultaneous recordings of MSNA from the right and left peroneal nerves (i.e., from the leg inside and outside of the LBNP chamber) in three subjects both at rest and during graded LBNP at -5 and -10 mm Hg. To further test the possibility that increases in transmural venous pressure in the calf might reflexly increase sympathetic outflow to calf muscles, we measured MSNA in the right and left peroneal nerves while inflating a pneumatic cuff on the right thigh to 20, 40, and 60 mm Hg for 2 minutes at each level; this sequence was repeated twice in each subject.

Protocol 3: Comparison of calf and forearm vascular responses to LBNP and saline infusion. The aim of this protocol was to compare changes in vascular resistance in the calf versus the forearm during increases and decreases in cardiac filling pressure. In 10 subjects, we performed simultaneous plethysmographic determinations of blood flow in the left calf and left forearm at rest, during LBNP at -5 and at -10 mm Hg, and during intravenous infusion of 500 and 1,000 ml normal saline. In each subject, vascular resistance was plotted as a function of the changes in central venous pressure evoked by these maneuvers. Reflex gain was calculated from the slope of the stimulus-response relation and expressed as the change in vascular resistance in units per change in central venous pressure in millimeters of mercury.
TABLE 2. Muscle Sympathetic Nerve Activity Recorded Simultaneously From the Right and Left Peroneal Nerves at Rest and During Lower Body Negative Pressure

<table>
<thead>
<tr>
<th>Subject</th>
<th>Left leg outside negative pressure chamber</th>
<th>Right leg inside negative pressure chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>LBNP</td>
</tr>
<tr>
<td>Subject 1</td>
<td>18</td>
<td>34</td>
</tr>
<tr>
<td>Subject 2</td>
<td>18</td>
<td>26</td>
</tr>
<tr>
<td>Subject 3</td>
<td>7</td>
<td>28</td>
</tr>
</tbody>
</table>

Mean±SEM

<table>
<thead>
<tr>
<th>Left leg outside negative pressure chamber</th>
<th>14±4</th>
<th>29±2</th>
<th>+15±4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right leg inside negative pressure chamber</td>
<td>15±4</td>
<td>30±3</td>
<td>+14±3</td>
</tr>
</tbody>
</table>

Lower body negative pressure (LBNP) was at −10 mm Hg. Sympathetic nerve activity is expressed in bursts/min.

Data Analysis

Steady-state values of arterial pressure, heart rate, central venous pressure, blood flow, and sympathetic nerve activity represent the mean value determined during each 2 minutes of control, intervention, and recovery periods. Statistical analysis was performed by repeated measures analysis of variance with the Bonferroni adjustment for multiple comparisons. A value of p<0.05 was considered statistically significant. Results are expressed as mean±SEM.

Results

Relation Between MSNA and Vascular Resistance in the Calf

Under resting conditions, each subject showed a strong linear relation (p<0.05) between spontaneous fluctuations in calf resistance and in MSNA, the latter being measured during the 15-second period preceding each blood flow determination (Figure 1).

LBNP caused significant (p<0.05) increases in MSNA and in calf vascular resistance that were parallel to the decreases in central venous pressure evoked by this maneuver (Table 1 and Figures 2 and 3). Saline infusion caused significant decreases in MSNA and in calf resistance that were parallel to the increases in central venous pressure (Table 1 and Figures 2 and 3). Neither of these interventions significantly altered arterial pressure or heart rate. During both increases and decreases in central venous pressure, the relation between calf resistance and peroneal MSNA was roughly linear (Figure 3).

Effect of Increasing Transmural Pressure in Calf Veins on Sympathetic Discharge to Calf Muscles

MSNA was comparable in the right and left peroneal nerves when measured simultaneously at rest and during LBNP performed on the right leg (Table 2 and Figure 4).

Inflation of a venous congesting cuff to 20, 40, and 60 mm Hg on the right thigh had no effect on MSNA in the ipsilateral or in the contralateral peroneal nerve.

Comparison of Calf and Forearm Responses

LBNP and saline infusion produced increases and decreases in calf vascular resistance that were comparable to or greater than the vascular responses in the forearm (Table 3 and Figure 5). Reflex gain (change in vascular resistance in units divided by change in central venous pressure in millimeters of mercury) was greater in the calf than in the forearm: 2.82±0.65 versus 1.18±0.23, p<0.05.

During infusion of saline, the decreases in vascular resistance were proportional to the initial value of baseline resistance (Figure 6). In contrast, during LBNP, increases in vascular resistance showed no relation to baseline vascular resistance.

The Valsalva maneuver also caused greater increases in vascular resistance in the calf than in the forearm: +13±4 versus +7±2 units, p<0.05.

