Effects of Atrial Pacing on Left Ventricular Performance in Patients with Heart Disease

By Richard F. Leighton, M.D., Stephen J. Zaron, M.D., John L. Robinson, M.D., and Arnold M. Weissler, M.D.

SUMMARY

Hemodynamic data and systolic time intervals were obtained at resting heart rate and during atrial pacing in 10 patients with heart disease, eight with left ventricular dysfunction, and two with mitral stenosis. The mean increase in heart rate was 44 beats/min. During atrial pacing there was no significant alteration in cardiac output, minute work, left atrial or pulmonary wedge mean pressure, or duration of left ventricular pre-ejection period.

When the pressure events which determine the duration of the isovolumic time and the left ventricular pre-ejection period were examined, aortic diastolic pressure rose while left ventricular end-diastolic pressure fell. The rate of pressure rise (dp/dt) determined from high-fidelity left ventricular pressure pulses in three patients increased out of proportion to the increased pressure developed throughout isovolumic contraction. The augmentation in dp/dt from lower end-diastolic pressure indicates improved mechanical performance of the left ventricle, which is not necessarily translated into hemodynamic improvement.

Additional Indexing Words:
Heart rate Isovolumic contraction Left ventricular pre-ejection period

Nearly a century has passed since Bowditch demonstrated that an increase in the rate of electrical stimulation of the frog heart resulted in an increase in the strength of ventricular contraction. The past decade has witnessed renewed interest in the effects of increasing heart rate on left ventricular function. Studies utilizing various mammalian heart preparations, including segments of ventricular muscle, papillary muscles, isovolumically contracting ventricles, and intact pumping ventricles, have tended to demonstrate that increases in heart rate induce an increased velocity of ventricular contraction without a consistent increase in its force. Similar observations have recently been reported for the human right ventricle studied at open heart surgery.

By contrast, the majority of studies of intact man have revealed little or no change in external hemodynamic performance when the heart rate is increased by atrial pacing.

The following study was designed to examine not only the hemodynamic effects of an increased heart rate induced by atrial pacing, but also alterations in the isovolumic pressure events as reflections of left ventricular performance.

Methods

Ten hospitalized patients with sinus rhythm, five male and five female, 26 to 60 years of age, were studied. Eight patients showed clinical evidence of left ventricular dysfunction, five of whom had myocardial dysfunction and three arteriosclerotic heart disease. Two patients had pure mitral stenosis, mild in one, and moderately severe in...
the other. Four patients were on maintenance digitalis therapy. None showed evidence of congestive heart failure at the time of the study.

Hemodynamic measurements were made during right heart catheterization in each patient and during transseptal left heart catheterization in six patients, at rest and 10 min following the institution of right atrial pacing. Pacing was accomplished with either a bipolar or unipolar platinum-tipped electrode catheter placed in the right atrium so that its tip lay in contact with the lateral right atrial wall. Square wave impulses of 2-msec duration were delivered from a battery-operated pacemaker unit at voltages just above the threshold for atrial capture.

A phonocardiogram, a carotid pulse tracing, and an electrocardiogram were recorded at a speed of 100 mm/sec for each patient. The left ventricular pre-ejection period was determined from these recordings by subtracting the ejection time from the interval between the Q wave and the aortic component of the second heart sound. Details of this method appear in a previous report.13

Pressure recordings, with the exception of those derived from a micromanometer, were obtained through fluid-filled catheters, using Statham P23Db transducers and an Electronics for Medicine DR-8 recorder. Cardiac outputs were determined in duplicate by an indicator-dilution technic, employing injections of indocyanine-green dye into the pulmonary artery with sampling of brachial arterial blood at a constant rate. Blood was reinfused through the catheter in the pulmonary artery following each determination.

In three patients an Allard-Laurens micromanometer was introduced into the left ventricle by a transseptal technic similar to that previously reported by Forman and his associates.14 In brief, the atrial septum was punctured by a no. 16T Ross needle ensheathed in a no. 9 Ross Teflon catheter which in turn was ensheathed in an ultra-thin walled Teflon sleeve. Once the sleeve was advanced into the left atrium, the needle and catheter were removed and were replaced by the micromanometer. The micromanometer tip was then manipulated into the left ventricle and the sleeve was pulled back to the right atrium. A second catheter was then placed in the ascending aorta by a retrograde technic. In two instances the aortic catheter was a no. 7 Gensini catheter and once it was a second Allard-Laurens micromanometer. The high-fidelity left ventricular pressure pulse was then matched with the conventional pressure pulse recorded through the side hole of the micromanometer catheter. The first derivative of left ventricular pressure was obtained through an RC differentiating circuit, previously calibrated to give the rate of pressure rise or dp/dt.

