Effects of Upright Posture and Exercise on Pulmonary Hemodynamics in Patients with Central Cardiovascular Shunts

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With the assistance of Curt A. Wiederhielm, Charlotte Hamilton, Claire Morgan, R.N., and Elizabeth Kendall, R.N.

Previous hemodynamic studies of patients with septal defects, or patent ductus arteriosus, have been made with the patient recumbent in the horizontal posture. Our studies indicate unexpected changes in pulmonary blood flow with the upright posture, and often further increments in flow during walking that are different from those reported for exercise in recumbency. It is suggested that such defects reveal the complexity of factors regulating preferential flow under these circumstances.

In the course of selecting patients with atrial or ventricular septal defects for surgery, it became apparent that little is known regarding the effects of the upright posture and exercise on the pulmonary hyperemia that is often associated with these lesions. Usually there is recirculation of oxygenated blood through the lungs because of the left-to-right shunt through an uncomplicated septal defect. Whereas in the absence of shunting, cardiac output may decrease on standing and increase with effort, the corresponding effects in the presence of a shunt have not been well described. This report summarizes our preliminary observations of these effects in carefully selected good risk patients.

Material and Methods

Fifteen patients have been studied; they ranged in age from 7 to 49 years (table 1). Six had atrial septal defects, 4 had ventricular septal defects, 3 had patent ductus arteriosus, and 1 of these was also in the fourth month of pregnancy. Two others, who had no shunts, served as controls. Each was tested for exercise tolerance by walking on a motor-driven treadmill on a 10 per cent grade at 1.7 m.p.h. for 10 minutes, and all were able to do this without evidence of ventricular irritability. Following completion of a diagnostic catheterization of the heart, while sedated with meperidine hydrochloride, each was given 25 mg. of ephedrine sulfate intramuscularly to combat faintness and nausea due to orthostatic hypotension that frequently develops when patients so sedated and catheterized assume the upright posture. None had any untoward effects from this supportive therapy, and the subsequent exercise performance was usually comparable to the initial test. All were carefully supervised, and the precordial electrocardiogram was monitored continuously. Only 2 patients exhibited ventricular premature beats in the upright posture with the tip of the catheter in the right branch of the pulmonary artery. It was not practical to study the effects of both posture and exercise in all patients, but 10 patients were studied with respect to either sitting upright or walking.

Oxygen consumption ($V_o_2$), corrected to STPD, was derived from gasometer measurements of ventilation (BTPS) over a period of 3 to 9 minutes, and from Scholander analyses of expired air while the patient was in a “steady state” and breathing room air through a mouth piece (table 2). Blood samples were analyzed for oxygen content ($C$) by the Van Slyke-Neill technic.

Blood flows ($Q$) were derived according to the Fick principle:

Total pulmonary blood flow = $Q_{TP} = \frac{V_o}{C_P - C_A}$

Effective pulmonary blood flow = $Q_{EP} = \frac{V_o}{C_P - C_V}$

Systemic blood flow = $Q_S = \frac{V_o}{C_S - C_V}$

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Dr. John was a Trainee of the National Heart Institute, 1955-1956.
Where $C_{Fr}$ was assumed to be 99 per cent of oxygen capacity, and $C_{Fe}$ represented the average of oxygen contents of blood samples withdrawn from the superior and upper part of the inferior vena cava. Shunt flows were derived as follows:

$$Q_{LR} = Q_{TP} - Q_{EP}$$
$$Q_{RL} = Q_S - Q_{EP}$$

When the patients were supine, 10 cm. above the table top was arbitrarily selected as the zero reference level for intrathoracic pressures, which were measured with a Statham gage (P23D). When the patients were in the upright position the gage was placed near the level of the pulmonic valve as determined by fluoroscopy, with the tip of the catheter just distal to the valve. Since changes in intrathoracic pressure secondary to posture were not measured, the mean pulmonary arterial pressure during walking was determined from the sum of the mean pressure while supine plus the difference observed in changing from sitting to walking with the new zero reference level for the gage. The pulmonary arterial pressures recorded over 2 respiratory cycles were utilized to derive the mean pressure by planimetric integration.