Discussion

Rusch et al15 first provided evidence that many reflex mechanisms exert differential effects on the circulation to the forearm as compared with the calf in humans. Regarding the reflex circulatory adjust-
vascular responses are linearly related to changes in pressure over the physiological range elicit vascular findings are these: 1) Alterations in central venous pressure also evoked comparable increases in sympathetic outflow to the muscles of both the forearm and the calf.6–8 In the present study, we performed simultaneous microneurographic measurements of sympathetic outflow to calf muscles and plethysmographic measurements of calf blood flow in humans to determine if alterations in the loading conditions of cardiopulmonary afferents trigger reflex changes in muscle sympathetic outflow that not only are statistically significant but also are large enough to alter vascular resistance in the calf. The major new findings are these: 1) Alterations in central venous pressure over the physiological range elicit vascular responses in the calf that are comparable with or even greater than those in the forearm. 2) These calf vascular responses are linearly related to changes in muscle sympathetic outflow and thus appear to be reflexly mediated. These findings challenge the concept of differential cardiopulmonary afferent regulation of vascular resistance in the forearm and calf.

The most likely explanation for the changes in sympathetic activity and corresponding changes in calf resistance during LBNP and saline infusion is that these are reflex responses caused mainly by cardiopulmonary afferents.9,10 In anesthetized animals with sinoaortic deafferentation, increases and decreases in cardiac filling pressure evoke reciprocal changes in sympathetic activity and vascular resistance that are mediated by vagal afferents.3 Alterations in central venous pressure also evoked reciprocal changes in both sympathetic nerve activity and vascular resistance in our human subjects.

Animal and human studies have indicated that sinoaortic as well as cardiopulmonary afferents contribute to the autonomic responses to even mild levels of LBNP.18,19 Although we, therefore, cannot exclude any influence of sinoaortic baroreceptors in the interpretation of our findings, arterial baroreflexes are unlikely to have played an important role in producing the sympathetic nerve responses to LBNP and saline infusion because these interventions had no detectable effects on arterial pressure.

Table 3. Effects of Lower Body Negative Pressure and Saline Infusion on Blood Flow and Vascular Resistance in the Forearm and Calf

<table>
<thead>
<tr>
<th></th>
<th>Mean arterial pressure (mm Hg)</th>
<th>Pulse pressure (mm Hg)</th>
<th>Heart rate (beats/min)</th>
<th>Central venous pressure (mm Hg)</th>
<th>Forearm blood flow (ml/min/100 ml)</th>
<th>Calf blood flow (ml/min/100 ml)</th>
<th>Forearm vascular resistance (units)</th>
<th>Calf vascular resistance (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBNP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>83±3</td>
<td>43±2</td>
<td>64±4</td>
<td>6.0±0.4</td>
<td>4.5±0.5</td>
<td>2.6±0.2</td>
<td>20.0±2.2</td>
<td>34.2±3.3</td>
</tr>
<tr>
<td>−5 mm Hg</td>
<td>82±2</td>
<td>46±2</td>
<td>64±3</td>
<td>3.4±0.7*</td>
<td>3.9±0.5*</td>
<td>2.2±0.2*</td>
<td>22.9±2.2*</td>
<td>39.4±3.5*</td>
</tr>
<tr>
<td>−10 mm Hg</td>
<td>81±3</td>
<td>43±2</td>
<td>66±3</td>
<td>1.8±0.8*</td>
<td>3.6±0.5*</td>
<td>2.0±0.2*</td>
<td>25.4±2.6*</td>
<td>44.6±3.7*</td>
</tr>
<tr>
<td>Recovery</td>
<td>81±3</td>
<td>44±2</td>
<td>65±3</td>
<td>5.8±0.3</td>
<td>4.7±0.4</td>
<td>2.7±0.2</td>
<td>18.6±2.1</td>
<td>32.2±3.0</td>
</tr>
<tr>
<td>Saline infusion</td>
<td>85±3</td>
<td>42±3</td>
<td>65±4</td>
<td>5.9±0.4</td>
<td>4.3±0.6</td>
<td>2.3±0.3</td>
<td>22.7±2.9</td>
<td>41.1±4.3</td>
</tr>
<tr>
<td>Control</td>
<td>87±3*</td>
<td>45±2</td>
<td>68±4</td>
<td>8.4±0.6*</td>
<td>5.3±0.7*</td>
<td>2.9±0.3</td>
<td>18.8±2.4*</td>
<td>32.9±3.9*</td>
</tr>
<tr>
<td>500 ml</td>
<td>90±3*</td>
<td>43±3</td>
<td>71±5*</td>
<td>10.1±0.9*</td>
<td>5.6±0.7*</td>
<td>3.3±0.4*</td>
<td>18.1±2.4*</td>
<td>30.5±3.8*</td>
</tr>
<tr>
<td>1,000 ml</td>
<td>90±3*</td>
<td>43±3</td>
<td>71±5*</td>
<td>10.1±0.9*</td>
<td>5.6±0.7*</td>
<td>3.3±0.4*</td>
<td>18.1±2.4*</td>
<td>30.5±3.8*</td>
</tr>
</tbody>
</table>

Values are mean±SEM for 10 subjects. LBNP, lower body negative pressure. *p<0.05 vs. control.
Change in vascular resistance (units)

