Effect of Decreasing the Force of Right Atrial Contraction on Right Ventricular Stroke Volume

By Daniel L. Boyd, M.D., and John W. Williams, Jr., M.D.

ABSTRACT

The effect of reducing the force of right atrial contraction on right ventricular stroke volume was determined in anesthetized open-chest dogs. Atrial contractile force, measured directly with a strain-gauge arch, was decreased by electrical stimulation of the right vagus nerve; right ventricular stroke volume was measured with an electro-magnetic flowmeter. Heart rate was maintained constant by electrical stimulation of the right atrium.

Vagal stimulation decreased atrial contractile force by an average of 47 ± 2.6 (SEM)% of the control, and stroke volume fell by 4.0 ± 0.9%. During vagal stimulation, no change was observed in right ventricular contractile force. In addition, no consistent change was noted in mean right atrial or right ventricular pressures. The relation between the decrease in atrial force and stroke volume was not altered significantly by the rate of right atrial pacing. In 7 of 10 experiments, increasing the inhibition of atrial force produced a further decrease in stroke volume.

Since neural, mechanical, and humoral factors modify atrial contractile force in the intact animal, the present study provides more definitive evidence that the ability to alter atrial force represents another adaptive mechanism in the regulation of cardiac performance.

ADDITIONAL KEY WORDS vagal stimulation atrial systole cardiac output anesthetized dogs

A number of investigations have contributed greatly to our understanding of the importance of atrial systole by demonstrating that the presence of a properly timed atrial contraction contributes to ventricular filling (1-9). However, most of these studies have been concerned with the effect of abolishing or restoring atrial contraction or with the effect of altering the timing of atrial systole in relation to ventricular activation. Since the absence of effective atrial contraction or marked impairment of atrioventricular conduction rarely occurs in the normal animal, there is little information as to whether variations in the force of atrial contraction significantly affect ventricular filling under normal conditions. Furthermore, until recently it has not been possible to measure changes in the force of atrial contraction directly in the intact animal; previous deductions concerning atrial force have been based on the analysis of atrial pressure pulses (4, 10-12). In a recent study in which a strain-gauge arch was used to measure the force of atrial contraction, it was observed that neural, mechanical and humoral factors can modify atrial contractile force in the intact animal (13). This observation would indicate that moderate changes in the force of atrial contraction may occur frequently under normal conditions. Indeed it led the authors to suggest that the ability to alter the force of atrial contraction may represent another adaptive mechanism in the regulation of cardiac performance. However, the effect of modify-
ing atrial force on ventricular dynamics was not determined in their study. To provide more definitive information concerning this potential function of the atria, the present study was performed to determine the effect of a moderate decrease in right atrial contractile force on right ventricular stroke volume. The right atrium and stroke volume of the right ventricle were chosen for investigation for several reasons. (1) The accessibility of the right atrium permitted easier attachment of the strain-gauge arch and recordings of force relatively free of artifact. (2) Right atrial contractile force can be inhibited to a greater extent by right vagal stimulation than can left atrial force when the left vagus is stimulated (13). (3) Preliminary observations indicated that left vagal stimulation of sufficient magnitude to depress left atrial contraction often impaired atrioventricular conduction.

Methods

Thirty-seven experiments were performed on 14 mongrel dogs of either sex weighing 16 to 30 kg. The animals were anesthetized with morphine (3 mg/kg), chloralose (48 mg/kg), and urethane (480 mg/kg). Respiration was maintained by a cuffed endotracheal tube connected to a Harvard respiratory pump. The vagus nerves were isolated and severed high in the neck of each animal. Through a sternum-splitting incision, a lightweight, sensitive strain-gauge arch1 was attached to the right atrium by sutures that extended through the entire atrial wall. In addition, a Walton-Brodie strain-gauge arch was sutured to the surface of the right ventricle. The segment of myocardium beneath the atrial gauge was stretched approximately 50% beyond its initial length, which has been shown to be near the peak of the active tension curves for the atria (13). The segment of myocardium beneath the ventricular arch was gradually stretched until maximum force developed. A gated sine-wave electromagnetic flowmeter2 with the flow transducer placed around the pulmonary artery was used to measure right ventricular stroke volume. Zero flow was obtained during cardiac arrest produced by vagal stimulation of the unpaced heart. Since this investigation was concerned only with percent changes in flow in an individual animal, the flowmeter was not calibrated after each study. However, each flow probe used in this study was calibrated three times during the investigation, and each time it was found to respond linearly to changes in flow over a range of 600 to 3500 ml/min. The area under the flow curve was calculated by planimetric integration of the flow tracing recorded at a paper speed of 100 mm/sec. Pressure in the femoral artery was measured continuously through a heparinized polyethylene catheter connected to a Statham P23 Db pressure transducer. Right atrial pressure also was measured in 30 experiments on 10 animals, and right ventricular pressure was determined in 15 experiments on 6 animals. The mid-right atrial level was used as the zero reference point. An electrocardiogram was obtained from a standard limb lead in each experiment. Heart rate was kept constant by electrical stimulation of the right atrium through bipolar platinum electrodes fixed to the atrial appendage. The frequency of stimulation was adjusted to just exceed the spontaneous sinus rate. All variables were recorded simultaneously on a multichannel oscillograph.