Arterial oxygen saturation was continuously recorded from an ear oximeter by means of Wiederhielm’s amplifier and a 10-inch strip recorder.

**RESULTS**

**Changes in Pulmonary Blood Flow with Sitting**

All 8 patients with central shunts showed some increase in pulmonary blood flow on
changing from supine to sitting posture (fig. 1). In 2 of these patients who also had pulmonary hypertension, the changes were negligible, whereas 2 other patients with patent ductus arteriosus complicated by other factors exhibited marked increases in total pulmonary blood flow. One of these latter patients was a young woman in the fourth month of gestation, while the other was a man who had a ventricular septal defect in addition to a ductus that was subsequently divided and ligated surgically.

Intermediate increases in pulmonary blood flow were observed in 4 patients with uncomplicated atrial septal defects. This change, which averaged 21 per cent, was directly proportional to the increase in oxygen consumption and ventilation. There was no significant change in pulmonary arterial oxygen content.

Two other patients without shunts showed slight decreases in pulmonary blood flow on sitting. These changes were comparable to those reported by Donald et al.\[^1\] for 16 patients and 2 normal subjects without shunts.

### Effects of Walking on Pulmonary Hemodynamics

The changes in total pulmonary arterial flow and mean pressure for 10 patients with central shunts during grade walking are shown in figure 2. The flow was observed to increase in all cases, whereas the pressure showed

### Table 1—Continued

<table>
<thead>
<tr>
<th>Patient, age, sex, and surf. area</th>
<th>Diag. compl. ECG</th>
<th>Clin. class # FFI</th>
<th>Blood flows while supine L/min.</th>
<th>Or Sat. % HgGm. %</th>
<th>0.5 sec. EV vital cap.</th>
<th>Dil. curve A D/A</th>
<th>Or cons. ml./M.I./min.</th>
</tr>
</thead>
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<tr>
<td>JW 49M 1.83 21F 1.63 AK 37F 1.5</td>
<td>PDA Bronchitis 1<em>KAV LBBB Preg. (4 months) PDA PH 1</em>KAV</td>
<td>IIB 18.0 IIIC 14.2</td>
<td>8.9 7.9 2.8 13.7 2.8 14.2</td>
<td>92.5 91.0 10.8 15.3 85.4 15.3</td>
<td>1.5 1.0 3.5 1.9 1.1 1.9</td>
<td>68 46 106 67 58 67</td>
<td>1.8 1.0 3.0 1.9 1.2 1.3</td>
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<tr>
<td>IH 32F 1.54 BW 7M 0.93</td>
<td>AI MIS AF HD</td>
<td>IIIC 12.0 IA 14.0</td>
<td>3.9 2.4 2.4 2.4</td>
<td>95.3 86.6 12.8 13.1</td>
<td>1.8 0.6 3.0 1.3</td>
<td>60 46 100 1.3</td>
<td>134 169</td>
</tr>
</tbody>
</table>

\# = Functional capacity (N. Y. Heart Assoc.)

PFI = Physical fitness index of tolerance of standardized exercise tests

TP = Total pulmonary blood flow

EP = Effective pulmonary blood flow

S = Systemic blood flow

LR = Left to right shunt

RL = Right to left shunt

EV = 0.5 sec. expiratory volume, (\% = per cent of observed VC)

VC = Vital capacity, (\% = per cent of predicted for age, sex, and height)

A = Appearance time, sec. ("Normals" = 10.6 ± 2.7 Sec.)

D/A = Disappearance time constant

(where D equals time for fall in concentration to one-half, and normal D/A = 0.5 ± 0.1 sec.)
<table>
<thead>
<tr>
<th>Patient</th>
<th>O₂ consumption (ml/min)-STP</th>
<th>Ventilation (L/min)-BTPS</th>
<th>O₂ ret. rate vol. %</th>
<th>Art. O₂ sat. %</th>
<th>PV-PA O₂ diff. mL/L</th>
<th>O₂ L/min</th>
<th>Heart rate</th>
<th>Pulmonary arterial pressure (mm Hg)</th>
<th>Total pulm. resistance dynes-se.-cm⁻²</th>
<th>Syst. pres.</th>
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<td>35</td>
<td>59</td>
<td>102</td>
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<td>31</td>
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<td>10</td>
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<td>4.25</td>
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<td>85</td>
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<td>90.2</td>
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<td>±15</td>
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<td>±43</td>
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<td>±S.E.</td>
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<td>±5 / ±3</td>
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<tr>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;0.000</td>
<td>&lt;0.000</td>
<td>&lt;0.000</td>
<td>&lt;0.000</td>
<td>&lt;0.000</td>
<td>&lt;.000</td>
<td>&lt;.03 / &lt;.18</td>
</tr>
</tbody>
</table>

