A Comparison of Aortic Baroreceptor Discharge in Normotensive and Spontaneously Hypertensive Rats

ARTHUR M. BROWN, M.D., PH.D., WILLIAM R. SAUM, PH.D., AND FLOYD H. TULEY, PH.D.

SUMMARY Electrophysiological characteristics of individual aortic baroceptors from normotensive rats (NTR) and spontaneously hypertensive rats (SHR) were compared. Impulse activity of all fibers was examined following the application of pressure steps to an in vitro aortic arch-aortic nerve preparation. Thirty-one fibers including seven unmyelinated fibers were studied completely over the range of 0-260 mm Hg, using steps 1-30 seconds in duration. The pressure threshold for peak transient discharge of baroceptors of SHR was 88.4 ± 10.1 (mean ± SE) mm Hg, whereas for baroceptors of NTR it was 77.5 ± 9.3 mm Hg. The pressure threshold for steady state discharge was 137.3 ± 5.2 mm Hg for SHR baroceptors and 103.5 ± 7.1 for NTR baroceptors. These values compare favorably to measurements in vivo in the rat. The relationship between peak transient impulse frequency and pressure was linear, whereas the relationship between steady state impulse frequency and pressure was hyperbolic. The curvature of the steady state frequency-pressure curves was significantly reduced for baroceptors of SHR. The steady state pressure-volume curves of the aortas of SHR’s and NTR’s were similar, so that a reduction in distensibility could not account for the larger, significant differences in threshold and sensitivity. Therefore resetting cannot be attributed simply to reduced vascular compliance.

IT IS WELL KNOWN that baroceptors have higher pressure thresholds in dogs with experimental renal hypertension. With multifiber recording techniques, these findings have been confirmed in the dog and extended to the rabbit and rat. The resetting was attributed to reduced distensibility of the vessels in which the receptors were located, although changes in the receptors themselves have not been excluded. Recently, Angell-James has reported that the pressure threshold was elevated in rabbits with chronic renal hypertension and that sensitivity measured as the slope of the linear portion of the steady state impulse frequency-pressure curves was reduced. She concluded that resetting was associated with either alterations in the mechanical properties of the arterial wall or changes in the receptors themselves.

The present study was undertaken to compare the physiological characteristics of aortic baroceptors from normotensive (NTR) and spontaneously hypertensive (SHR) rats. We chose the rat as our experimental animal because (1) certain strains have been bred which develop hypertension spontaneously, (2) a wide variety of experimental methods for inducing hypertension in this species have been introduced, and (3) neural discharge of aortic and carotid sinus baroceptors has been recorded in anesthetized, NTR’s and SHR’s. We developed an in vitro aortic arch-aortic nerve preparation to record single unit responses of myelinated and unmyelinated afferent fibers to varying pressure steps. We found that the steady state pressure thresholds were significantly higher in SHR’s and the curves relating steady state baroreceptor discharge to pressure were well fitted by rectangular hyperbolas. The curvature of the hyperbolas was significantly lower in SHR’s. Since the steady state aortic arch distensibility was similar between the two groups, increased stiffness of the aortic wall cannot be responsible for these differences. We also identified a group of rapidly adapting baroceptors which did not sustain a steady state discharge even at pressures of 260 mm Hg. Aortic baroceptors from both groups of rats showed adaptation and postexcitatory depression, and these phenomena are further examined in the next paper.

Methods

Experiments were performed on NTR’s (Wistar-Lewis strain, 300-400 g) and SHR’s (Okamoto-Aoki strain, 250-350 g) of either sex and 4-6 months old. For several days prior to an experiment, systolic blood pressure was measured by an indirect tail method. The rats were prewarmed in a heating chamber to 37°C. A programmed electrophysiogrammanometer was placed around the rat tail to obtain pressure and audio signals which were recorded on a Physiograph (Narco Bio-Systems) paper recorder. Five to ten pressure readings were obtained over a 10-minute period and the average value was taken as the pressure for that day.