Simultaneous recordings at 200 mm/sec were then made of the phonocardiogram, carotid pulse tracing, aortic pressure, the two left ventricular pressures, the first derivative of left ventricular pressure, and the electrocardiogram. Measurements were subsequently made of the rate of pressure rise at each 10 mm Hg of pressure rise throughout the isovolumic contraction period. The latter interval was measured from the initial rise of the undelayed micromanometer-derived left ventricular pressure to the aortic diastolic pressure level.

The statistical significance of the differences in data obtained from rest to atrial pacing was determined by using the t-test for paired samples.15

Results

The hemodynamic data obtained at rest and during atrial pacing are summarized in table 1. The average resting cardiac index was depressed, and the average resting left ventricular pre-ejection period was prolonged (fig. 1). The resting mean left atrial or pulmonary wedge pressure varied considerably (fig. 2).

Increasing the heart rate an average of 44 beats/min by atrial pacing resulted in no significant change in cardiac index, pre-ejection period, mean left atrial or pulmonary wedge pressure, or left ventricular minute work (av, + 0.34 kg-m/min/m², P > 0.10). While left ventricular stroke work fell in six patients (av, − 8.6 g-m/beat/m², P < 0.02), a linear decline with left ventricular end-diastolic pressure was not observed (fig. 3).

The left ventricular pressure events which determine the duration of the pre-ejection period, when examined in six patients (table 2), were found to be altered by atrial pacings. Left ventricular end-diastolic pressure fell while aortic or brachial artery diastolic pressure rose. As a consequence the left ventricular pressure increased during isovolumic contraction (fig. 4). This pressure, the difference between aortic diastolic and left ventricular end-diastolic pressure, increased by an average of 16 mm of mercury. The fall in left ventricular end-diastolic pressure occurred within one beat following the institution of atrial pacing.
ATRIAL PACING AND LEFT VENTRICULAR PERFORMANCE

2). During prolongation of the P-R interval associated with atrial pacing, the a wave of the left atrial pulse fused with the v wave of the previous cardiac cycle, resulting in a monophasic wave (fig. 6).

Discussion

A moderate increase in the heart rate induced by atrial pacing in these patients resulted in no significant alteration in the parameters which reflect external hemodynamic performance of the heart such as cardiac output, left ventricular minute work, and left atrial mean pressure. Likewise, examination of the relationship of stroke work to end-diastolic pressure revealed no change in left ventricular performance since both parameters declined in a nonlinear fashion.
LEFT VENTRICULAR PRE-EJECTION PERIOD

10 PATIENTS

REST ATRIAL PACING

AV. Δ HR = 44

134 ± 5.8
137 ± 5.7

P > 0.50

= S.E.

m sec.

CARDIAC INDEX

REST ATRIAL PACING

2.33 ± 0.20
2.49 ± 0.17

L/min/M²

P > 0.50

= S.E.

Figure 1

(Upper panel) Left ventricular pre-ejection period was prolonged at rest. No change occurred during atrial pacing. Av Δ HR = average change in heart rate in beats per minute. (Lower panel) The average cardiac index was depressed at rest. A slight increase, apparent during atrial pacing, was not statistically significant. se = standard error of the mean.

Isovolumic pressure events were then examined on the premise that they might reveal less obvious changes in left ventricular performance. In particular the relationship of the rate of pressure rise to the pressure developed throughout the isovolumic contraction time was analyzed. This relationship has recently been cited by Mason as a measure of left ventricular contractility which is relatively unaffected by changes in ventricular preload or afterload.

Although no change was found in the duration of the left ventricular pre-ejection

LEFT ATRIAL OR PULMONARY WEDGE MEAN PRESSURE

n = 10

P > 0.50

Figure 2

Mean left atrial or pulmonary wedge pressure. While there is considerable variability in the resting levels, no significant change occurred with atrial pacing.

LEFT VENTRICULAR STROKE WORK INDEX

n = 6

Figure 3

Left ventricular stroke work index related to end-diastolic pressure in six patients. Both parameters decline with atrial pacing but not in a linear fashion.
Table 2

