The mechanisms which control blood volume are as yet unknown. Henry and Gauer, Henry, Sicker, and Wendt have provided evidence suggesting that there are receptors in the heart which "translated changes in volume and consequently in the degree of stretching of the heart and great vessels into changes in glomerular filtration rate and sodium balance." They narrowed the sensitive diuresis-producing region to the left atrium and possibly the intrapericardial pulmonary veins. Left atrial distention, due to increased volume, increases the rate of neural (vagal) discharges from these receptors. These discharges set off a train of events which provoke diuresis. Because atrial distention is associated with antidiuresis in congestive heart failure, Eliahou, Clarke, and Bull provided evidence that the receptors responded to pulsatile stretch and that the absolute stretch is unimportant. Presumably, pulsatile stretch is not as great or as vigorous in failure as it is in health.

This study attempts to determine whether such a mechanism is operating during human congestive heart failure.

Methods
Sixty-seven consecutive patients, who underwent right and left heart catheterization, were studied. All left heart catheterizations were carried out by the transthoracic approach. Table 1 gives the findings at catheterization, as well as age, diagnosis, and functional status according to the classification of the American Heart Association. In addition, 49 patients were grouped into four categories depending on their clinical findings at the time of catheterization, but without knowledge of their catheterization findings. These groups were: (1) no clinical evidence of decompensation; (2) decompensation in the past, but no decompensation at catheterization; (3) decompensation in the past and mild decompensation at catheterization; (4) decompensation in the past and moderate decompensation at catheterization.

Because failure may be defined not only on a clinical basis but also in terms of the right ventricular end-diastolic pressure, the arteriovenous oxygen difference, and the cardiac output, the left atrial pulse pressure was plotted against each of these variables. In addition, since the impact of pressure on the left atrial wall may be related not only to the pulse pressure but also to the acceleration of the pressure wave, the rate of ascent of the pressure wave was also plotted against these variables.

For statistical purposes, an arteriovenous (A-V) oxygen difference of 5 per cent or less, a right ventricular end-diastolic pressure of 5 mm. Hg or less, and a cardiac output of 3.5 L. a minute or more were regarded as normal. The left atrial pulse pressure was regarded as the difference in mm. Hg between the maximal pressure in atrial systole and the minimal pressure in atrial diastole. The rate of ascent of the left atrial pressure was regarded as the average increase in mm. Hg per 0.1 second from the minimal pressure of the atrium in diastole to its maximum in systole.

The left atrial pulse pressures and their rates of ascent were measured in the groups with normal A-V oxygen difference, normal right ventricular end-diastolic pressure, and normal cardiac outputs and separately in the groups with abnormal values in these parameters. The statistical relationship between the pressure findings in the normal groups and those in the abnormal groups were determined and their P values computed. The four clinical groups were similarly related to the left atrial pressure findings.
Results

Figure 1 is a scattergram of the left atrial pulse pressure against the arteriovenous oxygen difference. Although the scatter is very wide, there is a tendency for the atrial pulse pressure to rise with increasing A-V oxygen difference. This difference was always high with very large pulse pressures ($P < 0.05$ when the subjects are separated into those with normal and those with abnormal A-V oxygen difference).

Figure 2 is a scattergram of the rate of ascent of the left atrial pressure wave against the arteriovenous oxygen difference. The scatter is even wider than figure 1 ($P > 0.4$ by the same standards).

Figure 3 is a scattergram of the pulse pressure against the right ventricular end-diastolic pressure. Again, although the scatter is wide, there is a tendency for the higher pulse pressure to be associated with higher end-diastolic pressures ($P > 0.01$ when the subjects are separated into those with a normal and those with an abnormal right ventricular end-diastolic pressure).

Figure 4, a scattergram of the rate of ascent of the left atrial pressure wave against the right ventricular end-diastolic pressure is similar to figure 3 ($P < 0.05$ by the same standards).

Figure 5 is a scattergram of pulse pressure against cardiac output as measured by the Fick principle. Again, there is a tendency for the left atrial pulse pressure to rise as the cardiac output falls ($P < 0.05$ when the subjects are separated into those with a normal and those with a subnormal cardiac output).