ISOLATION AND PERFUSION OF AORTIC ARCH

The rats selected for study were anesthetized with sodium pentobarbital (Nembutal, 30-40 mg/kg) administered intraperitoneally after initial induction with ether. The trachea was cannulated and the rats were ventilated artificially with a positive-pressure respirator. A midline thoracotomy was performed and the ascending aorta, the right and left subclavian arteries, and the right and left common carotid arteries were prepared for subsequent ligation. A dissecting microscope at 8x magnification was used for visualization, and the left aortic nerve was freed from connective tissue on the surface of the aortic arch, dissected proximally for 1-2 cm, and cut. The brachiocephalic trunk and the descending aorta at the level of the left atrium were cannulated in a retrograde manner with stainless steel cannulas (outside diameter = 1.42 mm), and the isolated segment was excised.

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and pinned out in a plexiglass chamber (Fig. 1). The aortic arch was perfused with a Krebs-Henseleit solution through the descending aorta and the effluent was drained out via the brachiocephalic trunk. The perfusate had the following composition: NaCl, 120 mM; KCl, 4.8 mM; MgSO₄, 1.2 mM; CaCl₂, 1.1 mM; KH₂PO₄, 1.2 mM; NaHCO₃, 25 mM; dextrose, 5.5 mM. The solution was saturated with 95% oxygen and 5% carbon dioxide to give a final pH of 7.35–7.45. The flow through the preparation could be varied between 5 and 12 ml/min by adjusting the flow rate of a Holter infusion pump. The aortic arch and aortic nerve were covered with warmed mineral oil. The chamber and the perfusate were maintained between 37°C and 38°C by means of a thermostatically controlled heater pump system.

Pressure steps of varying amplitude (0–260 mm Hg) and duration (3 seconds to 3 minutes) were applied singly or in combinations from separate mercury manometers to the aortic arch (Fig. 1). The manometers were connected to the inflow cannula via electrically activated solenoid valves. The aortic arch pressure was measured from a side arm of the inflow cannula with a strain gauge pressure transducer (Statham P23Db) and the cannula and transducer had a flat (±5%) frequency response of 25 Hz. The pressure steps had rise and fall times of approximately 100 msec over the entire range of pressures examined. The pressure signal was displayed on an oscilloscope and recorded on an FM tape recorder (Hewlett-Packard 3960A).

ELECTROPHYSIOLOGICAL MEASUREMENTS

Slips of baroreceptor fibers were teased from the left aortic nerve and mounted on platinum-iridium electrodes. Dissection continued until one or two identifiable units were obtained. The action potentials were recorded with a high gain (25,000×) capacitance-coupled amplifier (Princeton Applied Research, model 113) and displayed on an oscilloscope. The output from the amplifier was also led to an audio monitor and an FM tape recorder. Permanent records were made on 35-mm photographic film with a Grass Kymograph camera. Conduction velocities of the whole nerve trunk and of single units were determined by applying rectangular pulses 0.05–0.1 msec in duration through a second pair of platinum-iridium bipolar electrodes placed on the more peripheral part of the nerve trunk. In some experiments the position of the stimulating electrodes was changed by a fixed amount and conduction velocity was determined from the new latency. Units were identified by equivalencies in amplitude and duration during mechanical and electrical stimulation and by occlusion of the electrically evoked potentials during supramaximal pressure stimuli (Fig. 2).

DATA ANALYSIS

An off-line computer system (PDP 11/40) was used to digitize the signals recorded on analog tape. Hard copy plots of instantaneous impulse frequency which we define as the reciprocal of the period between two successive action potentials were made on a Versatec (model 1100) printer-plotter. Isochronal frequency-pressure curves were also computed. Curves were fitted using a nonlinear least squares program with a precision of 1% on the PDP 11/40 computer. This processing is done in several stages as described below. The digitizing program has two analog...
inputs: the input of action potentials and the pressure stimulus input. The nerve signal is digitized continuously at a specified sampling interval of 70 μsec. When the amplitude of an action potential exceeds a threshold level set by a Schmitt trigger, 82 points characterizing the action potential, the interspike interval, and the amplitude of the pressure at that instant are sent to the output buffer. The 82 points include 32 before the amplitude threshold is crossed and 50 afterward, so that the entire spike is adequately characterized. When the output buffer accumulates 50 spikes its contents are written on digital magnetic tape in a "raw data" format. Although the transfer to tape occurs simultaneously with continued spike collection, one or two spikes will be lost while the transfer is initiated. The "raw data" digital tape is converted to a Fortran binary file compatible with the operating system. This file may be stored on a disk pack or on magnetic tape.

