Correlation of Clinical and Hemodynamic Findings in Patients with Systemic Arteriovenous Fistulas

By Joseph J. Muenster, M.D., John S. Graettinger, M.D., and James A. Campbell, M.D.

Although studies of the pathologic physiology of arteriovenous fistula have been reported, the circulatory responses to exercise and the nature of the syndrome resembling congestive heart failure have not been elucidated.

The alterations in the circulation caused by a systemic arteriovenous fistula have been studied extensively and the occasional occurrence of a syndrome resembling congestive heart failure in the presence of a chronic fistula has long been recognized. In recent years cardiac catheterization has permitted more thorough study of such patients but concomitantly, since the potential hazard of the lesion has been better appreciated, early surgical correction of the defect has usually been carried out. Cardiac failure resulting from peripheral arteriovenous fistula therefore is now a rare entity and to our knowledge hemodynamic studies have been performed in only cases presenting congestive heart failure.

In the present paper studies before and after operation in patients with arteriovenous fistulas are reported. Two patients were in a state of congestive heart failure without apparent cause other than the fistula. The physiologic data observed in the patients with congestive heart failure not only clearly separated them from the others but also qualitatively resembled in many respects data obtained in patients with congestive failure resulting from primary myocardial disease.

Material and Methods

The fistulas in 4 patients had been present from 10 to 23 years; 2 were of recent onset (S.A., J.E.). In 5 cases the shunt was located in either the iliac or femoral vessels and in the sixth the brachial vessels were involved (J.E.). In 1 (J.P.) the shunt was congenital; the remainder were traumatic in origin resulting from either gunshot or stab wounds. Following physiologic studies surgical repair of the fistula was performed for the 5 acquired lesions. The diameters of the fistulas as estimated or measured by the surgeons at the time of surgery fell within a range of 1.0 to 1.5 cm. The proximal artery was dilated and tortuous in each of the patients in whom surgery was performed with the exception of patient S.A., whose shunt had been functional less than 2 weeks. In no case was there evidence of constriction by scar or surrounding fibrous tissue. Arteriography demonstrated similar tortuosity and dilatation and presumably a shunt of comparable size in the case of J.P. who had congenital lesions for which surgery was not performed.

The 2 patients (S.A., J.E.) whose fistulas were of relatively short duration are referred to as “short-term non-failure” patients and the other 2 without congestive failure whose fistulas had been functional for 18 and 19 years as the “long-term non-failure” patients (E.W., J.P.). The clinical histories of these 4 patients contained no symptoms suggestive of congestive failure. The 2 long-duration patients were laborers who were working without limitation until the time of their hospital admissions for study and elective surgery. The physical examination in each case revealed swelling and a bruit at the site of the fistula with venous engorgement in the affected areas.

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Supported in part by a grant from the U. S. Public Health Service (H-404) and in part by a grant from the Otho S. A. Sprague Memorial Institute.

Done during Dr. Muenster’s tenure of a James B. Herrick Fellowship in Cardiology.

1079 Circulation, Volume XX, December 1959
extremities, but no edema. Examinations of the heart and teleoentgenograms in 3 patients were entirely normal; 1 of the long-term patients (E.W.) had moderate enlargement of the heart and a grade III systolic apical murmur. Following surgery the murmur disappeared and the heart size returned to normal. Hemoglobin values were within normal limits in all patients. Blood volumes were normal in the 2 "short-term" and elevated in the 2 "long-term non-failure" patients.

The histories and findings of the 2 cases which we refer to as the "failure patients" differed markedly from the group above.

The first patient (C.J.) was a 41-year-old Negro woman who had been shot in the left upper thigh 19 years prior to admission. Slight swelling of the entire extremity had persisted throughout the years. Eighteen months prior to admission at our initial examination she had no complaints or signs of cardiovascular disease except for the arteriovenous fistula. Her blood pressure was 120/80 and the heart rate was 80 per minute. At that time she refused surgical correction. About 2 months prior to admission she noted an increase in the edema of the affected extremity and the onset of edema of the other limb. At this same time she began to experience shortness of breath on exertion, palpitation, and a nonproductive cough which was worse in the recumbent position, and she noted a rapid increase of her body weight.