Figure 6 shows the rate of ascent of the atrial wave measured against the cardiac out-
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FIGURE 3
Scattergram of left atrial pulse pressure against right ventricular end-diastolic pressure.

FIGURE 4
Scattergram of rate of ascent of left atrial pressure against right ventricular end-diastolic pressure.

put. The more rapid ascents are most frequently seen with the lower cardiac outputs. In addition, no rapid rise is found when the cardiac output is high (P < 0.05 by the same standards).

Figure 7 is a diagram plotting the left atrial pulse pressure against the clinical status of the patient. The highest pulse pressures are seen in those with moderate decompensation at the time of catheterization (P < 0.01 when the subjects are separated into those with and those without edema).

Figure 8, a diagram plotting the rate of ascent of the left atrial pulse wave against the clinical status, shows findings similar to figure 7 (P < 0.01 by the same standards).

Discussion
The subject of salt and water volume receptors has been fascinatingly reviewed by Smith and the evidence for receptors recently documented by Gauer, Henry, and Sicker, to which the reader is referred. They regard atrial stretch receptors as important factors in the control of fluid (water) volume. Our findings indicate that higher left atrial pulse pressure and faster ascents of the left atrial pressure wave are associated with congestive heart failure. They are inconsistent with the hypothesis postulated by Gauer et al. and Eliahou et al. Indeed, even the pulse pressure in those without clinical evidence of failure was higher than the normal. Thus, our average left atrial pulse pressure in this group of patients was 8.4 mm Hg. Braunwald reported an average of 3.4 mm Hg with a range of 1 to 7 mm Hg in normal subjects. He used the transseptal approach to enter the left atrium. Nevertheless, we interpret this discrepancy to mean that this group of our cases had a slight degree of failure which
could not be recognized on clinical grounds at rest. This interpretation is supported by the A-V oxygen difference, the right ventricular end-diastolic pressure, and the cardiac output. It would appear, therefore, that even failure not clinically recognizable is associated with higher than normal pulse pressure in the left atrium.

Eliahou et al. 5 showed that the left atrial pressure curve in dogs under an acute load followed the Starling curve. It is difficult to correlate such acute changes in animals with the human left atrium which has been subject to prolonged abnormal pulsatile changes. Note, for instance, the findings in our fourth group of patients in whom a moderate degree of decompensation was present both at the time of, and for months or years before, catheterization. Our data suggest that pulse pressure rises above normal before abnormalities in the rate of ascent of the pressure appear.

Paintal 9 has reported that the rate of discharge of the afferent impulses in the vagus nerves set in motion by atrial distention decreases with time. These observations may reconcile the results of acute animal experiments with our findings in the human. It is possible that vagal discharges become inadequate when increased atrial pulsation becomes chronic.

On the other hand, it is possible that pulsations in the left atrium play little, if any, role in the control of blood volume. Ledsome, Linden, and O’Connor 10 have clearly shown that diuresis so produced is transient, small, and variable in volume.

Summary
The concept that the left atrial pressure or pulse pressure acts as a stimulus to receptors for control of fluid volume was tested by examining the data on 67 persons who under-
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FIGURE 7
Diagram of the left atrial pulse pressure in the various clinical states of compensation.

FIGURE 8
Diagram of rate of ascent of left atrial pressure wave in the various clinical states of compensation.

went right and left heart catheterization. Although there is no direct relationship between left atrial pulse pressure and congestive heart failure, no patient in failure had a pulse pressure below normal. Furthermore, those with the more severe grade of failure had the highest left atrial pulse pressure and the more rapid ascent of the left atrial pressure curve. These findings are inconsistent with the concept that a diminished left atrial pressure or pulse pressure stimulates left atrial receptors to set in motion a train of events which provoke antidiuresis in congestive heart failure. On the other hand, if increased left atrial pressure or pulse pressure promotes diuresis, the mechanism is completely overridden by more potent factors in human congestive heart failure.
References


Left Atrial Pressure Curve as an Index of Control of Fluid Volume
Stephen J. Dubel and Louis A. Soloff

Circ Res. 1962;11:337-342
doi: 10.1161/01.RES.11.2.337

Circulation Research is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7330. Online ISSN: 1524-4571

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