If the nerve signal contained 2–3 different impulses, a program enabled the experimenter to select the action potentials generated by a single fiber, the time intervals between the selected spikes, and the instantaneous pressure. A CRT digital display was used to compare the spike of interest and any later spike, as well as the interspike interval. After establishing criteria for categorizing the spikes based on spike amplitude, duration, and shape, the experimenter used push-button controls to move forward and backward in time through the binary file until he found the next sequential spike from the same fiber. The selected spikes were saved on a new file in the same Fortran binary format.

**HISTOLOGY**

Histological studies to determine the fiber population of the left aortic nerve were performed in two NTR's. The left aortic nerve was dissected from the aortic arch proximally for 1 cm, fixed in a 3% gluteraldehyde solution and postfixed in a 1% OsO₄ solution for 1–2 hours. After dehydration the preparation was embedded in an epoxy resin mixture. Thick sections (0.5–1.0 μm) were made of the plastic-embedded nerves and stained with methylene blue-azure II stains. The myelinated fibers could easily be recognized with the light microscope; however, because of their small size the unmyelinated fibers were identified with the transmission electron microscope (Phillips EM 201). Thin sections (500–600 Å) were made with the use of diamond knives and an Ivan Sorvall MT-2B ultramicrotome and these sections were then mounted on 300-mesh Athene grids and stained with lead citrate and uranyl acetate.

**Results**

**CONDUCTION VELOCITIES OF AORTIC BARORECEPTOR FIBERS**

The aortic nerve of the rabbit and cat contains both myelinated and unmyelinated afferent fibers, but the composition is unknown in the rat. In two experiments the aortic nerve was stimulated with a separate pair of bipolar electrodes and the compound action potential was recorded. The conduction velocities of the different waves of the evoked compound action potential were calculated by measuring the interval between the beginning of the stimulus artifact and each wave (Fig. 2). The earliest wave which could be distinguished from the artifact had the lowest threshold and had conduction velocities of 21.5–22.5 m/sec. This wave is, therefore, due to propagation through myelinated fibers. At higher voltages, 1–6 waves appeared and several were all-or-none in nature. Their conduction velocities ranged from 3–12 m/sec and these waves are probably due to propagation through thinly myelinated Aδ afferents although preganglionic myelinated B fibers may make some contribution. At still higher voltages, large, slowly conducting waves having conduction velocities of 0.5–2 m/sec appeared. These waves are due to propagation through unmyelinated or C fibers which may be afferent or efferent.

In seven fibers the conduction velocities ranged from 0.6 to 2 m/sec (mean = 1.1 ± 0.1 m/sec), indicating that they were C fibers (Fig. 2, C₁-C₆). Similar conduction velocities were calculated when the stimulating electrodes were moved to a fixed distance. Three fibers had conduction velocities of 10, 20, and 25 m/sec, indicating that they were myelinated fibers. In five experiments the conducted action potentials were obscured by the stimulus artifact, indicating high conduction velocities. In the remaining experiments the length of nerve was too short for accurate measurements or the measurements were not performed.

**HISTOLOGICAL OBSERVATIONS OF THE AORTIC NERVE**

Histological examination of cross sections from the aortic nerve confirmed our electrophysiological findings. Thus, we observed thickly and thinly myelinated fibers and a large group of unmyelinated fibers. The myelinated fibers had diameters of 1.5–6.5 μm and were located primarily at the periphery of the nerve trunk (Fig. 3A). On the other hand, the unmyelinated axons with diameters of 0.25–0.9 μm were grouped in bundles surrounded by Schwann cell sheaths and...
were dispersed throughout the cross section of the nerve fiber (Fig. 3B).

RESPONSES OF BARORECEPTORS TO STEPS OF PRESSURE

The effects of a series of square wave pressure steps upon the discharge of single baroreceptor fibers were examined over the range of 0–260 mm Hg. In the rats we used, the mean systolic blood pressure was 110–125 mm Hg for unanesthetized NTR's and 185–200 mm Hg for unanesthetized SHR's. The discharge features of 13 baroreceptor fibers from 11 NTR's (Wistar) were fully characterized and fell into three distinct types. Each type was often found in the same rat and many more units than are reported here were studied incompletely. Fibers were studied over periods as long as 6 hours without any change in their responses. When changes did occur fibers were not studied further. The three types are as follows:

**Figure 3** Anatomical composition of rat aortic nerve. A: distribution of myelinated fibers: 1,500×. B: grouping of unmyelinated fibers: 21,000×.
1. Slowly adapting fibers (seven units, five experiments) responded with an initial high frequency burst or transient phase followed by adaptation to a steady state frequency. An example of a slowly adapting fiber is shown in Figure 4. When the pressure was increased from 0 to 60 mm Hg there was no discharge, but when a pressure step of 0–80 mm Hg was applied a single baroreceptor unit responded with a short burst of high amplitude spikes (Fig. 4A). The lowest pressure at which the fiber discharged was termed the transient threshold ($P_t$) and this pressure was examined more closely by applying pressure steps on either side of it which differed by 10 mm Hg. The rise time of the pressure steps was the same in any given experiment and among all the different experiments. As the amplitude of the pressure step was increased to 100 mm Hg, the discharge was more prolonged but ceased before the step was terminated (Fig. 4B). With a pressure step of 120 mm Hg the fiber continued to discharge at a constant frequency while the pressure was maintained (Fig. 4C). This pressure was designated as the steady state threshold pressure ($P_M$). Closer examination of this pressure was also made as described above. An "off" discharge often occurred at pressures below $P_M$, as shown in Figure 4A and B and as reported by Landgren and Green.

If the impulse frequency for a series of pressure steps was plotted as a function of time, it was evident that both the peak transient or maximum frequency and the steady state frequency increased with higher pressure (Fig. 5). The maximum frequency generally occurred within 250 msec after the initiation of the pressure step and then rapidly adapted to a steady state firing rate. In the majority of experiments, 90% of the adaptation had occurred within 2–3 sec after the maximum frequency, and a steady state level was reached in about 10–20 sec.

2. Rapidly adapting fibers (two units, two experiments) demonstrated an initial transient response at the onset of the pressure step, but stopped firing or discharged infrequently even at very high pressures of 200–260 mm Hg. The particular example shown in Figure 6 came from an NTR. An "off" discharge occurred sometimes when the pressure was decreased from a constant level to 0 mm Hg. These fibers were present in the same preparations as slowly adapting fibers and were often identified first. We never observed a transformation from slowly adapting to rapidly adapting discharge.

3. Spontaneously active fibers (four units, four experiments) at 0 mm Hg showed a discharge in response to pressure steps which was similar to the slowly adapting fibers (Fig. 7). The spontaneous rate for any given fiber remained fairly constant for the duration of the experiment and ranged between 3 and 14 impulses/sec. As the pressure was increased, a level, $P_i$, was reached at which the discharge clearly but transiently increased. Eventually a pressure was reached at which an increased steady state discharge also occurred ($P_M$). In 50% of the fibers, pressure steps below $P_M$ actually decreased the spontaneous rate (Fig. 7, lowest trace), a finding which suggests that the receptive field of the baroreceptor was distorted at 0 mm Hg and...
The transient threshold pressure ($P_t$) ranged from 16 to 120 mm Hg. The three types of activity described previously in the NTR’s were also present in the SHR’s, and we characterized eight slowly adapting fibers (four experiments), four rapidly adapting fibers (two experiments), and six spontaneously active fibers (four experiments). Adaptation in slowly adapting fibers was similar to that shown in NTR’s as was postexcitatory depression in spontaneously active fibers. Differences between the two groups of rats are described in the following two sections.

The unmyelinated fibers were distributed almost evenly among the three types of activity in the two groups of animals. Thus there were two slowly adapting fibers in NTR’s, two slowly adapting fibers in SHR’s, one rapidly adapting fiber in each group, and one spontaneously active fiber in the SHR’s.

**FREQUENCY-PRESSURE CURVES OF NORMOTENSIVE RATS**

The results of an analysis of the discharge characteristics of 13 aortic baroreceptor fibers are summarized in Table 1. The transient threshold pressure ($P_t$) ranged from 16 to 120 mm Hg (mean = 77.5 ± 9.2 mm Hg) and was determined as follows. The pressure steps were increased by 10–20 mm Hg and the first non-zero impulse frequency point is the threshold value (Fig. 8). The average values in Table 1 were computed from these individual values. The curve relating peak transient frequency to pressure was usually linear over the range of pressures tested (60–240 mm Hg) (Fig. 8). For the NTR and SHR fibers shown in Figure 8 the slopes were 2.40 and 1.31 impulses/sec per mm Hg, respectively. In three of 13 fibers a plateau was approached at which greater pressure steps produced smaller increases in the impulse frequency; occasionally a decrease in frequency occurred. There were no apparent differences in threshold and peak transient frequency-pressure relationships among the slowly adapting, rapidly adapting, and spontaneously active fibers.