* R = Recumbent, S = Sitting, W = Walking.
† Omitting PS who was not studied during walking.
‡ T wave in precordial ECG inverted.
considerable increases in all but 4 of these patients.

Five patients with atrial septal defects provided a fairly homogeneous group for further analysis of the changes with walking. Significant increases \((p < .003)\) were observed during this exercise for ventilation, oxygen consumption, oxygen removal rate, and heart rate. The increases in pulmonary vein-pulmonary artery oxygen difference, and total pulmonary blood flow were less certain due to greater variation \((p < .006)\). Increments in pulmonary stroke volume and systolic pressure of the systemic circuit were not significant. Neither was the slight rise in the average of mean pulmonary arterial pressures from 21 to 32 mm. Hg nor the calculated decrease in total pulmonary arterial resistance from an average of 245 to 176 dynes-sec.-cm.\(^{-5}\) significant. Thus it is apparent that under the circumstances of these observations, patients with atrial septal defects exhibit primarily an increase in pulmonary arterial flow rather than pressure during exercise in the upright posture. This is opposite to the responses reported by Swan\(^6\) for exercise studies performed in the supine posture. Further studies will be needed to delineate the factors favoring preferential flow across a septal defect rather than through the mitral valve to account for these differences in responses to exercise in the supine position.

**Changes in Arterial Oxygen Saturation with Walking**

The changes in arterial oxygen saturation that occurred during walking in 10 patients with central shunts are shown in relation to changes in pulmonary blood flow in figure 3. One patient with an atrial septal defect was desaturated at rest, and markedly so with effort. Since the saturation was normal and ventilation higher when he had the initial exercise test prior to catheterization, this difference was attributed to hypoventilation secondary to depression of the respiratory center by sedation with meperidine hydro-
chloride. As a possible contributory factor, he also had clinical evidence of moderate emphysema secondary to chronic bronchitis. Three other patients exhibited a fall in arterial oxygen saturation with walking. All had ventricular septal defects. The most marked desaturation occurred in the patient with marked pulmonary hypertension, whereas the least change occurred in the patient with a small patent ductus arteriosus in addition to the ventricular septal defect. Furthermore, another patient with a large patent ductus also showed a slight fall in oxygen saturation from 92.5 to 91.0 per cent.

**Discussion**

From these preliminary observations, it is apparent that pulmonary hemodynamic responses in patients with circulatory shunts differ in respect to changes with upright posture and exercise from either normal subjects or cardiac patients without shunts. In contrast to the patient without a shunt, these cases show some increase in total pulmonary blood flow in the upright position. Pressure gradients across septal defects or patent ducti apparently change enough to permit greater recirculation of blood through the lungs. In patients with atrial defects this may be related to a gravitational fall in pressure in the right atrium, which is in communication with the inferior vena cava. In patients with a patent ductus, the aortic pressure may increase proportionately more than the pulmonary pressure to adjust for postural changes. Thus the redistribution of blood depends upon the complicated balances between pulmonary and systemic resistances to arterial flow and factors affecting venous return.

Inasmuch as the intrathoracic pressure was not measured, it is not possible to determine from these data whether there were any changes in true intravascular pressure in relation to changes in posture. If one assumes that the pulmonary vascular resistance was unchanged, i.e., no change in lumen size or distensibility, then there should be a change in pressure proportional to the change in blood flow. Since wedged pulmonary arterial pressures were not obtained this cannot be evaluated further.

