PRESSURE GRADIENT AND BLOOD FLOW IN HUMAN ARM VEINS
—A Proposed Explanation of the Pumping Mechanism—

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In a patient with mitral stenosis we previously found a negative periphero-central pressure gradient (P-C PG) despite a forward peripheral venous blood flow velocity (PVBVF) during supine leg exercise. The present study was undertaken to confirm this finding and elucidate its mechanism. In 6 patients with congestive heart failure, P-C PG was reversed from -2.4 to -18.7 cm H₂O for 1 to 5 minutes during exercise. PVBVF, measured simultaneously with peripheral venous pressure (Pv) in 8 subjects, remained positive; 5 of these were patients with a negative P-C PG. The effect of intravenous lidocaine (1-26 mg) was studied in 13 patients: In 4 of 13 patients the change in Pv by saline injection was smaller than that after lidocaine (2-5 mg) injection (-0.5 ± 0.5, 3.9 ± 0.8 cm H₂O, mean ± SE, respectively) (p < 0.02). In 13 patients Pv rose after a small dose of lidocaine. After a larger dose the rate of rise of Pv decreased or Pv dropped. No significant change was observed in the central venous pressure. In 6 patients who performed Valsalva’s maneuver, the rate of rise of Pv during the test decreased or unchanged after lidocaine injection. The probability of a pumping mechanism in superficial human arm veins was discussed.

It is generally accepted that venous return is regulated chiefly by the pressure gradient. However, Lemp et al have reported a negative periphero-central pressure gradient (P-C PG) between the antecubital and central veins in heart failure patients during leg exercise in the supine position. We have also described a negative P-C PG, ranging from -1.9 to -5.3 cm H₂O during the leg exercise in 7 out of 22 patients with various cardiopulmonary diseases. Furthermore, we observed a forward (centripetal) antecubital venous blood flow velocity with a negative P-C PG during exercise in a patient with mitral stenosis.

A negative P-C PG was observed during supine leg exercise tests in 6 of 10 patients with cardiopulmonary diseases and the negative P-C PG roughly paralleled the severity of heart failure. The purpose of this study is to confirm our previous observations and to study the mechanism which causes a forward venous blood flow in spite of a negative P-C PG.

METHODS

Peripheral venous pressure (Pv) and central venous pressure (Pcv) were measured with a low-pressure transducer (LUP-0.1 Nihon-Koden Co.), with a reference point set at the phlebostatic level. To record Pv, a fluid-filled plastic tube, 1.1 mm in diameter and 6 cm long, was inserted into the antecubital vein and another fluid-filled tube, 1.6 or 1.2 mm in diameter and 53 cm long,

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was inserted into the contralateral antecubital vein and its tip was placed at the upper end of the superior vena cava or the innominate vein. The tips of the PcV and Pv tubes were placed at the same hydrostatic level. During the study, the patients lay supine with their arms at an angle of 60 degrees from the body. The zero drift of the manometer used was $0.9 \pm 0.1$ cm H$_2$O (mean $\pm$ SE, $n = 23$) over 2 hours. The gain drift, checked with a water-manometer, was $6.2 \pm 2.0\%$ ($n = 23$) over 2 hours.

To record the blood flow velocity and Pv simultaneously, a needle type sensor of a self-adjusting current heating thermoelectric flowmeter (Fig. 1a, b) was inserted into the vein through a plastic tube which had a thermal compensation layer, made of a metallic pipe 1.0 mm in diameter and 1 cm long, near its top. This sensor was attached to the plunger of a syringe. As the plunger was withdrawn, the thermocouple came into contact with the thermal compensation layer and a value equivalent zero was recorded. This value and the mechanical zero were checked before each recording. The difference between the two was small. The range of velocity that could be measured was from zero to 10 cm per second. This flowmeter could also detect the direction of flow. The frequency response of this flowmeter was less than 10 Hz. Since the purpose of this study was to find out whether or not a reverse flow exists, this flowmeter was sufficient for our needs. The diameter