By a similar approach the mean steady state threshold pressure, $P_{ss}$, was determined in 11 fibers. The mean value was 103.5 ± 7.1 mm Hg (Table 1) and ranged from 38 to 124 mm Hg. The pressure-response curve of all fibers was nonlinear and an example is shown in Figure 8. The relationship between steady state discharge in impulses/sec$^{-1}$, $f_{ss}$, and pressure, $P$, is fitted by a rectangular hyperbola of the form

$$f_{ss} = \frac{(P - P_{ss})}{a_0 + a_1(P - P_{ss})} + f_0$$

where $a_0$ is in units of sec impulse$^{-1}$ and $a_1$ is in units of (impulses/sec)$^{-1}$ mm Hg, and $f_0$ is the threshold frequency in impulses/sec. $1/a_0$ is the asymptotic value which the steady state discharge approaches and $a_1$ influences the eccentricity of the hyperbola. $a_1$ can be evaluated at the half maximal response, i.e., when $f_{ss} = f_0 = \frac{1}{2}a_0$ for $a_1 = a_0(P - P_{ss})$. The values of $a_0$ and $a_1$ for the NTR curve shown in Figure 8 are 0.015 and 0.57, respectively. Similarly, for the SHR

**TABLE 1 Comparison of the Discharge Characteristics of Aortic Baroreceptors from Normotensive and Spontaneously Hypertensive Rats**

<table>
<thead>
<tr>
<th></th>
<th>Normotensive</th>
<th>Spontaneously hypertensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of experiments</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Threshold, transient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of fibers</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>Pressure (mm Hg)</td>
<td>77.5 ± 9.3</td>
<td>88.4 ± 10.1</td>
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<tr>
<td>Frequency (impulses/sec)</td>
<td>32.7 ± 4.9</td>
<td>37.9 ± 5.4</td>
</tr>
<tr>
<td>Maximum frequency</td>
<td>131.6 ± 12.3</td>
<td>153.6 ± 17.5</td>
</tr>
<tr>
<td>Slope (impulses/sec per mm Hg)</td>
<td>1.38 ± 0.15</td>
<td>0.91 ± 0.08*</td>
</tr>
<tr>
<td>Threshold, steady state</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of fibers</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Pressure (mm Hg)</td>
<td>103.5 ± 7.1</td>
<td>137.3 ± 5.2*</td>
</tr>
<tr>
<td>Frequency ($f_0$)</td>
<td>21.1 ± 4.1</td>
<td>25.8 ± 2.8</td>
</tr>
<tr>
<td>(impulses/sec)$^f$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of fibers</td>
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<td>11</td>
</tr>
<tr>
<td>Pressure at maximum frequency (mm Hg)</td>
<td>151.8 ± 21</td>
<td>197.4 ± 71*</td>
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<tr>
<td>Asymptotic frequency ($1/a_0$ (impulses/sec)$^f$)</td>
<td>56.4 ± 4.9</td>
<td>53.2 ± 3.6</td>
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<tr>
<td>$a_1$ [(impulses/sec)$^{-1}$ mm Hg]$^f$</td>
<td>0.676 ± 0.096</td>
<td>1.420 ± 0.814*</td>
</tr>
</tbody>
</table>

Values are means ± SE.

* $P < 0.001$

† See Equation 1. $P < 0.05$. 

**FIGURE 7** Response of a spontaneously active unit (normotensive rat) to pressure steps of 60, 120, 140, and 160 mm Hg. At the "subthreshold" pressure in the lowest trace, the spontaneous rate of discharge was reduced. Postexcitatory depression followed pressure steps A, B, and C (120, 140, and 160 mm Hg), and the corresponding trajectories for the recovery curves are labeled A, B and C as well.
In two experiments the flow of the perfusate was stopped for 30 seconds to 3 minutes prior to applying a pressure step. This procedure had no detectable effect on the pressure-response curves. In addition, prolonged periods (3-5 minutes) of zero flow did not alter the firing rate of the spontaneous units.

