Dynamic Discharge Characteristics of Low Pressure Receptors in the Rat

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SUMMARY. An in vitro preparation was used to examine the discharge of low pressure receptors in response to a pulsatile pressure stimulus. Both slowly adapting and rapidly adapting receptors were examined. After an increase in the mean level and/or dP/dt of a pulsatile pressure input, the discharge of slowly adapting receptors reached a steady state level within 2 minutes. An increase in mean pressure, with constant pulsatile amplitude and dP/dt, produced a sustained increase in the number of spikes/cycle, in the average number of spikes/second, and in the average frequency during the burst within the cycle. In slowly adapting receptors, an increase in dP/dt at a constant mean pressure and pulsatile amplitude produced a decrease in the number of spikes/cycle and an increase in both the average number of spikes/second and the frequency during the burst. Rapidly adapting receptors showed very different characteristics, responding to a pulsatile pressure input above threshold with an irregular discharge which averages approximately 1 spike/cycle at all mean pressure levels. Although rapidly adapting receptors transiently increased their discharge in response to an increase in mean pressure, within 60 seconds discharge returned to the pre-increase level. Rapidly adapting receptors continued to discharge with an average of 1 spike/cycle as dP/dt was increased. Since dP/dt was raised by increasing the frequency of the pulsatile input, the number of spikes/second increased. In the steady state, slowly adapting receptors transmit information reflecting mean pressure levels. They are also sensitive to the rate of change of pressure. Rapidly adapting receptors, on the other hand, are insensitive to mean pressure but do respond to the frequency of the stimulus. (Circ Res 55: 660–668, 1984)

ATRIAL receptors normally are exposed to a pulsatile pressure wave. Therefore, knowledge of their dynamic discharge characteristics is critical to an understanding of the information these receptors send the central nervous system. The atrial pressure waveform reflects the filling and emptying sequence of the atria, as well as its contraction. These waveforms are superimposed on other lower frequency components which result from changes in atria volume due to respiratory fluctuations of intrathoracic pressure and changes in venous return. To what extent are the receptors sensitive to the rate of change of pressure (dP/dt), and over what mean pressure range?

Unfortunately, it is difficult to answer this question in vivo studies, because one cannot simultaneously control the mean level, amplitude, rate of change, or frequency of the pressure stimulus. In vitro studies applying stretch to atrial strips containing receptors have partially overcome these problems (Arndt et al., 1974; Chapman and Pankhurst, 1976). However, the results in that type of in vitro study are difficult to relate to physiological parameters such as threshold pressure and sensitivity to suprathreshold pressure. Such studies also distort in vivo geometry which might alter discharge characteristics.

In this study we report an in vitro preparation in which the discharge of low pressure mechanoreceptors located at the junction of the superior vena cava and the right atrium can be recorded under steady state conditions free of the complex atrial pressure pulse. In this system, the mean level, amplitude, and frequency of a phasic pressure wave can be varied independently. Earlier, we differentiated a slowly (SA) and a rapidly (RA) adapting class of receptor on the basis of the response to a step increase in pressure (Mifflin and Kunze, 1982). Using this preparation, we have now quantified the steady state responses of these receptors to a phasic pressure wave in order to determine the variables which these receptors may monitor in vivo and the information which is transmitted to the central nervous system.

This study examined two aspects of the dynamic response characteristics of atrial receptors: (1) the effects of changes in dP/dt at a given mean pressure as a measure of the dynamic sensitivity of the receptors, and (2) the effects of dP/dt at varying mean pressures to assess the pressure range over which dP/dt is effective.

Methods

The dissection and in vitro perfusion system have been described in detail (Mifflin and Kunze, 1982). Briefly, the
left superior vena cava (SVC) of 15- to 20-week-old Sprague-Dawley rats was cannulated between the azygos vein and the junction of the left SVC and the right atrium. This was done in vivo to maintain geometry of preparation as much as possible when removed from the animal. The vessel was excised with its innervation intact and perfused with warmed, oxygenated Krebs-Henseleit solution to maintain viability. Pressure waves of desired form, frequency, amplitude, and mean level could be applied and independently controlled by a function generator connected to a shaker pot (Ling) and bellows (Robert-Shaw, Inc). The frequency response of the in vitro perfusion system between the vessel and the pressure transducer was determined by the free vibration, or "balloon pop," method (McDonald, 1974) and was found to be 25–30 Hz with a damping coefficient of 0.06.