Physical examination revealed an obese, orthopneic woman with a blood pressure of 158/102 and a heart rate of 120 per minute. Her neck veins were distended, the hepatojugular reflux was positive, and moist fine rales were present in both bases. A grade-II apical systolic murmur and a protodiastolic gallop rhythm were noted with an increased second sound at the pulmonic area. The liver was palpable 4 cm. below the costal margin. There were moderate edema of the right leg to the level of the midthigh and marked pitting of the left limb to the inguinal region. A thrill and a bruit were present in the area of the lesion in the upper left thigh. The Nicoladoni-Branham bradycardiac sign was demonstrable.24, 25 The protodiastolic gallop rhythm disappeared while the fistula was compressed.

The arm-to-tongue circulation time was 60 seconds (Decholin). The venous pressure was 300 mm. of saline. The chest x-ray disclosed clouding of the lower half of the left lung field and a shift of the mediastinum to the left as a sequel to collapse therapy for tuberculosis. The left cardiac border could not be identified. The vascular markings in the right lung field were increased. The electrocardiogram was consistent with left ventricular hypertrophy. The hemoglobin was 12.5 Gm. per cent. Following physiologic studies she was treated with bed rest and sodium restriction for 2 weeks prior to surgery. She lost 17 pounds and the edema of the right leg disappeared as did the signs of pulmonary edema. Blood volume preoperatively was 29 per cent above predicted. Re-anastomosis of both the femoral artery and vein was successfully accomplished. She had a diuresis of 4,700 ml. of urine during the first 24 hours following surgery. Her total weight loss was 33 pounds, and a 1,000 ml. decrease in blood volume had occurred 13 days after surgery. Five months following study she was fully active without symptoms; her blood pressure was within normal limits.

The second patient in failure (R.A.) was a 47-year-old Negro who had been stabbed in the right thigh 23 years prior to admission. Since that time he had noted a pulsating mass in the region of the scar. His service in the army during World War II included combat duty. On examination 7 years prior to study the blood pressure was 146/80 and the cardiac examination, including chest x-ray, was normal. For the 3 to 4 months preceding study he had noted steadily increasing exertional dyspnea, edema, and weight gain. Examination revealed a moderately dyspneic man with a blood pressure of 150/80 and heart rate of 93. Moderate cardiac enlargement, a protodiastolic gallop and a grade-II apical systolic murmur were noted. The liver was enlarged 6 cm. below the right costal margin. A pulsating mass and a thrill were present over the lesion in the right midthigh. Moderate edema of the left leg to the midthigh and marked edema of the right leg extending to the inguinal region were present. The Nicoladoni-Branham sign was demonstrable and the protodiastolic gallop disappeared during compression. The arm-to-tongue circulation time (Decholin) was 40 seconds; venous pressure was 270 mm. of water. Fluoroscopy and teleroentgenograms revealed enlargement of the left ventricle, right ventricular outflow tract, and increased pulmonary vascular markings with small pleural effusions bilaterally. Hemoglobin was 13 Gm. per cent. An electrocardiogram disclosed only low voltage of the T waves. After physiologic studies the patient was treated with bed rest, digitalis, mercurial diuretics, and sodium restriction for 30 days. On this regimen he lost 10 pounds, edema disappeared, blood pressure and heart rate returned to normal but blood volume changed only from 65 to 56 per cent above the predicted value. Re-anastomosis of the femoral artery was then performed and the femoral vein ligated. Postoperatively he developed bacterial endocarditis and consequent aortic regurgitation.
SYSTEMIC ARTERIOVENOUS FISTULAS

Despite this complication 2½ months after surgery he was active and asymptomatic; the cardiac silhouette and lung fields were within normal limits. His total weight loss was 15 pounds.

The studies were performed in an air-conditioned room on patients in the postabsorptive state, usually after a sedative dose of sodium allyl barbiturate. Details of the methods used in this laboratory have been previously described. In 3 cases observations were made with the shunt totally occluded by direct pressure. Blood volume studies were made with Evans blue dye (T-1824) or with I\textsuperscript{131} tagged albumin. A correction of 0.92 was used for total body hematocrit level. The same method was used in a given patient for each serial study.

RESULTS

The data obtained during these studies are shown in table 1.

Cardiac Output

The cardiac output in the resting state was abnormally high in each patient. During exercise a qualitatively normal increase in cardiac index was observed in the 2 short-term non-failure patients (S.A., J.E.). The exercise response was less than normal in one long-term non-failure patient (E.W.) and insignificant in the other (J.P.). A decrease in cardiac output during exercise occurred in the 2 failure patients.

Five patients were restudied after surgery and in each instance the resting cardiac output was considerably lower than the preoperative value and a normal increase occurred during exercise.