A comparison was made of the relationship between the transient and steady state frequency and the aortic arch pressure during a series of increasing and decreasing pressure steps delivered at intervals of greater than 60 seconds. As illustrated in Figure 9, the curves obtained at descending pressure were shifted to the right, especially at the lower pressure levels. In four out of five experiments, both the transient and steady state threshold pressures were elevated for descending pressures.

FREQUENCY-PRESSURE CURVES FOR SPONTANEOUSLY HYPERTENSIVE RATS

The stimulus-response characteristics of 18 aortic baroreceptor fibers from nine SHR's were compared with those obtained from NTR's. The results are summarized in Table 1 and a representative response is shown in Figure 8. The average of the threshold pressures at which peak transient frequencies were elicited was higher than that for NTR's, although the difference was not statistically significant. However, the average of the threshold pressures at which steady state discharges were elicited was significantly elevated in the SHR's (103.5 ± 7.1 mm Hg for NTR's and 137.3 ± 5.2 mm Hg for SHR's) (P < 0.01). Both the curvature of the hyperbolic relationship between steady state frequency and pressure and the slope relating peak transient frequency to pressure were significantly less in SHR's (Fig. 8). An average increase in pressure of 16 mm Hg above threshold had an associated average value for \( \frac{df_{\text{trans}}}{dP} \) of 0.43 in nine SHR's. A subsequent average pressure increase of 15 mm Hg was associated with an average value for \( \frac{df_{\text{trans}}}{dP} \) of 0.25. The stimulus-response curves of two baroreceptors of SHR's having unmyelinated afferent fibers fell within the range of this group.

PRESSURE-VOLUME CURVES OF THE AORTIC ARCH IN NORMOTENSIVE AND SPONTANEOUSLY HYPERTENSIVE RATS

Pressure-volume curves of the isolated aortic arch were obtained from three NTR's and two SHR's (mean systolic pressures, 118.5 ± 3.7 and 198.0 ± 5.6 mm Hg, respectively) (Fig. 10). The excised aortic arch was emptied completely and small volumes (0.1-0.7 ml) of the warmed perfusate were injected into a side arm of the aortic cannula and the steady state pressure was recorded. The volume of blood in the aortic arch at the time of excision was not determined; however, all measurements were made from initial pressures of 0 mm Hg, at which point the vessels had zero volumes. The stiffness or inverse distensibility which was calculated as \( \frac{\Delta P}{\Delta V} \) over the pressure range of 40-160 mm Hg from curves such as those shown in Figure 10 was 4.6 and 4.3 × 10^4 dynes cm^-1 in SHR's and NTR's, respectively. Since the aortic volumes were equivalent, these values represent the true distensibilities. The stiffness of the SHR aortas was only about 15% greater than that of NTR's.
The significant differences between the aortic baroreceptors of NTR’s and SHR’s are the increased threshold for steady state discharge and the reduced curvature of the impulse frequency-pressure relationship of the SHR’s. The slope of the peak frequency curve also differs significantly, but, as discussed later, interpretation of this curve is not straightforward. The increased pressure threshold, also known as resetting, has been repeatedly described in a variety of species, including the rat, from electrophysiological recordings of multifiber preparations.

Nosaka and Okamoto found that the mean threshold pressures for eliciting the mass neural discharge in NTR’s and SHR’s were 68 and 80 mm Hg, respectively, as compared to 78 and 88 mm Hg for our preparation in vitro. However, they used the arterial pressure pulse as the stimulus, therefore the pressure waveforms were different. They also reported that the blood pressure at which the maximum discharge was attained was greater in SHR than in NTR’s. Our results are similar in this regard. Thus the results obtained in the preparation in vitro appear similar to those obtained from the aortic arch in situ. Angell-James also found that aortic arch-aortic nerve preparations in vitro from the rabbit gave similar results when compared to the preparations in situ or in vivo.

The differences in threshold between hypertensive and normotensive animals have been attributed to a reduction in the distensibility of the vessel wall in which the baroreceptors are embedded. This explanation is insufficient in the present experiments since the distensibility of the excised aortic arch was essentially the same for NTR’s and SHR’s. One explanation for the difference between our results and those of earlier authors might be that we used SHR’s. At present, we have been unable to find other reports on SHR’s with which to compare our values for aortic capacitance. A better explanation is that reduced distensibility of the vessel wall is not the most important factor in resetting.