The discharge of single mechanoreceptor units with afferent fibers in the vagus nerve was recorded with a pair of platinum iridium wire electrodes. The data were stored on a tape recorder. An off-line computer (PDP 11/70) calculated the instantaneous frequency of discharge as the reciprocal of the interspike interval. Instantaneous frequency and pressure were plotted as a function of time on a Versatec (model 1100) printer plotter. Where frequencies of a group of fibers are averaged, values are expressed as mean ± SE.

There is a fairly linear, ramp-like increase in atrial pressure and diameter as the atria passively fill during the v-wave (Recordati et al., 1974, 1975). In the rat, atrial receptors have been reported to discharge only during the rising phase of the v-wave (Thorén et al., 1979). Therefore a similar waveform, a triangle pressure wave, was chosen as the stimulus input. Random step increases in the mean level of a 2.5 mm Hg triangle pressure wave were made from 0 mm Hg to 3.8 mm Hg (maximum/minimum = 5.0/2.5), 6.3 mm Hg (maximum/minimum = 7.5/5.0), or 8.8 mm Hg (maximum/minimum = 10.0/7.5). The frequency of the pressure wave was varied between 0.05 and 20.0 Hz, while amplitude was held constant. This produced a range of dP/dt's from 0.25 to 100 mm Hg/sec at each dP/dt, a mean level of 3.8, 6.3, or 8.8 mm Hg was tested. Measurements were made 2 minutes after the dp/dt or mean pressure was adjusted to the test level. After each test period, perfusion pressure was lowered to 0 mm Hg for 2 minutes before the next dp/dt and/or mean pressure was applied. This was done to reverse any acute resetting effects (Mifflin and Kunze, 1982). The mean pressures and dp/dt values were chosen to include the range the receptors were likely to encounter in vivo. For example, mean transmural right atrial pressure under normal conditions can range from 2 to 5 mm Hg. Values of 8–11 mm Hg may be reached after volume loading and 0–3 mm Hg following hemorrhage. dP/dt during the v-wave ranges from 5 to 15 mm Hg/sec in mammals with a slower heart rate, such as cats (calculated from records of Recordati et al., 1974, 1975), to 15–35 mm Hg/sec in mammals with a more rapid rate, such as rats (calculated from records of Thorén et al., 1979). This protocol and set of stimulus parameters were used to study both slowly and rapidly adapting receptors.

There are several parameters which can be used to describe discharge in response to a pulsatile stimulus. As will be shown, discharge was cyclic; therefore, the discharge grouped within a given cycle can be examined or discharge can be averaged over several cycles to give an average discharge rate. We calculated the average number of spikes/second (the product of spikes/cycle and stimulus frequency) as an indication of mean discharge over time. We also examined several parameters during the cycle which reflect grouping of the spikes. These included (1) duration of the burst of periodic discharge measured as the time between the first and last spike in a cycle, (2) the average frequency of discharge during the burst (Fburst of the cycle) which was calculated as the number of spikes/cycle divided by the duration of the burst and represents the average frequency during the burst, and (3) the number of spikes/cycle.

**Results**

In the rat, there are two classes of low pressure receptor based on the response to static stimuli—slowly and rapidly adapting. Fiber discharge of each
Effects of Step Changes in Mean Pressure at Constant Pulsatile Amplitude and dP/dt

Slowly Adapting Receptors

The response to a triangular waveform was a cyclic burst. This is illustrated in Figure 1a, where the discharge of a single slowly adapting fiber is shown at three mean pressures with constant pulse amplitude and dP/dt. The instantaneous frequency of the same fiber is plotted corresponding to the digitized pressure input (Fig. 1b). In response to an increase in mean pressure, discharge increased to a peak value and then subsided to a new steady state value within 2 minutes. This was similar to what occurs in response to an increase in mean pressure of a nonpulsatile input (Mifflin and Kunze, 1982). The transient phase was not studied, as the rise time of the increase in pressure was often several seconds.