Isovolumic Time and Pressure Events

<table>
<thead>
<tr>
<th>Patient</th>
<th>HR (msec)</th>
<th>PEP (msec)</th>
<th>IVCT (msec)</th>
<th>AoDP (mm Hg)</th>
<th>LVEDP (mm Hg)</th>
<th>LVP during IVCT (mm Hg)</th>
<th>dp/dt max (mm Hg/sec)</th>
</tr>
</thead>
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<tr>
<td>M.F.</td>
<td>Rest</td>
<td>100</td>
<td>80</td>
<td>81</td>
<td>30</td>
<td>51</td>
<td>963</td>
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<td>82</td>
<td>89</td>
<td>24</td>
<td>65</td>
<td>1060</td>
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<tr>
<td>B.S.</td>
<td>Rest</td>
<td>66</td>
<td>98</td>
<td>61</td>
<td>3</td>
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<td>1068</td>
</tr>
<tr>
<td></td>
<td>Paced</td>
<td>120</td>
<td>96</td>
<td>64</td>
<td>0</td>
<td>64</td>
<td>1225</td>
</tr>
<tr>
<td>E.W.</td>
<td>Rest</td>
<td>58</td>
<td>85</td>
<td>51</td>
<td>10</td>
<td>41</td>
<td>918</td>
</tr>
<tr>
<td></td>
<td>Paced</td>
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<td>81</td>
<td>78</td>
<td>0</td>
<td>78</td>
<td>1435</td>
</tr>
<tr>
<td>C.B.</td>
<td>Rest</td>
<td>73</td>
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<td>75</td>
<td>2</td>
<td>73</td>
<td>—</td>
</tr>
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<td>—</td>
<td>85</td>
<td>2</td>
<td>83</td>
<td>—</td>
</tr>
<tr>
<td>R.Y.</td>
<td>Rest</td>
<td>72</td>
<td>—</td>
<td>73</td>
<td>14</td>
<td>59</td>
<td>—</td>
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<td>—</td>
<td>81</td>
<td>12</td>
<td>69</td>
<td>—</td>
</tr>
<tr>
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<td>Rest</td>
<td>73</td>
<td>—</td>
<td>76</td>
<td>26</td>
<td>50</td>
<td>—</td>
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<td>131</td>
<td>—</td>
<td>88</td>
<td>20</td>
<td>68</td>
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</tr>
</tbody>
</table>

Abbreviations: PEP = pre-ejection period; IVCT = isovolumic contraction time; AoDP = aortic diastolic pressure; LVEDP = left ventricular end-diastolic pressure; LVP during IVCT = left ventricular pressure developed during isovolumic contraction (AoDP minus LVEDP); dp/dt max = maximum rate of pressure rise during the isovolumic time (mm Hg/sec).

Figure 4

The pressure events which determine the duration of the left ventricular isovolumic contraction and pre-ejection periods. From left to right in response to atrial pacing, left ventricular end-diastolic pressure fell, aortic or brachial artery diastolic pressure rose, and left ventricular pressure developed during isovolumic contraction.

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period and isovolumic contraction time during atrial pacing, the isovolumic pressure events were found to be changing. An increase occurred in the left ventricular pressure developed throughout the isovolumic time; this was accounted for both by a rise in aortic diastolic pressure and a fall in left ventricular end-diastolic pressure. These observations suggested
that the rate of pressure rise must be accelerating during isovolumic contraction. This impression was confirmed by examination of the differentiated high-fidelity left ventricular pressure pulses in three patients. While it has been noted previously in animal experiments that an increase in the maximum isovolumic dp/dt accompanies the tachycardia induced by atrial pacing, such experiments have been conducted with aortic diastolic and left ventricular end-diastolic pressures (and presumably end-diastolic volume and fiber stretch) held constant.\textsuperscript{5} The increase in dp/dt under these circumstances has been interpreted as a reflection of a chronotropic augmentation in myocardial contractility. In the studies reported in this communication the rate of pressure rise increased despite a fall in end-diastolic pressure and presumably in end-diastolic volume. These data would therefore strengthen the thesis that left ventricular contractile performance in man is indeed enhanced by increasing the heart rate by atrial pacing.

The reasons for the rise in aortic diastolic pressure are not clear but may be related to the diminished stroke volume (table 1) as
well as to a decreased time for diastolic run-off in the aorta and its branches.

The fall in left ventricular end-diastolic pressure presumably reflects a diminished end-diastolic volume as has been suggested by radiographic studies of left ventricular dimensions employing epicardial markers. Such studies have shown a greater reduction in left ventricular end-diastolic size than in endsystolic size, suggesting that systolic emptying of the ventricle is reduced. The diminished filling volume of the left ventricle must therefore be accounted for by factors other than systolic emptying such as a decreased diastolic filling time or a mistimed left atrial systole, reflected in the fusion of the v and a waves seen in the left atrial pressure pulse. The latter mechanism is further supported by an unchanged mean left atrial pressure accompanying the reduction in left ventricular end-diastolic pressure, suggesting a loss of the booster pump action of atrial systole. Thus the loss of an effective atrial systole may be one of the mechanisms which prevents a significant rise in cardiac output when the mechanical performance of the left ventricle is improved during atrial pacing.

Acknowledgment

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References


50 Years Ago
Starling on Cardiac Regulation
Picturesque Language Generated by an Army Environment

Perhaps the most telling and graphic passage in the RAMC lecture relates to the significance which Starling placed upon the work from his own laboratory. He wrote: 'The extraordinary powers with which the heart muscle is endowed represent but the central fortress of the system, and under normal conditions are protected, and, to a large extent, prevented from coming into play by the activities of the defending positions and outposts provided by the central nervous system and its servants. It is only when these other defences fail that the heart is called upon to display those reactions which are at once brought to light in our study of the isolated organ'.—From I. De Burgh Daley: Some aspects of their separate and combined research interests (The Second Bayliss-Starling Memorial Lecture). J Physiol 191: 1, 1967.
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