In our experiments, the maximum steady state impulse frequencies were similar between SHR’s and NTR’s. The difference in pressure for SHR’s and NTR’s at which these frequencies were attained was 45 mm Hg (197-152 mm Hg). The threshold pressure difference between the two groups was 34 mm Hg (137-103 mm Hg). At each of these pressures the corresponding aortic volume was relatively greater for the SHR’s (Fig. 10), so that the aortic baroreceptors were stretched more in SHR’s than in NTR’s, both at threshold and at peak steady state discharge. Similar results were obtained by Angell-James. A comparison of Figures 4 and 9 in her paper indicates that the threshold for aortic baroreceptors in normotensive rabbits was reached at a pressure of about 50 mm Hg and an aortic arch volume of about 75% of its initial volume, whereas the threshold for aortic baroreceptors in rabbits with chronic renal hypertension was attained at a pressure of about 110 mm Hg and a volume of about 175% of its initial volume. The initial aortic volume in hypertensive rabbits was greater than that of normotensive rabbits. Therefore, the pressure threshold for steady state baroreceptor discharge in hypertensive rabbits occurred at aortic volumes which were about double those in normotensive rabbits and with aortic diameters which were about 1.4 times greater.

This resetting at greater aortic volumes is also associated with a reduction in the sensitivity of hypertensive baroreceptors. Sensitivity might be inferred from either the slope of the transient stimulus-response curves or the curvature of the steady state curves. However, because of the dependence of the peak transient discharge on higher order derivatives of pressure with respect to time, the curvature of the steady state curves is a more reliable estimate. The asymptotic steady state frequencies of SHR’s and NTR’s were similar, but the values for the parameter \(a\) of the hyperbolic impulse frequency-pressure curves were significantly different. Therefore it was this difference that determined the difference in the two curves. The first derivative of the rising phase of the hyperbolic relationship was also markedly decreased for SHR’s. This comparison of SHR’s and NTR’s is a more complete description than measurements of the slope of the initial, more linear parts of the curves and is the best evidence that the sensitivity of SHR baroreceptors is reduced significantly.

The reduced sensitivity and increased threshold of SHR baroreceptors occurred at aortic volumes and aortic pressures which were greater in SHR’s than in NTR’s. Since the baroreceptors are stretch receptors, these functional differences cannot be attributed to reduced aortic distensibility. We suggest that the differences in threshold and sensitivity between hypertensive and normotensive baroreceptors are due to differences between the properties of the receptors themselves or the way in which the receptors are coupled to the vessel wall rather than to differences in aortic distensibility.

**DISCHARGE CHARACTERISTICS OF AORTIC BARORECEPTORS IN VITRO**

Spontaneous activity at zero pressure indicates that some receptors were distorted probably as a result of excision and...
realignment of the aortic arch in the perfusion chamber. However, these fibers had clear thresholds and were useful in demonstrating adaptation and postexcitatory depression.

Hysteresis was not marked at long times between pressure steps. This is similar to the findings of Franz et al.\textsuperscript{27} and, unlike Angell-James,\textsuperscript{6} we found no differences in hysteresis between SHR's and NTR's.

The time relationship of the neural discharge to the pressure steps was not altered appreciably even for C fibers. Since the maximum distance over which the impulse was propagated was about 2.5 cm and a minimum conduction velocity of 0.5 m/sec was obtained, the discharge would be delayed by about 50 msec under the worst of circumstances. This is only about 0.5% of the duration of the pressure steps used and is equivalent to the rise and fall times of the pressure steps we employed.

The occurrence of slowly adapting baroreceptors has already been described;\textsuperscript{28} rapidly adapting baroreceptors have not been reported heretofore. These receptors were found in preparations that contained slowly adapting receptors, and none of the fibers in the latter group ever became rapidly adapting. Perhaps rapidly adapting baroreceptors occur only in the rat, or only in preparations in vitro. How rapidly and slowly adapting mechanoreceptors are connected to cat hairs and also occur as stretch receptors in invertebrates,\textsuperscript{29} the other main features of aortic baroreceptor discharge were adaptation and postexcitatory depression which are dealt with in another study.\textsuperscript{14}

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References

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