Discharge was measured 2 minutes after each increase in mean pressure at each of the dP/dt values. As mean pressure was increased, there were changes in the grouping of the spikes. The number of spikes/cycle and the duration of the burst in a cycle increased as mean pressure was increased at any dP/dt less than 36 mm Hg/sec with a more pronounced increase at lower dP/dt values (Fig. 2, a and b). Mean and standard deviations of discharge parameters are given in Table 1. The frequency during the burst also increased with increasing mean pressure (Fig. 2c). However, at 36 mm Hg/sec or greater (and at 25 mm Hg/sec, 3.8 mm Hg mean pressure), the receptors discharged with only 1 spike/cycle, and increases in mean pressure did not increase the number of spikes/cycle or, thus, burst duration. The average frequency (spikes/sec) measured over several cycles is plotted in Figure 2d. The slope of the curves between 3.8 and 6.3 mm Hg mean levels of pressure were similar below 36 mm Hg/sec. At a dP/dt of 5 mm Hg/sec, the gain of individual SA receptors between the mean pressures
TABLE 1
Effects of Changes in Stimulus Frequency and dP/dt on the Discharge of Slowly Adapting Receptors (n = 6)

<table>
<thead>
<tr>
<th>Mean pressure</th>
<th>Frequency (Hz)/dP/dt (mm Hg/sec)</th>
<th>Spikes/cycle</th>
<th>Spikes/sec</th>
<th>Duration burst (sec)</th>
<th>Fburst cycle (spikes/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>20/100</td>
<td>1.0 ± 0</td>
<td>20 ± 0</td>
<td>17.6 ± 3.1</td>
<td>6.1 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>10/50</td>
<td>1.0 ± 0</td>
<td>10 ± 0</td>
<td>13.1 ± 2.1</td>
<td>9.9 ± 1.1</td>
</tr>
<tr>
<td></td>
<td>7/36</td>
<td>1.0 ± 0</td>
<td>7 ± 0</td>
<td>2.47 ± 0.060</td>
<td>7.4 ± 0.8</td>
</tr>
<tr>
<td></td>
<td>5/25</td>
<td>1.2 ± 0.2</td>
<td>3.6 ± 0.6</td>
<td>2.9 ± 0.3</td>
<td>13.1 ± 1.1</td>
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<td></td>
<td>3/15</td>
<td>2.9 ± 0.3</td>
<td>2.9 ± 0.3</td>
<td>0.021 ± 0.030</td>
<td>15.6 ± 3.1</td>
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<td>1/5</td>
<td>4.8 ± 0.4</td>
<td>2.4 ± 0.2</td>
<td>0.477 ± 0.060</td>
<td>9.9 ± 1.1</td>
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<td>0.5/2.5</td>
<td>18.2 ± 2.8</td>
<td>1.8 ± 0.3</td>
<td>2.459 ± 0.130</td>
<td>7.4 ± 0.8</td>
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<td></td>
<td>0.1/0.5</td>
<td>30.4 ± 3.6</td>
<td>1.5 ± 0.2</td>
<td>4.980 ± 0.460</td>
<td>6.1 ± 0.5</td>
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<tr>
<td>6.3</td>
<td>20/100</td>
<td>1.0 ± 0</td>
<td>20 ± 0</td>
<td>24.5 ± 2.8</td>
<td>7.8 ± 1.2</td>
</tr>
<tr>
<td></td>
<td>10/50</td>
<td>1.0 ± 0</td>
<td>10 ± 0</td>
<td>22.7 ± 3.3</td>
<td>13.8 ± 1.8</td>
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<tr>
<td></td>
<td>7/36</td>
<td>1.0 ± 0</td>
<td>7 ± 0</td>
<td>1.043 ± 0.110</td>
<td>8.9 ± 1.3</td>
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<td></td>
<td>5/25</td>
<td>1.8 ± 0.2</td>
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<td>17.2 ± 2.5</td>
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<td>3/15</td>
<td>2.9 ± 0.1</td>
<td>8.7 ± 0.3</td>
<td>0.128 ± 0.027</td>
<td>15.640 ± 0.970</td>
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<td>8.3 ± 0.3</td>
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<td>2.459 ± 0.130</td>
<td>6.1 ± 0.2</td>
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<td>14.4 ± 0.7</td>
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<td>7.8 ± 1.2</td>
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<td>0.1/0.5</td>
<td>64.3 ± 2.2</td>
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<td>0.05/0.25</td>
<td>122 ± 3</td>
<td>6.1 ± 0.2</td>
<td>15.640 ± 0.970</td>
<td>8.9 ± 1.3</td>
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<tr>
<td>8.8</td>
<td>20/100</td>
<td>1.0 ± 0</td>
<td>20 ± 0</td>
<td>25.9 ± 3.1</td>
<td>19.5 ± 2.4</td>
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<tr>
<td></td>
<td>10/50</td>
<td>1.0 ± 0</td>
<td>10 ± 0</td>
<td>25.9 ± 3.1</td>
<td>16.1 ± 2.0</td>
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<tr>
<td></td>
<td>7/36</td>
<td>1.4 ± 0.2</td>
<td>9.8 ± 1.4</td>
<td>25.9 ± 3.1</td>
<td>9.7 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>5/25</td>
<td>2.0 ± 0</td>
<td>10 ± 0</td>
<td>25.9 ± 3.1</td>
<td>9.7 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>3/15</td>
<td>3.2 ± 0.2</td>
<td>9.6 ± 6</td>
<td>25.9 ± 3.1</td>
<td>9.7 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>1/5</td>
<td>10.0 ± 0</td>
<td>10.0 ± 0</td>
<td>25.9 ± 3.1</td>
<td>9.7 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>0.5/2.5</td>
<td>20.5 ± 1.8</td>
<td>10.1 ± 0.9</td>
<td>25.9 ± 3.1</td>
<td>9.7 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>0.1/0.5</td>
<td>95.5 ± 4.2</td>
<td>9.5 ± 0.4</td>
<td>25.9 ± 3.1</td>
<td>9.7 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>0.05/0.25</td>
<td>170 ± 7</td>
<td>8.4 ± 0.4</td>
<td>25.9 ± 3.1</td>
<td>9.7 ± 1.6</td>
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</tbody>
</table>