Fig. 1. a: Structure of the sensor: The needle type sensor is composed of a heated thermocouple with 3 thermojunctions, A, B and C. Each junction is made of copper-constantan. The central junction B is the hot junction, and a heater is wound around it. The heating current is adjusted to keep a temperature difference between B and C ranging from 0.7 to 1.0°C. Flow velocity is determined from the heating current necessary to keep the prescribed temperature difference between B and C. When liquid flows in the direction of the arrow, junction A will become warmer than C, and thermoelectric current generated between A and C will show the direction of flow.

b: Sensor of the self-adjusting current heating thermoelectric flowmeter and plastic tube with thermal compensation layer.
TABLE I PERIPHERO-CENTRAL PRESSURE GRADIENT AND BLOOD FLOW VELOCITY DURING EXERCISE IN CONTROLS AND IN PATIENTS WITH VARIOUS CARDIOPULMONARY DISEASES

<table>
<thead>
<tr>
<th>No. of Cases</th>
<th>Age/Sex</th>
<th>Diagnosis</th>
<th>Exercise Type</th>
<th>Duration</th>
<th>Pov (cm H2O) At rest</th>
<th>During exercise</th>
<th>Pcv (cm H2O) At rest</th>
<th>During exercise</th>
<th>P–C PG (cm H2O) At rest</th>
<th>During exercise</th>
<th>PVBFV (cm/sec) At rest</th>
<th>During exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28/M</td>
<td>Control</td>
<td>Ergometer</td>
<td>5'</td>
<td>11.0</td>
<td>14.5</td>
<td>10.0</td>
<td>9.5</td>
<td>1.0</td>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>65/M</td>
<td>Control</td>
<td>Ergometer</td>
<td>4'</td>
<td>2.1</td>
<td>4.5</td>
<td>0.4</td>
<td>2.4</td>
<td>1.7</td>
<td>2.1</td>
<td>1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
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<td>Control</td>
<td>Ergometer</td>
<td>4'</td>
<td>5.5</td>
<td>5.2</td>
<td>5.0</td>
<td>2.5</td>
<td>0.5</td>
<td>2.7</td>
<td>&gt;8</td>
<td>3.2</td>
</tr>
<tr>
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<td>31/M</td>
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<td>Ergometer</td>
<td>4'</td>
<td>5.3</td>
<td>8.0</td>
<td>4.6</td>
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<td></td>
</tr>
<tr>
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<td>52/M</td>
<td>Control</td>
<td>Ergometer</td>
<td>4'</td>
<td>7.7</td>
<td>10.2</td>
<td>5.5</td>
<td>6.9</td>
<td>2.2</td>
<td>3.3</td>
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<tr>
<td>6</td>
<td>61/F</td>
<td>MR, Af</td>
<td>Bilateral leg</td>
<td>1'47''</td>
<td>22.2</td>
<td>29.2</td>
<td>23.0</td>
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<tr>
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<td>MR, Af</td>
<td>Ergometer</td>
<td>4'</td>
<td>12.5</td>
<td>16.1</td>
<td>13.5</td>
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<td>−1.0</td>
<td>−18.7</td>
<td>&gt;10</td>
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<tr>
<td>8</td>
<td>66/M</td>
<td>MSR, AR, Af</td>
<td>Ergometer</td>
<td>4'</td>
<td>9.5</td>
<td>16.0</td>
<td>10.0</td>
<td>21.0</td>
<td>−0.5</td>
<td>−5.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>9</td>
<td>30/M</td>
<td>MS, CI</td>
<td>Unilateral leg</td>
<td>2'30''</td>
<td>13.0</td>
<td>17.0</td>
<td>9.0</td>
<td>14.5</td>
<td>4.0</td>
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</tr>
<tr>
<td>10</td>
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<td>MS, ASR, TR, Af</td>
<td>Ergometer</td>
<td>3'10''</td>
<td>15.7</td>
<td>18.9</td>
<td>19.9</td>
<td>27.9</td>
<td>−4.2</td>
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<td>0.2</td>
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<tr>
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<td>MI, Af</td>
<td>Ergometer</td>
<td>1'20''</td>
<td>29.0</td>
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<td>28.5</td>
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<td>9.5</td>
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<tr>
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<td>Ergometer</td>
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<td>7.2</td>
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Abbreviations: MR = Mitral regurgitation; Af = Atrial fibrillation; MSR = Mitral stenosis and regurgitation; AR = Aortic regurgitation; MS = Mitral stenosis; ASR = Aortic stenosis and regurgitation; TR = Tricuspid regurgitation; MI = Myocardial infarction; CI = Cerebral infarction; Pov = Peripheral (antecubital) venous pressure; Pcv = Central venous pressure; P–C PG = Periphero-central pressure gradient; PVBFV = Peripheral venous blood flow velocity.
of the tip of the sensor was from 0.5 to 0.8 mm and that of the stem was from 0.3 to 0.5 mm. The cross sectional area of the plastic tube, when a needle type sensor was inserted, ranged from 0.6 to 0.7 mm². The P₀ before and after the insertion of the sensor was 7.2 ± 0.9 cm H₂O and 6.7 ± 0.8 cm H₂O (n = 21), respectively. The difference between their values was significant (p < 0.001). Similarly, P₀ before and after the withdrawal of the sensor during exercise was 12.7 ± 2.5 and 12.2 ± 2.5 cm H₂O (n = 6), respectively. The difference between the values was significant (p < 0.05). The cause of the pressure drop using these procedures remains obscure, but it was not related to the presence of the sensor in the vein. All recordings were made with a 4-channel polygraph (Nihon-Koden Co.). Brachial arterial pressures were measured with a mercury sphygmomanometer.