Blood flow was calculated from the arteriovenous oxygen difference estimated from analysis of blood withdrawn from the pulmonary artery, and the assumption that oxygen saturation of pulmonary venous blood was never less than 99 per cent. If there was a diffusion defect, all the flows necessarily would be higher than reported. Furthermore, it is presumed that there is sufficient turbulence in the pulmonary artery to achieve at the point of sampling perfect mixing between systemic venous blood and shunted oxygenated blood. This may not be a valid assumption in some patients with patent ductus arteriosus.

Hemodynamic changes during both upright posture and exercise in patients with shunts indicate the magnitude of the pressure and flow work loads imposed on the heart under these circumstances. Numerous complex factors are responsible for these effects. These include the size and location of the defect, distensibility and contractile force of the heart chambers during the cardiac cycle, and resistance to flow imposed by obstructing lesions or pulmonary vascular disease. Circulatory effects of respiration and possibly changes in the volume of blood in the lungs constitute additional variables.

From these preliminary observations, a definite decrease in arterial oxygen saturation with exercise in the upright posture is more likely to be associated with a ventricular septal defect if hypoventilation or pulmonary disease can be excluded. A slight decrease can be observed with a large patent ductus arteriosus. None of the patients with uncomplicated atrial septal defects exhibited this response in the absence of inadequate alveolar ventilation. Possibly this difference may be of diagnostic value in predicting the type of shunt before definitive studies are obtained by cardiac catheterization.

**Summary**

Contrary to changes reported for patients without shunts, 4 patients with an uncomplicated atrial septal defect showed an average increase of 21 per cent in total pulmonary
blood flow when posture was changed from supine to sitting. The flow hardly changed in 2 patients with shunts complicated by pulmonary hypertension, whereas the flow markedly increased with this postural change in 2 other patients with either double shunts or a shunt plus pregnancy.

Total pulmonary blood flow increased in variable amounts in all patients with shunts who were studied during exercise of grade walking on a treadmill. There was a significant increase in flow in patients with uncomplicated atrial septal defects.

Pulmonary arterial pressure increased by variable amounts in all 10 patients during this exercise. The increment was not significant in 5 patients with uncomplicated atrial septal defects, but probably it was significant in patients with pulmonary hypertension at rest.

Patients with uncomplicated atrial septal defects usually maintained peripheral arterial oxygen saturation during exercise in the upright posture. One exception was a patient with mild degree of emphysema who hyperventilated, probably due to depression of the respiratory center during the study. A negligible decrease occurred in a patient with a large patent ductus arteriosus. All patients with ventricular septal defects exhibited desaturation that varied in degree with the presence of other shunts or pulmonary hypertension.

The presence of a central shunt modifies the usual circulatory adaptations to changes in posture. This difference is altered by pulmonary hypertension. Patients with uncomplicated atrial septal defects exhibit a significant increase in pulmonary flow, but not in pressure, with exercise in the upright posture. Arterial desaturation with exercise is more likely to be observed with ventricular than atrial septal defects.

**SUMMARIO IN INTERLINGUA**

Le presentia de un derivation central modifica le usual formas del adaptation circulatorii a alterationes del postura. Iste differentias es altere per hypertension pulmonar. Patientes con non complicate defectos atrio-septal exhibi un augmento significative del fluxo pulmonar sed non del pression quando

**REFERENCES**


Human tissues obtained at necropsy from patients with rheumatoid arthritis, disseminated lupus erythematosus, dermatomyositis, glomerulonephritis, periarteritis nodosa, and tissues obtained at operation from patients with appendicitis and placentas obtained at delivery as well as biopsied rheumatic nodules and muscle from patients with dermatomyositis, were studied to detect the presence of fibrinoid. Thin sections of the tissue were stained with rabbit antihuman fibrin antisera labeled with fluorescein. Other sections of these tissues were stained with conventional stains to detect fibrinogen and fibrin in the tissue. The fluorescent antibody method for staining to detect fibrin was much more sensitive than conventional stains. Fibrin deposited as fibrinoid was not restricted to collagen diseases, but was found in other inflammatory conditions as well. Further, the interaction of fibrin with dyes was dependent upon the medium in which the conversion of fibrinogen to fibrin occurred. This reaction is enhanced by albumin. It is considered that interstitial albumin is increased locally by the inflammatory processes, and this may be one of the parameters for the production of the dye-positive form of fibrin.

Harvey
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