Results are expressed as mean ± se.

3.8 and 6.3 mm Hg ranged from 3 to 7 spikes/sec per mm Hg (mean = 5.8 ± 0.6 spikes/sec per mm Hg). At 8.8, the discharge tended toward saturation at 10 spikes/sec until a dP/dt was reached ≥50 mm Hg/sec where it was only 1 spike/cycle. At most values of dP/dt, there is a decrease in slope of the pressure frequency curves between 6.3 and 8.8 mean pressure. This is not unexpected, as it is in this range that static pressure frequency curves begin to show saturation (Mifflin and Kunze, 1982).

In summary, there are increases in both average discharge frequency over several cycles and the frequency within the cyclic burst in slowly adapting receptors in response to an increase in the mean level of a pulsatile pressure. The receptors are most sensitive between the mean pressure of 3.8 and 6.3 mm Hg. At dP/dt levels of 36 mm Hg/sec or greater, when slowly adapting receptors discharge only once per cycle, they no longer change their firing frequency with changes in mean pressure.

Rapidly Adapting Receptors

The responses of a rapidly adapting receptor at three different mean pressures are shown in Figure 3a. These receptors did not discharge when the vessel was perfused at a mean pressure of 0 mm Hg, but there was sustained discharge, albeit irregular and low frequency, when the mean pressure was increased to 3.8 mm Hg. However, further increases in the mean pressure only transiently increased discharge, and by 60 seconds, discharge had returned to the same level, whether mean pressure was 3.8, 6.3, or 8.8 mm Hg. The lack of effect of mean pressure on discharge of four rapidly adapting fibers is shown in Figure 4. Thus, elevations in mean pressure produced no increase in spikes/second (measured 60 seconds after the increase in mean pressure) in rapidly adapting receptors, once the mean level was above the level necessary to maintain the irregular discharge characteristic of these receptors. Since, 60 seconds after an increase in mean pressure, rapidly adapting receptors discharged with approximately 1 spike/cycle, the definitions of Fburst and burst duration are not meaningful in describing the discharge of these receptors. In summary, in the steady state situation, rapidly adapting receptors are capable only of informing the central nervous system if mean pressure is above threshold for their discharge; their signal is not related to the value of the mean pressure.