**Exercise test:** Bicycle ergometer exercise with a load of 20 to 25 watts per minute was performed for 3 to 5 minutes until the patient complained of dyspnea. In 2 patients with valvular disease, bilateral or unilateral leg extension and flexion exercise was performed 30 times per minute. Thirteen patients had various cardiopulmonary diseases (Table I). Six of the 13 patients had had a recent episode of severe congestive heart failure. Roentgenograms and electrocardiograms showed cardiomegaly and atrial fibrillation at the time of the study. The control group consisted of 5 patients with no history of heart disease and with normal physical examinations, roentgenograms and electrocardiograms.

**Dextran infusion:** In 17 patients without any history of heart failure, low molecular weight dextran (Otsuka) was infused at a rate of 500 ml

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![Image of graphs and diagrams]

Fig.2 Effect of exercise on peripheral and central venous pressure, periphero-central pressure gradient and peripheral venous blood flow velocity.

a: The antecubital and central venous pressure were recorded alternately using a 3-way stopcock in a 66-year-old man with mitral stenosis and regurgitation and aortic regurgitation. The mean pressure was recorded except for the underlined 2 intervals on the left side of the figure. Before exercise, the periphero-central pressure gradient was −0.5 cm H₂O. At the end of exercise, it reached −5 cm H₂O. The antecubital venous blood flow velocity remained unchanged during the course of the test.

P = Antecubital venous pressure, C = Central venous pressure, EO = Equivalent zero

b: The antecubital and central venous pressure were recorded alternately using a 3-way stopcock in a 64-year-old man with mitral regurgitation. Only the mean pressure was recorded during this test. Before exercise, the periphero-central pressure gradient was −1.0 cm H₂O. During exercise, it reached −18.7 cm H₂O. At that time, antecubital venous blood flow velocity decreased but did not reach zero level. The tracing of polarity showed a forward blood flow. A calibration recording made soon after the test is shown on the left side of the figure.

MO = Mechanical zero

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per 30 minutes until marked hypertension, arrhythmia or a moderate reverse P-C PG occurred.

Valsalva's manuver: was performed in 14 patients. In 6 of them, after the test, was repeated lidocaine injection.

Phlebography: Roentgenograms were obtained after the injection of a contrast medium into the antecubital vein and the number of valves from the site of the Pw measurement to the central vein were counted in 6 non-cardiac patients.

Pharmacological test: Lidocaine, 1 to 26 mg/ml, was injected slowly over 1 minute to in 13 patients. Six control patients received intravenous injections of 1 ml saline.

Lidocaine was intravenously administered in the bilateral antecubital veins in 4 patients: 1 with cerebral atrophy and unilateral edema of arm and leg, 1 with cervical injury and peripheral edema of a hand and 2 with cerebral infarction.

Statistical method: Data were analyzed by the paired or unpaired t tests. When the analysis of variance between 2 groups was significant, the difference of the means was evaluated using Welch's formula. All values were expressed as mean ± SE.