Following control observations, right atrial contractile force was decreased by electrical stimulation of the distal end of the severed right vagus nerve, using square-wave impulses of 2 to 5 v, with a frequency of 2 to 6 cycle/sec, and a duration of 4 to 5 msec.

Statistical analyses were performed by standard methods (14).

Results

The changes in atrial contractile force and stroke volume during vagal stimulation are presented in Figure 1. Right atrial contractile force decreased abruptly in each experiment following the institution of vagal stimulation and, within an average of 5 sec (range 3 to 8 sec), reached a constant force that could be maintained for an additional 30 to 40 sec. The maximum decrease in atrial force ranged from −14 to −82% of the control and averaged −47 ± 2.6% (SEM). At the time of the maximum decrease in atrial force, right ventricular stroke volume was unchanged in 8 experiments, increased in 3 and decreased in 26. The changes in stroke volume ranged from +6.2 to −19.0% of the control and averaged −4.0 ± 0.9%, a decrease of statistical significance (P < .01). The cause of the increase in stroke volume during 3 experiments in 2 animals was not apparent

1Myocardial Force Transducer, Model 3106A-145-5P, Honeywell, Minneapolis, Minnesota.
2Model BL-310, Biotronics Laboratory, Inc., Silver Spring, Maryland.
ATRIAL CONTRACTILE FORCE AND STROKE VOLUME

Figure 1
The effect of right vagal stimulation on right atrial (RA) contractile force and right ventricular stroke volume (SV) expressed as percent change from control. The open circle with bars represents the mean value ± SEM of the 37 observations.

Table 1
Effect of Vagal Stimulation on Right Atrial, Right Ventricular, and Systemic Arterial Pressure (mm Hg)

<table>
<thead>
<tr>
<th></th>
<th>RA pressure</th>
<th>RV pressure</th>
<th>Systemic arterial pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>VS</td>
<td>C</td>
</tr>
<tr>
<td>Average</td>
<td>4</td>
<td>4.3</td>
<td>30</td>
</tr>
<tr>
<td>Range</td>
<td>2-10</td>
<td>2-11</td>
<td>16-42</td>
</tr>
</tbody>
</table>

RA = right atrium; RV = right ventricle; C = control; VS = vagal stimulation; SP = systolic pressure; EDP = end-diastolic pressure.

The average and range of values for mean right atrial, right ventricular, and systemic arterial pressure at rest and at the time of the maximum decrease in atrial force are presented in Table 1. With vagal stimulation, mean right atrial pressure remained unchanged in 12 experiments, decreased by 0.5 mm Hg in 4 experiments, and increased by 0.5 to 3 mm Hg in 14 experiments; right ventricular systolic pressure fell by 3.0 mm Hg or less in 5 experiments and was unaffected in the remainder. Right ventricular end-diastolic pressure was unaffected by vagal stimulation in 11 experimen-
ments, increased by 2.0 mm Hg in 2 experiments and fell by 1.0 mm Hg in the remaining 2 studies. Systemic arterial pressure either remained constant or decreased slightly during the later phases of vagal stimulation; the maximum decrease in systolic pressure was 15 mm Hg. Right ventricular contractile force was unchanged during vagal stimulation in each experiment.

The P-R interval of the electrocardiogram averaged 103 msec (range 90 to 110) during control observations and 123 msec (range 100 to 150) during vagal stimulation. In 6 experiments, the P-R interval was unaffected by vagal stimulation. No other electrocardiographic changes were observed.

After instituting vagal stimulation, it was possible in 10 animals to increase the intensity of the stimulation and obtain an even greater inhibition of atrial contractile force. In 7 of these 10 animals, this increased inhibition was associated with a further decrease in stroke volume, although some of these decreases were small. These results are presented in Figure 2.

Heart rate, which was kept constant during each experiment, ranged from 90 to 205 beat/min and averaged 162 ± 3.5 beat/min. In 5 animals, the frequency of atrial stimulation was increased stepwise, and the effect of vagal stimulation was examined. However, in 3 animals, the magnitude of the decrease in atrial force during vagal stimulation became less as heart rate increased, while in the remaining 2 the opposite occurred. Thus it was not possible in an individual animal to determine whether the effect of decreasing atrial force on stroke volume was modified by heart rate. To provide some information on the possible effect of differences in heart rate on these results, the changes in atrial force and stroke volume in three arbitrarily selected ranges of heart rates were compared. The results are given in Table 2. Although the magnitude of the decreases in atrial force during vagal stimulation was similar at each of the heart rates, the effect on stroke volume appeared to be progressively less with increasing heart rates. However, the differences between these stroke volumes is not of statistical significance. Furthermore, multiple regression analyses of the changes in atrial force, stroke volume, right atrial pressure and the paced heart rate revealed no statistically significant correlations among these variables.