Stroke Volume and Heart Rate

The elevation in cardiac output at rest in 3 of the 4 non-failure patients was caused by an increase of both stroke volume and heart rate. In the fourth patient (E.W.) a markedly increased stroke volume was accompanied by a normal heart rate. In the failure patients the cardiac output elevation at rest was more attributable to a tachycardia than to elevation of stroke volume and a marked drop in stroke volume occurred during exercise.

Arteriovenous Oxygen Difference

A markedly reduced arteriovenous oxygen difference was found in each patient regardless of the presence or absence of clinical heart failure. During exercise the arteriovenous oxygen difference remained abnormally narrowed. Thus both at rest and during exercise the cardiac output was greater than expected on the basis of oxygen consumption.

Central and Peripheral Venous Pressures

The systemic venous and right atrial pressures of the 4 non-failure patients were within normal limits and during exercise the increases in cardiac output occurred without significant changes in atrial pressure. The venous and right atrial pressures were greatly elevated in the 2 patients with congestive failure and a further rise of atrial pressure was observed in each during exercise. After surgery the venous and atrial pressures in each patient were within normal limits.

Systemic Arterial Pressure and Total Systemic Resistance

Systemic arterial pressure was low normal in one short-term non-failure patient (S.A.) and high normal in the other, J.E.; systemic resistances were reduced. Postoperatively the pressures and resistances were unchanged in the patient whose fistula had been only of 8 days' duration and, in the other, resistance was restored to normal.

In one long-term non-failure patient (J.P.) pressure was high normal and resistance reduced. In the other, E.W., arterial pressure was low and resistance was remarkably low; compression of the fistula in this patient resulted in a 2-fold increase of diastolic and mean arterial pressure. After surgery pressure was normal and resistance had increased. The data in the 2 failure patients distinctly differed from the non-failure patients. Systemic hypertension was present and systemic resistances were markedly higher than were found in the non-failure group; during exercise a marked rise in systemic resistance occurred. Postoperatively, mean
### Table 1.—Hemodynamic Data

<table>
<thead>
<tr>
<th>Patient</th>
<th>Duration of fistula</th>
<th>Age</th>
<th>Sex</th>
<th>Surface area $-$ M$^2$</th>
<th>Oxygen consumption (ml/min, M$^2$)</th>
<th>Cardiac index (L/min, M$^2$)</th>
<th>Cardiac output (L/min)</th>
<th>Oxygen consumption (ml)</th>
<th>Stroke index (ml/beat, M$^2$)</th>
<th>Heart rate (beats/min)</th>
<th>A-V oxygen difference (mL/100 ml)</th>
<th>Mean right atrial pressure (mm Hg)</th>
<th>Mean pulmonary arterial pressure (mm Hg)</th>
<th>Mean pulmonary wedge pressure (mm Hg)</th>
<th>Systolic pressure (mm Hg)</th>
<th>Diastolic pressure (mm Hg)</th>
<th>Total pulmonary resistance (dPa cm$^{-5}$ sec$^{-1}$)</th>
<th>Total blood volume (ml)</th>
<th>Plasma volume (ml)</th>
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<td>S.A.</td>
<td>8 days</td>
<td>21-M</td>
<td>1.02</td>
<td>159</td>
<td>379</td>
<td>5.52</td>
<td>7.90</td>
<td>3.47</td>
<td>2.08</td>
<td>55</td>
<td>66</td>
<td>100</td>
<td>120</td>
<td>2.87</td>
<td>4.80</td>
<td>6</td>
<td>19</td>
<td>18</td>
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<td>J.E.</td>
<td>6 weeks</td>
<td>30-M</td>
<td>1.80</td>
<td>171</td>
<td>388</td>
<td>8.88</td>
<td>11.56</td>
<td>5.19</td>
<td>2.98</td>
<td>74</td>
<td>89</td>
<td>120</td>
<td>130</td>
<td>1.92</td>
<td>3.36</td>
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<td>30</td>
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<tr>
<td>E.W.</td>
<td>18 years</td>
<td>32-M</td>
<td>1.91</td>
<td>159</td>
<td>300</td>
<td>8.53</td>
<td>9.81</td>
<td>5.36</td>
<td>3.27</td>
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<td>129</td>
<td>61</td>
<td>75</td>
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<tr>
<td>J.P.</td>
<td>19 years</td>
<td>19-M</td>
<td>2.06</td>
<td>153</td>
<td>226</td>
<td>6.59</td>
<td>7.00</td>
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<td>96</td>
<td>2.32</td>
<td>3.23</td>
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<td>20</td>
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<td>Congestive failure</td>
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<td>C.J.</td>
<td>10 years</td>
<td>41-F</td>
<td>1.78</td>
<td>143</td>
<td>169</td>
<td>5.62</td>
<td>3.76</td>
<td>3.93</td>
<td>2.22</td>
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<td>27</td>
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<td>140</td>
<td>2.55</td>
<td>4.48</td>
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<tr>
<td>R.A.</td>
<td>23 years</td>
<td>47-M</td>
<td>1.70</td>
<td>125</td>
<td>211</td>
<td>4.84</td>
<td>4.20</td>
<td>3.87</td>
<td>1.99</td>
<td>49</td>
<td>37</td>
<td>98</td>
<td>114</td>
<td>2.59</td>
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*Compression over site of fistula during preoperative study.
†After intravenous infusion of 100 Gm. of salt-free albumin.
arterial pressures and the systemic resistances were normal.