RESULTS

1. Effect of exercise on periphero-central pressure gradient and peripheral venous blood flow velocity. As shown in Table I, a P-C PG during exercise was positive in the 5 controls and 8 of the 13 patients (group A). It was negative in 4 with valvular disease and 1 with myocardial infarction (group B). Pw, the change of Pw (ΔPw), Pcv and the change of Pcv (ΔPcv) were:

8.1 ± 1.2, 3.0 ± 0.5, 5.6 ± 0.8 and 2.4 ± 1.0 cm H2O in group A, and 17.8 ± 3.5, 5.4 ± 0.8, 19.0 ± 3.3 and 12.2 ± 2.3 cm H2O in group B, respectively. The difference of the mean Pw between group A and group B was not significant. However, the ΔPw, Pcv and ΔPcv in group B were significantly higher than those in group A (p < 0.05, 0.02, 0.001, respectively). Of the 8 subjects in whom peripheral venous blood flow velocity (PVBVFV) was recorded, 5 showed a negative P-C PG. However, in these 8 subjects PVBVFV was positive during exercise as well as at rest (Table I, Fig. 2a, b).

One month later, a patient with mitral regurgitation was tested during single leg exercise. The femoral venous pressure in the opposite leg, the central venous pressure, antecubital venous pressure and PVBVFV were recorded. Before exercise, Pcv was lower than antecubital venous pressure. During exercise, Pcv rose with femoral venous pressure and reached a higher level than the antecubital venous pressure. No significant change was observed in PVBVFV during this test.

2. Effect of dextran infusion on Pw, Pcv and periphero-central pressure gradient. The changes in Pcv after dextran infusion varied more than that in Pw (Fig. 3). Before the dextran infusion, a negative P-C PG was observed in 6 of the 17 patients, ranging from -0.4 to -4.0 cm H2O. During the infusion, the negative P-C PG con-
Fig. 4. Pressure record of a dextran infusion test of a 67-year-old man with systemic hypertension and pancreatic cysts. Following infusion, the central venous pressure became much higher than the antecubital venous pressure, so the infusion was stopped when the dextran volume was 220 ml. Eight minutes later, the tracing drifted upwards markedly when we changed from recording antecubital venous pressure to recording central venous pressure using a stopcock. The negative periphero-central pressure gradient reached −12 cm H₂O and central venous pressure was definitely higher than the peripheral venous pressure throughout cardiac cycle.

m = Mean pressure

Fig. 5. Effect of Valsalva’s maneuver on peripheral venous pressure and peripheral venous blood flow velocity in a 75-year-old man with gastric cancer. During Valsalva’s maneuver, the antecubital venous pressure rose from 8.5 to 15.7 cm H₂O and the central venous pressure rose from 8.8 to 18.8 cm H₂O. In the middle of the rise in antecubital venous pressure, a small fluctuation occurred which coincided with the peak of the central venous pressure. At the end of the rise in antecubital venous pressure, venous blood flow stopped temporarily. The tracing of the polarity indicated that the recovery of the blood flow was due to forward blood flow.

continued for 10 to 42 minutes and, at the end of the test, it was −1.0 to −12.0 cm H₂O in 5 patients. These patients did not have cyanosis or edema of the extremities during the tests. These 5 patients were over 59 years of age, as were 10 of the 17 tested. No significant correlation was found between age and P-C PG before and after the infusion, and no correlation was observed between the changes in pulse pressure or the mean pressure of the brachial artery and the change in P-C PG induced by the infusion. In 2 patients who showed a markedly negative P-C PG
Fig. 6. Effect of various doses of lidocaine on peripheral (antecubital) and central venous pressure in 13 patients with various diseases. 
\[ \Delta P = \text{change of venous pressure} \]

Fig. 7. Typical records of peripheral venous pressure after lidocaine injection.

(a) A 40-year-old man with unilateral hydronephrosis: After two injections of 2 mg of lidocaine, the pulsations in antecubital venous pressure decreased. After two injections of 10 mg of lidocaine, the antecubital venous pressure increased gradually; it rose rather slowly during Valsalva's maneuver then decreased suddenly. Six minutes later, it dropped slightly, then the slight pulsations returned and it rose abruptly during Valsalva's maneuver.