Effects of dP/dt at Different Mean Pressures

The data just presented can also be examined as a function of dP/dt at each given mean level to visualize better the effects of dP/dt on receptor discharge.
FIGURE 3. The discharge of a rapidly adapting fiber is illustrated in the top set of traces (panel a) at mean pressures of 3.8, 6.3, and 8.8 mm Hg in response to a triangular waveform 2.5 mm Hg at 1/sec. The lower part (panel b) represents the instantaneous frequency in relation to the digitized pressure trace.

Slowly Adapting Receptors

The effect of dP/dt at each of the three mean pressures is illustrated in Figure 5. The modulation of discharge within each cycle was influenced by dP/dt. In slowly adapting receptors (n = 6), the total number of spikes/cycle decreased as dP/dt was increased by increasing the stimulus frequency and fell to 1 spike/cycle at 25–36 mm Hg/sec (Fig. 5a). Since amplitude was held constant, this may reflect the decreased duration of the rising phase of the pressure wave. The receptors continued to discharge with 1 spike/cycle, regardless of the mean pressure level up to the highest dP/dt value tested (100 mm Hg/sec). The duration of burst decreased as dP/dt increased, reflecting the decreasing number of spikes/cycle (Fig. 5b). The frequency during the burst was increased as dP/dt increased (Fig. 5c), indicating a dynamic sensitivity.

At the two lower mean pressures, the average frequency increased as dP/dt increased (Fig. 5d). At the highest mean pressure, there was an increase only at the lowest dP/dt values. Thus, changes in dP/dt are not very effective in altering the average frequency from the receptors at the higher mean atrial pressure. At the point at which the receptors discharge with only 1 spike/cycle (indicated by arrows), the relationship between dP/dt and spikes/second in a cycle reflects only the increase in stimulus frequency. When values of dP/dt that evoke more than one spike/cycle are used, a linear relationship between average frequency and log dP/dt is described by spikes/sec = 1.15 log dP/dt + 2.12 at a mean pressure of 3.8 mm Hg and spikes/sec = 1.52 log dP/dt + 6.91 (r² = 0.98 and 0.97, respectively).

Rapidly Adapting Receptors

The responses of rapidly adapting receptors (n = 6) to increases in dP/dt differed markedly from those of slowly adapting receptors. The discharge declined within 60 seconds to a frequency determined by the number of spikes/cycle and the stimulus frequency. The average number of spikes/cycle remained approximately 1 spike/cycle, and was unchanged as dP/dt was increased in three of the six rapidly adapting receptors. In the other three, rapidly adapting receptors at dP/dt of less than 1 mm Hg/sec several spikes were seen; however, as dP/dt increased above 1 mm Hg/sec, these, too, decreased to approximately 1 spike/cycle. This is reflected in the averaged data of Figure 6, which gives the

FIGURE 4. This figure illustrates the lack of response of four rapidly adapting receptors to increases in mean pressure. This was compiled from data of experiments of the type presented in Figure 3.
number of spikes/cycle in relation to dP/dt. Thus, in the physiological range of v-wave pressures, the rapidly adapting receptors were indistinguishable from each other.

As dP/dt increased, the average number of spikes/second increased (Fig. 7). Since the number of spikes/cycle was generally 1 averaged over 10 cycles, the apparent increase in spike frequency simply reflects the increase in stimulus frequency (spikes/second = spikes/cycle × stimulus frequency). As expected, the curves for two mean pressures are not different, since the discharge of these receptors has no mean component in the steady state. Four of the six rapidly adapting receptors followed a frequency of 7–10 Hz with 1 spike/cycle, whereas the discharge of the remaining two receptors continued with 1 spike/cycle to at least 20 Hz, equal to that of the slowly adapting receptors.
There was a minimum dP/dt below which discharge could not be elicited. In four rapidly adapting receptors, no discharge occurred at a dP/dt less than 0.20 mm Hg/sec, and in the remaining two receptors, a dP/dt of greater than 0.15 mm Hg/sec was required.