**Pulmonary Arterial Pressure and Total Pulmonary Resistance**

The total pulmonary resistances were low in the non-failure patients and pulmonary arterial pressures were high normal. The pressures and resistances were elevated in the 2 patients in congestive heart failure and a marked decrease in pulmonary arterial pressure was observed in each following surgery.

**Discussion**

The clinical state of congestive heart failure present in 2 of these patients was similar to the syndrome of congestive failure that has been observed by others in certain patients with arteriovenous fistulas. Furthermore, it was similar to the syndrome of chronic congestive heart failure which may be present in patients suffering from heart disease of any etiology. Yet, after surgical excision of the fistulas, no heart disease was demonstrable in one of these 2 individuals and in the other a quite normal functional capacity and heart size were found despite the development of aortic regurgitation following postoperative acute bacterial endocarditis. Similar clinical sequences have been observed previously, but it has been proposed that this syndrome does not represent actual heart failure and is attributable to circulatory congestion simulating congestive heart failure without actual myocardial inadequacy.

The physiologic data obtained during and following the syndrome of congestive failure in these 2 patients, however, clearly indicate that actual myocardial inadequacy was present. Their cardiac outputs were relatively lower than those found in the 4 other patients with arteriovenous fistulas and significant elevations of venous, atrial, pulmonary arterial, and systemic arterial pressures were found at rest. During exercise their cardiac outputs fell to still lower levels and their intravascular pressures became more abnormal. With the exception of the absolute level of the cardiac output, the hemodynamic findings in these 2 individuals were, in fact, quite similar to those usually found in patients suffering from chronic congestive heart failure due to heart disease of any etiology. The physiologic data obtained postoperatively suggested, however, that no antecedent underlying heart disease had been present to explain the transient occurrence of clinical congestive heart failure; this syndrome therefore seemed to have been the result solely of transient heart failure produced by the systemic arteriovenous fistulas.

In these 2 patients, who had chronic congestive heart failure on clinical examination and myocardial inadequacy as measured by cardiac output and intravascular pressure observations, the duration and anatomy of the fistulas and collateral vessels did not differ importantly from those found in the 2 long-term non-failure patients and the magnitude of the compensatory hypervolemia was not markedly greater than in the long-term non-failure patient E.W. Myocardial inadequacy would, therefore, seem to have been the result of a finite ability of the myocardium to increase and maintain stroke volume in the face of the demand imposed by the decreased total peripheral resistance caused by the fistula and the increased venous return caused by the compensatory hypervolemia. As a result of myocardial inadequacy, lower cardiac outputs and elevated right atrial and pulmonary arterial pressures occurred.

Systemic arterial hypertension was also present in these 2 failure patients with elevation of the total systemic resistance to the normal range, despite the presence of the fistulas. The inadequate cardiac output resulting from the volume load apparently had as its consequence a generalized increase in systemic arteriolar resistance of sufficient magnitude to result in an increase in total systemic resistance to normal despite the locally low resistance of the fistula. In these patients maintenance of blood flow through the fistula in the face of a decreasing car-
Diastolic output thus required vasoconstriction with a consequent reduction in the circulation to the remainder of the body. Systemic hypertension in these individuals is therefore thought to have represented the consequence of an increased peripheral resistance due to heart failure in the presence of an overfilled circulation. Systemic hypertension has been reported in certain other patients with systemic arteriovenous fistulas and congestive heart failure but has not invariably been found. It would seem likely, therefore, that myocardial inadequacy developed initially from the volume load imposed by the fistulas and was subsequently augmented by the pressure load imposed by the hypertension that occurred as a consequence of the development of heart failure. The development of transient systemic hypertension during exacerbations of chronic congestive heart failure in patients with heart disease of various etiologies is well recognized. The severity of the hypertension that may result from an increase in total systemic resistance in the presence of hypervolemia is evident in the pressures obtained during occlusion of the fistulas in the 2 failure patients.