FIGURE 5. Graph showing changes in vascular resistance in the calf and forearm plotted as a function of the decreases in central venous pressure (CVP) produced by graded lower body negative pressure (LBNP) and increases in CVP produced by graded intravenous infusion of normal saline. Data are mean±SEM for 10 subjects. Alterations in CVP over the physiological range elicited changes in calf resistance that were at least as large and actually larger than those in the forearm. *Significant differences (p<0.05) between calf and forearm responses.

or heart rate. There is compelling evidence that heart rate is governed by arterial baroreceptors rather than by cardiopulmonary afferents during physiological conditions in humans.5

We considered the possibility that increases in sympathetic outflow to calf muscles during LBNP could have been caused not only by deactivation of cardiopulmonary afferents resulting from reduction in central venous pressure but also by activation of venoarteriolar reflexes resulting from distension of leg veins enclosed within the LBNP chamber. Previous studies have suggested that distension of leg veins activates axonal and spinal venoarteriolar reflexes that contribute to the compensatory increases in calf resistance during orthostatic stress in humans.20,21 Activation of unilateral axonal or spinal venoarteriolar reflexes does not explain the sympathetic nerve responses to LBNP in our experiments because application of LBNP to only one leg caused comparable increases in MSNA in both legs. Venous distension causing bilateral increases in sympathetic outflow also is unlikely to explain our findings because, without LBNP, venous distension alone (i.e., inflation of a constricting cuff on the thigh) had no detectable effect on the MSNA.

The present data, together with previous microneurographic findings,7,8 provide abundant evidence that even small alterations in central venous pressure evoke reproducible changes in sympathetic outflow to calf muscles. However, the functional importance of this sympathetic effect has been controversial. Essandoh and colleagues9,10 previously reported that maneuvers designed to alter cardiopulmonary afferent activity, such as LBNP at −10 mm Hg, upright posture, and head-down tilt, consistently evoked substantial changes in forearm blood flow but had little or no effect on blood flow and vascular resistance in the calf. One could hypothesize that small changes in central venous pressure produce sympathetic responses that, while statistically significant, are not large enough to alter vascular resistance in the calf. Our data directly refute this hypothesis and suggest that sympathetic outflow to calf muscles is an important determinant of vasomotor tone in the calf both at rest and during alterations in central venous pressure over the physiological range. We found that LBNP at −10 mm Hg consistently increased calf vascular resistance in each of 39 experiments performed on 18 different subjects.

We also found that both increases and decreases in central venous pressure triggered changes in vascular resistance in the calf that were at least as large as, and actually somewhat larger than, the corresponding changes in the forearm. This observation is consistent with the recent report that MSNA in the radial and peroneal nerves, when recorded simultaneously, showed approximately comparable increases during nonhypotensive LBNP.8

The statistical differences in the magnitude of the calf versus forearm vascular responses in the present study should be interpreted cautiously. In this regard, baseline values of vascular resistance were 50% higher in the calf than in the forearm, as previously reported.22

FIGURE 6. Graphs showing effects of baseline vascular resistance on changes in calf and forearm vascular resistance during saline infusion and lower body negative pressure (LBNP). The vasodilator responses to saline infusion showed a positive correlation (r=0.67, p<0.05) to the baseline level of resistance. In contrast, the vasoconstrictor responses to LBNP showed no such correlation. Data represent peak responses in 10 subjects.
Studies in animals have demonstrated that an elevation in baseline limb vascular resistance causes a nonspecific enhancement of vasomotor responses to superimposed vasodilator stimuli but not to vasoconstrictor stimuli. In our human studies, we also found that the magnitude of the vasodilator responses evoked by infusion of saline showed a positive correlation with baseline values of vascular resistance, whereas vasoconstrictor responses evoked by LBNP showed no such relation.

The finding that LBNP caused a somewhat larger vasoconstrictor response in the calf than in the forearm might be related to the fact that plethysmographic determinations of blood flow represent the composite of flow in both muscle and skin. Selective measurements of skin blood flow with laser Doppler velocimetry have indicated that LBNP at —5 and —10 mm Hg does not decrease skin blood flow in either the forearm or the calf. Those observations, together with our present finding of a close correlation between increases in muscle sympathetic outflow and in calf vascular resistance during LBNP at —5 and —10 mm Hg, suggest that the increases in forearm and calf vascular resistance evoked by these mild levels of LBNP occur primarily in muscle. Thus, a larger vasoconstrictor response to LBNP in calf versus forearm tissue might be related to a larger volume of muscle relative to skin in the calf as compared with the forearm. The additional finding that the Valsalva maneuver, another potent stimulus to MSNA, also caused greater vasoconstriction in the calf than in the forearm is consistent with this interpretation.

In summary, the present findings strongly suggest that the stimulation of skeletal muscle sympathetic outflow caused by unloading of cardiopulmonary afferents is an important autonomic adjustment to orthostatic stress. In conscious humans, this reflex sympathetic response is accompanied by vasoconstriction in all of the extremities.

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References


KEY WORDS • cardiopulmonary receptors • sympathetic nerve activity

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