In summary, rapidly adapting fibers respond to dynamic stimulus; however, since they usually respond with only 1 spike/cycle, the discharge reflects the fact that a dynamic input has occurred. It is not related to the value of dP/dt, but is related to the increase in frequency accompanying increasing dP/dt.

Discussion

There are several parameters which one can use to describe receptor discharge in response to a pulsatile stimulus, and it is still uncertain as to what is important to the central nervous system. The average number of spikes/second is an index of the average input to the central nervous system per unit time. There is some evidence that the average number of spikes/second is the information important centrally in the depressor reflex of anesthetized rabbits (Douglas et al., 1956). That report showed that the fall in blood pressure in response to electrical stimulation of the aortic nerve depended mainly on the total number of shocks applied in a 3-minute period, and very little on the pattern in which they were applied. However, Richter et al. (1970) found that adaptation within medullary neurons responding to carotid sinus nerve stimulation in anesthetized dogs was greater in response to continuous as opposed to grouped stimuli, and that intermittent stimulation produced greater reflex effects than did continuous stimulation, a conclusion supported by a study of the carotid sinus reflex of anesthetized cats (Kendrick et al., 1973). Thus, other indices of spike discharge which reflect the grouping of impulses may also be relevant. Such studies using low pressure receptors have not been done. The grouping of impulses within a burst indicates the frequency at which these impulses arrive at a central synapse, and is important, considering that excitatory postsynaptic potentials can summate temporally. Although we have described the changes in the grouping which occur with changing dP/dt and mean pressure, it is premature to speculate on the importance of such grouping. To resolve such questions will require a more detailed knowledge of the central components of cardiovascular reflexes than is presently available.

The division of low pressure receptors in the rat into a slowly and a rapidly adapting class is warranted in describing the responses to a step increase in either a static pressure or a pulsatile pressure. There is a steady state component to the discharge of slowly adapting receptors dependent on the mean pressure level. At any dP/dt less than 36 mm Hg/sec, this steady state component of the discharge is increased in response to an increase in mean pressure. At dP/dt levels greater than 36 mm Hg/sec, slowly adapting receptors only transmit information on the frequency; however, functionally, this probably is not important, since such high dP/dt levels rarely are reached in vivo. In addition, a dynamic component also operates in the pulsatile steady state to determine receptor discharge. This is seen as the average instantaneous frequency increases during the burst when dP/dt increases over the physiological range. This information provided to the central nervous system (CNS) on the rate of change of the atrial v-wave could be offset by the decrease in the number of spikes and the duration of the burst. Slowly adapting receptors appear to function as do atrial type B receptors reported in other species (Paintal, 1953; Kappagoda et al., 1972; Gilmore and Zucker, 1974).

Following a step increase in the mean level of a pulsatile pressure, the discharge of rapidly adapting
receptors returns to the pre-increase level within 60 seconds. This explains why the rapidly adapting feature has previously been overlooked, because discharge usually was measured within 30 seconds after a pressure increase, while discharge was still elevated. The steady state component of receptor discharge is very low frequency, and not dependent on the mean pressure level; therefore, rapidly adapting receptors can only transiently provide the CNS information regarding a change in mean pressure. These receptors could be important in signaling a decrease in atrial volume below a particular level. This is because cessation of discharge when transmural pressure falls below the threshold (on the average, 4 mm Hg) would remove their input to medullary centers. Rapidly adapting receptors discharge with approximately 1 spike/cycle throughout most of the in vivo range of stimulus frequencies. Therefore, they can also provide information about the frequency of pulsation similar to Pacinian corpuscle, cutaneous mechanoreceptors, which also rapidly adapt following static stimuli, yet follow stimulus frequencies of up to 100 Hz with 1 spike/ cycle (Lowenstein, 1971). Rapidly adapting receptors could perform a function similar to that postulated for atrial type A receptors in other species (Paintal, 1953; Arndt et al., 1971). However, the rapidly adapting receptors in the rat are stimulated by passive stretch, whereas type A receptors are stimulated by atrial contraction.