(b) A 59-year-old woman with utero-cervical cancer: After an injection of 26 mg of lidocaine the pulsations in the antecubital venous pressure decreased. Next, the pressure dropped. During Valsalva's maneuver, the central venous pressure rose, but the antecubital venous pressure remained unchanged.

after infusion, Pcv was definitely higher than Pv throughout the cardiac cycle (Fig. 4). A similar tendency was observed in the remaining 3 patients.

3. Effect of Valsalva’s maneuver on Pv and peripheral venous blood flow velocity. By this test, Pcv rose immediately and reached its peak within 1.9 ± 0.6 sec., while Pv rose in 3 to 36 sec. (mean 13.8 ± 3.8 sec. n = 8). The difference between the time required for Pv and Pcv to reach its peak was highly significant (p < 0.01). In 5 of the 8 patients, when Pv reached its plateau with a small pulsation, the level of Pcv was higher than that of Pv. The difference between the pressure levels ranging from 0.4 to 6.5 cm H₂O (average of 2.9 cm H₂O) but was not statistically significant (p < 0.1). In 2 of the 5 patients, PVBFV was recorded simultaneously with pressures. During Valsalva’s maneuver, it became zero or almost zero temporarily in each patient (Fig. 5).

4. Phlebography: In 6 patients, phlebography revealed 1 to 4 valves (average 3) in the venous segment between the measuring point of Pv and the central vein.

5. Pharmacological test: In 12 of the 13 patients, following lidocaine injection, pulsations of Pv decreased or disappeared. Four of these 13 patients were also injected with saline. ΔPv after lidocaine injection (2 to 5 mg) was 3.9 ± 0.9 cm H₂O and after saline injection —0.5 ± 0.5 cm H₂O, and the difference was significant (p < 0.03). In 6 patients, including the 4 who were also injected with lidocaine, ΔPv and ΔPcv after saline injection were —0.5 ± 0.4 cm H₂O (n = 6) and —0.1 ± 0.5 cm H₂O (n = 3), respectively, but the differences were not significant.

In 13 patients after a small dose lidocaine injection, Pv rose, but with a larger dose of the drug, the rate of the rise of Pv tended to decrease and Pv dropped. The maximal and minimal values of ΔPv in each patient and the corresponding values of ΔPcv ranged from 9.0 to —10.0 cm H₂O and from 1.0 to —4.0 cm H₂O, respectively (Fig. 6). The difference between the variance of ΔPv and of ΔPcv was highly significant (p < 0.01), but the difference between the mean (1.4 ± 1.6, 0.7 ± 0.3 cm H₂O n = 13) was not significant. ΔPv after lidocaine injection of either dose began to decrease within several minutes, and later pulsations returned to normal.

After lidocaine injection, Valsalva’s maneuver was performed in 6 patients. In 4 patients, the rate of rise of Pv during Valsalva’s maneuver de-

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Fig. 8. a: Effect of bilateral lidocaine injection on saphenous venous pressure in a 53-year-old woman with unilateral edema of extremities associated with cerebral atrophy.
iv = Intravenous injection
b: Effect of bilateral lidocaine injection on peripheral venous pressure in 4 patients with diseases of the central nervous system.
* = Saphenous veins were used.

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Fig. 9. Effect of lidocaine injection on peripheral (antecubital) venous pressure and peripheral venous blood flow velocity. A 52-year-old man with mitral stenosis and aortic stenosis and regurgitation. After an injection of 3 mg of lidocaine, the antecubital venous pressure rose from 17.5 to 20.0 cm H₂O and the flow velocity decreased rapidly and became almost zero. The central venous pressure was 20 cm H₂O and remained unchanged during the course of the test.

creased more after the lidocaine injection compared than in the controls (Fig. 7a). In the remaining 2 patients, the rise of Pᵥ was nearly zero during Valsalva's maneuver (Fig. 7b).