Figure 3 is a recording obtained during an experiment in which a significant decrease in stroke volume is apparent as atrial force declines. In this experiment, the fall in atrial contractile force was approximately 60%,
TABLE 2

<table>
<thead>
<tr>
<th>Heart rate (beat/min)</th>
<th>Number of experiments</th>
<th>Beat/min</th>
<th>Percent change RV stroke volume</th>
<th>Percent change RA force</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;130</td>
<td>6</td>
<td>116 ± 5.7</td>
<td>-4.6 ± 1.5</td>
<td>-43 ± 5.7</td>
</tr>
<tr>
<td>130-175</td>
<td>22</td>
<td>163 ± 3.0</td>
<td>-4.0 ± 1.1</td>
<td>-48 ± 3.7</td>
</tr>
<tr>
<td>&gt;175</td>
<td>9</td>
<td>192 ± 3.4</td>
<td>-3.4 ± 1.9</td>
<td>-46 ± 3.3</td>
</tr>
</tbody>
</table>

RV = right ventricle; RA = right atrium.

Discussion

An average decrease of 47% in right atrial contractile force was accompanied by an average decrease in stroke volume of 4%. Although this decrease in stroke volume is relatively small, it is apparent that a moderate reduction in the force of atrial contraction can reduce stroke volume acutely. Furthermore, the magnitude of the decrease in stroke volume also seems to have some relationship to the magnitude of the decrease in atrial force. Although such a relationship could not be established statistically for the entire series, in 7 of 10 animals a further decrease in stroke volume did occur when it was possible to increase the inhibition of atrial contraction. In addition, although it was not the purpose of the study to determine the effect of the absence of atrial systole on stroke volume, in 2 animals in which marked decreases of 80 and 82% in
force of atrial contraction. Thus the lesser response of the stroke volume at higher heart rates, and indeed some of the variability of response among animals, may be attributed to the degree of sympathetic stimulation exerted at the time each experiment was performed.

In the present study, there was no consistent change in mean right atrial pressure during vagal stimulation, although the average mean atrial pressure increased by 0.3 mm Hg. This is somewhat at variance with previous investigations in which mean atrial pressure has been reported to increase during vagal stimulation (4,12). However, these studies were concerned primarily with left atrial pressures, and it is apparent from Figure 7 in the study by Sarnoff et al. (12) that mean right atrial pressure can be unaffected by vagal stimulation which at the same time produces an increase in mean left atrial pressure.

It has been demonstrated that ventricular filling can be maintained in the presence of a decrease in the force of atrial contraction if mean atrial pressure is increased appropriately (4). Thus in the present study, it was expected that greater decreases in stroke volume might be found in the experiments in which mean atrial pressure fell or remained unchanged than in those in which it rose. Surprisingly, the opposite was found. In the experiments in which mean atrial pressure rose, stroke volume fell by an average of 6.2%, whereas in experiments in which mean atrial pressure fell or was unchanged, stroke volume declined by an average of 3.4%. However, the significance of this observation is unclear since atrial contractile force decreased slightly more (average 51%) in experiments in which atrial pressure rose than in those in which it fell or was unchanged (average 47%).

The present study provides no information concerning the role of left atrial contraction in ventricular filling. Certainly it is possible that quantitative differences may exist between the contribution of right and left atrial systole to the filling of their respective ventricles. Also it must be realized that the results of this study may not apply directly to the failing or diseased heart in which the contribution of atrial systole may be of greater importance. In addition, it must be appreciated that these were open-chest, anesthetized animals.

However, these observations do have important physiological significance. It has been demonstrated that moderate baroreceptor hypertension can produce decreases in atrial force of a magnitude comparable to those observed in the present study (13). Also it has been observed that baroreceptor stimulation in man reduces stroke volume (24) and cardiac output (25). The results of this present investigation, therefore, indicate that a decrease in the force of atrial contraction may well contribute to the reduction in cardiac output under these conditions. Also, it has been observed in the intact animal that the Frank-Starling mechanism is operative in the atria and that a variety of humoral substances which are known to affect ventricular function also alter the force of atrial contraction (13). Thus it is apparent that the force of atrial contraction can vary widely in response to a variety of stimuli which normally are utilized in the regulation of cardiac output in the intact animal. The present study therefore provides further evidence to support the previous suggestion that the ability to alter atrial force may represent another adaptive mechanism in the normal control of cardiac performance.

Acknowledgment

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References

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