In vivo, the v-wave is superimposed upon a lower frequency respiratory fluctuation in atrial transmural pressure, and these fluctuations alter receptor discharge (Paintal, 1963; Thames et al., 1977). The low frequency pressure waves we examined provide clues on how such respiratory fluctuations in atrial transmural pressure will affect discharge. Discharge on the descending limb of a cycle is always less than that measured on the ascending limb—therefore, discharge during the v-wave may be expected to be greater during inspiration as atrial transmural pressure is increasing. During expiration, as transmural pressure is falling, discharge will be less than if the v-wave were the only component of the transmural pressure trace. Slow changes in venous return would be expected to influence discharge similarly.

Whatever the mechanisms underlying the discharge characteristics of slowly adapting and rapidly adapting receptors, the end result is that there will be differences in the information each class of receptor sends to the central nervous system. An interesting aspect of this distinction is that experiments could now be designed to exploit these differences and selectively stimulate only one group of afferent fiber. For example, any reflex effect which persists for longer than 60 seconds after an increase in mean atrial pressure at a constant dP/dt can be attributed to slowly adapting receptors, since the discharge of rapidly adapting receptors will return to the pre-increase level within this time. This approach has recently proven useful in determining the individual reflex effects of groups la, lb, and II muscle spindle afferents in the cat (Binder et al., 1982).

Receptors such as aortic baroreceptors which are attached to unmyelinated fibers have been shown to have a low dynamic sensitivity, such as the receptors in this study show (Brown et al., 1978). We were unable to obtain conduction velocities for these fibers because of the short length of the nerve (1 cm). However, we feel, for the following several reasons, that both classes of fibers recorded in the study have unmyelinated axons which might explain their low dynamic sensitivity: (1) Thoren et al. (1979) were unable to find atrial receptors in the rat with fibers conducting in the myelinated range, (2) Kaufman et al. (1981) were unable to locate complex unencapsulated nerve endings in this area, and (3) the dP/dt values between 25 and 36 mm Hg/sec correspond to stimulus frequencies of 5–7 Hz. At this range of frequencies, the number of spikes/cycle at all mean pressures is 1 per cycle. These values compare to those of unmyelinated aortic baroreceptors, which also begin to fire at 1/cycle at these frequencies, while myelinated baroreceptors still discharge with between 4 and 10 spikes/cycle (Brown et al., 1978). At 8 Hz, atrial myelinated fibers also still fire several spikes/cycle (Arndt et al., 1974). Coloridge et al. (1973) have described slowly conducting atrial fibers in cats which have an irregular sparse discharge that resembles the discharge of rapidly adapting fibers described here. Thoren (1976) also has described low frequency discharging receptors in the cat with conduction velocities in the unmyelinated range. Atrial receptors connected to unmyelinated fibers are thought to be responsible for the reflex depression in arterial pressure, heart rate, and renal sympathetic nerve activity that results from increasing atrial volume or pressure (for review, see Thoren, 1979). Kaufman et al. (1981) have shown a reflex increase in heart rate upon stretching the superior vena cava in the rat. One of the groups of fibers described here might contribute to this response. The type of stimulus used, a sustained distension of the vena cava for several minutes, would suggest activation of the slowly adapting group.

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References


Kappagoda CT, Linden RJ, Snow HM (1972) The effect of stretching the superior vena caval-right atrial junction on right atrial receptors in the dog. J Physiol (Lond) 227: 875–887


Paintal AS (1953) A study of right and left atrial receptors. J Physiol (Lond) 120: 596–610

Paintal AS (1963) Natural stimulation of Type B atrial receptors. J Physiol (Lond) 169: 116–136


Thames MD, Donald DE, Shepherd JT (1977) Behavior of cardiac receptors with nonmyelinated vagal afferents during spontaneous respiration in cats. Circ Res 41: 694–701


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