Following bilateral lidocaine injection, in a patient with unilateral peripheral edema of his extremities associated with cerebral atrophy, Pᵥ dropped in the affected leg and rose in the opposite leg (Fig. 8a). In another patient with unilateral hand edema, possibly due to cervical injury due to head trauma, Pᵥ in the affected arm temporarily fell to zero after the injection of lidocaine, and then returned to its previous level 10 minutes later. In this case also Pᵥ rose on the opposite side after the increased dose of lidocaine. A similar tendency in ΔPᵥ was observed in 2 patients with cerebral infarction (Fig. 8b). Following the lidocaine injection, no significant change of Pᵥ was observed in the opposite arm or leg in these 4 patients. The difference between the variance of ΔPᵥ in the injected and contralateral veins was significant (p < 0.025). However, the difference of these means was not significant. During these tests, no significant change was observed in pulse rates, systemic blood pressures or electrocardiograms.

PᵥBFV was recorded in 4 patients, and in 3 without apparent heart disease no significant change was observed following the lidocaine injection. However, after the injection of 3 mg of lidocaine in a patient with valvular disease and a negative P-C PG, PᵥBFV became almost zero (Fig. 9).

DISCUSSION

The graphic analysis of venous return was advanced by Guyton6,7,8 who introduced the venous return curve. The concept of "pressure gradient for venous return" is now generally accepted. However, if blood flows from the arm into the thorax due to the pressure gradient, a reverse flow should occur, or at least the forward blood flow should stop, in patients with a negative P-C PG. However, in fact, the forward flow in the peripheral vein does not stop in these patients.

Brecher9 studied the mechanism of the respiratory pump and divided the period of inspiration into a depleting stage and a collapsing stage. He showed that during the depleting stage the outflow from the extrathoracic veins increased in direct proportion to the pressure gradient, while in the collapsing stage the outflow remained constant despite the greater pressure gradient.
In any case, the respiratory pump depends on a positive P-C PG. However, in our cases Pcv was positive and higher than Pv even during inspiration (Fig. 4). Therefore, the respiratory pumping mechanism does not help to explain our observations.

Henderson has demonstrated the activation of the venopressor mechanism for venous return by observing an increased electrical discharge on the electromyogram after placing a weight in the hand of a resting arm. This activated the capillary and venule pumps in the arm muscles. Since a negative P-C PG was observed between the central vein and medium-sized superficial veins, the venopressor mechanism, though applicable to intramuscular capillaries and venules, does not help to explain our results.

In order to investigate the effects of cardiac contraction on venous return, Gabe et al. studied the relationship between the cardiac cycle and velocity changes in the superior and inferior vena cavae using an electromagnetic catheter-tip velocity probe. Kalmanson et al. and Matsuo et al. has measured the jugular venous blood flow velocity transcutaneously using a directional ultrasonic Doppler flowmeter. They demonstrated a diphasic forward blood flow with the corresponding downward movement of the atrioventricular junction caused by ventricular contraction and the rapid inflow to the right heart. However, as we have previously reported PVBFV in a patient with neurocirculatory asthenia showed monophasic waves corresponding to the digital pulse waves of the photoelectric plethysmograph.

The venous pump is now generally used as a synonym for the muscular pump. Any factor which causes successive compression of the veins will produce a forward blood flow in them. Guyton has noted that arterial pulsation may be one of the causes of venous pumping when the brachial artery is close to the veins. However, no correlation was observed between the increase of the negative P-C PG and the pulse pressure of the brachial artery during dextran infusion (Fig. 4).

We observed that, in patients with congestive heart failure who had a negative P-C PG during exercise, Pcv was definitely higher than in patients without heart failure. The following combination of factors was considered to be the cause of the rise of Pcv during exercise: (1) the shift of blood from the legs and from the splanchnic venous bed to the central vein on exercise, (2) the pooling of blood in the central vein due to impairment of ventricular function and (3) increased tone not only the peripheral veins but also in the central vein. We have previously reported a marked decrease of a negative P-C PG during exercise in a patient with valvular disease after the intravenous injection of tetraethylammonium bromide. Pcv rose markedly and P-C PG reversed only in elderly patients during dextran infusion. In these patients, there could have been a disturbance of the cerebral circulation which caused an increased sympathetic outflow from the vasomotor centers. Shepherd and Vanhoutte have suggested the role of increased venous tone in the rise of Pcv in patients with congestive failure. Bartelstone has described a marked rise of Pcv after carotid occlusion in dogs.