In these 2 patients with systemic arteriovenous fistulas we suggest that maintenance of an adequate arterial pressure eventually required levels of cardiac output that their hearts could not sustain with the consequent development of myocardial inadequacy. The compensatory hypervolemia, which, prior to the development of heart failure aided in the maintenance of an adequate arterial pressure, then became a deleterious mechanism, since it contributed to the volume load presented to the failing heart and to the development of the pressure load imposed by systemic hypertension. We see in the hypervolemia, therefore, an example of an essential homeostatic mechanism becoming an undesirable factor in the presence of heart failure.

Finally, in these individuals who had presented congestive heart failure, surgical correction of the peripheral circulatory lesion resulted in the apparent return of circulatory and myocardial function to normal. These data thus provide evidence that heart failure may be produced in the apparently healthy heart by a peripheral circulatory load and, furthermore, they also permit a description of the sequences and adjustments by which this may occur.

Summary

A correlation of clinical and hemodynamic data in 6 patients with systemic arteriovenous fistulas has been presented. Two of the patients presented overt congestive failure. With the exception of the high absolute level of cardiac output, the decrease in cardiac output with exercise in the presence of elevated central venous pressure in the 2 patients with congestive failure was similar to the finding in patients with congestive failure of any etiology. Systemic hypertension occurred with the development of congestive failure despite the low resistance lesion of the fistula.

Myocardial inadequacy seemed to have been the consequence of a finite capacity of the heart to increase and maintain stroke volume in the face of the demand imposed by the low resistance lesion and the compensatory hypervolemia. Surgical correction of the fistulas resulted in return of circulatory dynamics to normal. These data, therefore, provide evidence that heart failure may be produced in the apparently healthy heart by a peripheral circulatory load.

Acknowledgment

Patient R. A. was studied through the courtesy of Dr. L. A. Baker, former Chief of Medical Service, Veterans Administration Hospital, Hines, Illinois. The other patients were studied through the courtesy of their attending surgeons, Dr. O. C. Julian and Dr. F. V. Theis.

Summario in Interlingua

Es presentate un correlation del datos clinic e hemodynamic ab sex patientes con fistulas arterio-venose in le circulation systemic. Duo del patientes exhibiva patente disfallimento congestive. Con le exception del
alte livello absolute del rendimento cardiac, le reduction del rendimento cardiac occorrente in exercitio in le presentia de elevate tensiones centro-venose in le duo patientes con disfallimento congestive in le presente studio esseva simile al constatazione in patientes con disfallimento congestive de non importa qual etiologia. Hypertension systemica occurreva con le disveloppamento de disfallimento congestive in despecto del basse resistencia occasionate per le fistulas.

Inadequatia myocardial esseva apparentemente la consequentia de un finite capacitae del corde pro augmentar e mantenere le volumente per pulso in le presentia del requirimenti imponite per le lesion a basse resistencia e le hypervolemia compensatori. Le correction chirurgie del fistulas resultava in le retorno del dynamica circulatori a condizioni normal. Per consequente le datos hic presentate demuestra que disfallimento cardiac pote esser produce in apparentemente normal cordes per un carga in le circulation periphaic.

REFERENCES
Exercise must be taken within the limits which each individual soon learns to recognize. In severe recurring attacks induced by slight muscular efforts, a period of absolute rest should be enjoined. The sudden, quick movements which rapidly increase the blood pressure and throw a strain upon the heart are the most dangerous; and most of all those with which are associated strong emotions. The patients should be urged to walk on the level, in the literal as well as metaphorical meaning of the phrase. He should learn “to live within the income of his circulation,” with which wise saw from the lips of the late Dr. Sibson a friend with organic heart disease has been comforted and sustained for a quarter of a century.—William Osler, M.D. Lectures on Angina Pectoris and Allied States, 1897.
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_Circulation_. 1959;20:1079-1086
doi: 10.1161/01.CIR.20.6.1079

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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