It might be thought that the forward blood flow during exercise depends on the pooling of blood in the arm veins. If blood stagnates in the arm veins, Pv should rise to the level of Pcv, as shown in Valsalva’s maneuver, or at least ΔPv would be higher in group B than ΔPv in group A, although the blood volume in the arm veins might be less than in group A. In fact, no significant difference was observed in mean ΔPv between groups A and B. PVBFV remained positive during exercise even in patients with a negative P-C PG. Forward blood flow could result from a positive P-C PG during systole. Furthermore, the muscular pump in the arm may have been activated during exercise even though the arm was kept immobile. However, as shown in Figs. 3 and 4, a marked negative P-C PG throughout the cardiac cycle was observed at rest following infusion and continued for 10 to 42 minutes without any signs of stagnation of blood in the extremities. These results suggest that blood stagnation in the arm veins is unlikely and there may be a pumping mechanism in the human arm veins to cause forward blood flow in spite of a negative P-C PG.

Nicoll and Webb have described the vasmotion of veins in bat wings which sweeps centripetally as a peristaltic wave and assists venous return. Wiedeman reported that in bat wings the increase in frequency of venous vasmotion was caused by an increased blood volume propelled from the arteries. D’Agrosa observed that rhythmic contractions occur in the venous segments between valves in bat wings, and the contractions started in the distal segment and proceeded to the proximal segment.

If the human arm veins have their own pumping mechanism as discovered in bat wings, then vascular tone plays and important role in that function. We tried intravenous lidocaine injection in the expectation of a direct action upon local venous smooth muscles. The difference between the mean values of $\Delta P_v$ after lidocaine and that after saline injection indicates that $\Delta P_v$ after lidocaine injection is directly dependent upon the effect of lidocaine on the local veins. It has been reported that local anesthetics tend to cause biphasic reactions in vascular smooth muscles. If the rise of $P_v$ is caused by vasoconstriction, as has been shown in “in vitro” experiments, pulsation of $P_v$ after lidocaine injection should be augmented, and during Valsalva’s maneuver the rate of rise of $P_v$, which is determined by the blood flow and vascular tone in the local veins, should be increased. However, in fact, the pulsation decreased as did the rate of rise of $P_v$ during Valsalva’s maneuver. (Fig. 7a) Therefore, the $\Delta P_v$ after lidocaine injection may be a result of the stagnation of blood in the local veins caused by the spasmylocytic action of the local anesthetic and can be explained as follows: Phlebography has shown that the arm veins are separated into venous segments by valves. The pumping action of the venous segments may be caused by the pulsatile blood flow transmitted from arteries. The decrease of venous tone caused by lidocaine could result in a decrease of the ejection fraction in the venous segments and a rise of $P_v$ due to a stagnation of blood in the local veins. Either the decrease in $P_v$ or its rate of rise observed after larger doses of the drug could be the result of variations in the relaxation of the venous smooth muscles. The different effects of the same doses of lidocaine on $P_v$, observed after bilateral lidocaine injection in patients with an impaired central nervous system may be explained by the difference in the “basal tone” of the local venous smooth muscles.

The activation of this pumping mechanism in the local circulation in arm veins varies in different physiological or pathological conditions, as is shown by the different effects of lidocaine on PVBVF in patients with or without heart disease. Using electrical stimulation, Vanhoutte and Leusen have shown different degrees of distention of isolated segments of the dog saphenous vein. Shepherd and Venhoutte have demonstrated a progressive and stepwise elevation of pressure during contraction and relaxation by increasing the extension of a strip of dog mesenteric vein. In human arm veins, the proximal segment is considered to be more distensible than the distal segment when the blood volume is increased because there is less branching. Venoconstriction in response to adrenergic stimulation occurs with progressively stronger contractions in the proximal segments as compared with the distal ones because of the reduced volume of blood. Systolic and diastolic pressures in the proximal venous segments may increase stepwise and become higher than in the distal segments when the pulsatile flow travels from the small veins to the central vein and causes serial contractions of the venous segments. If this mechanism operates, blood would flow from the arm veins into the thorax even in spite of a negative P-C PG.

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