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Effects of adrenoceptor agonists and antagonists on smooth muscle cells and neuromuscular transmission in the guinea-pig renal artery and vein

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1 In the guinea-pig renal artery and vein, the membrane potential was − 66.8 mV and − 46.8 mV, the length constant 0.54 mm and 0.43 mm, and the time constant 240 ms and 98 ms, respectively. The maximum slope of the depolarization produced by a 10 fold increase $[K]_o$ was 46 mV in the renal artery and 39 mV in the renal vein.

2 Noradrenaline (NA over 5×10^{-7} M in the artery and over 10^{-7} M in the vein) depolarized the membrane and slightly reduced the membrane resistance, assessed from relative changes in the amplitude of electrotonic potential. The action of NA was suppressed by prazosin in the artery but by yohimbine in the vein, i.e. the α_1-adrenoceptor is present in the extrajunctional muscle membrane in the renal artery while the α_2-adrenoceptor is present in the renal vein. Dopamine and isoprenaline did not modify the membrane properties.

3 In the renal artery, repetitive perivascular nerve stimulation (0.1 ms, 50 Hz, 5 shocks) evoked excitatory junction potential (e.j.p.). Applications of guanethidine (10^{-6} M) or tetrodotoxin (3×10^{-7} M) abolished the generation of the e.j.p.. Low concentrations of phentolamine (5×10^{-7} M), prazosin (10^{-7} M) and yohimbine (5×10^{-7} M) enhanced the e.j.p. amplitude, while high concentrations of phentolamine (10^{-5} M) and prazosin ($> 10^{-5}$ M) reduced the amplitude of e.j.p.s. NA, dopamine and clonidine consistently suppressed the amplitude of e.j.ps, at any given concentration over 10^{-7} M.

4 Spontaneously generated miniature e.j.ps (m.e.j.ps) were recorded on rare occasions. Phentolamine and yohimbine both at 5×10^{-7} M and prazosin 10^{-7} M increased the appearance of m.e.j.ps.

5 In the renal vein, repetitive nerve stimulation failed to generate the e.j.p. Sympathetic innervation to this tissue seems to be sparse.

6 Specificity of innervation and adrenoceptors present on smooth muscle cells in both the renal artery and vein are discussed, and the presynaptic regulation of NA release is compared with findings in other vascular tissues.

Introduction

Histochemical studies have shown that the kidney receives a rich nerve supply from the sympathetic nervous system and in this organ, there are relatively high concentrations of noradrenaline (NA) and dopamine (Nilsson, 1965; McKenna & Angelakos, 1968; Halushka & Hoffman, 1968; Barajas, 1978). Pharmacological evidence indicated that renal vessels possess both α- and β-adrenoceptors as well as dopamine receptors (Rosendorff, Bomzon, Farr & Scrieven, 1973; Taira, Yabuuchi & Yamashita, 1977; Goldberg, Volkman & Kohli, 1978). However, despite the extensive capacity of the renal circulation to respond to activations of the sympathetic nervous system, interpretations of the role of adrenergic innervation in the regulation of renal blood flow remain controversial (Smith, 1951; Pappenheimer, 1960; Hollenberg, Adams, Rashid, Epstein, Abrams & Merrill, 1971; Burger, Hopkins, Tulloch & Hollenberg, 1976; Hollenberg, 1979).

Electrical stimulation of the renal nerves normally leads to vasoconstriction of renal blood vessels (Di Salvo & Fell, 1971; Coote, Johns, Macleod & Singer, 1972). This neurally-induced vasoconstriction can be almost eliminated by pretreatment with blockers of the α-adrenergic pathway. Vasodilator responses to renal nerve stimulation, under conditions of α-adrenoceptor blockade, have been reported. The β-adrenoceptor blocking agent, propranolol, did not

modify the vasodilator response (DiSalvo & Fell, 1971; Gomer & Zimmerman, 1972). The existence of dopaminergic vasodilator nerves has also been reported (Chapman, Horn & Robertson, 1982).

As there are few reports on the sequence of electrical events during neuromuscular transmission in the renal vascular beds, the passive membrane properties of smooth muscle cells, responses of the membrane to exogenously applied catecholamines and the mechanism of neuromuscular transmission were investigated in renal vascular beds of the guinea-pig.

Methods

Guinea-pigs of either sex, weighing 250–300 g were stunned and bled. From the retroperitoneum, the renal arteries and veins together with the surrounding connective tissues and fat were excised, under a binocular microscope. The renal artery or vein (1.0–1.5 mm external diameter and 15 mm in length, helically cut preparation) was mounted in an organ bath (capacity 2 ml) to record electrophysiological phenomena.

To stimulate the perivascular nerves (0.1 ms pulse duration) and the muscle membrane (1–1.5 s pulse duration), the partition stimulating method was used (Abe & Tomita, 1968). The electrical activity of single smooth muscle cells was recorded using a glass capillary microelectrode filled with 3 M KCl; the resistance of the electrode ranged between 80 and 100 MΩ. The microelectrode was inserted into the muscle cell from the outer surface through the surrounding connective tissue. The organ bath was superfused with Krebs solution at 35–36°C and the flow rate was 2 ml min^{-1}. For tension recording, the vessel was carefully dissected by means of jeweller's forceps, opened in the longitudinal direction and a circularly cut strip of 0.3 mm width and 1 mm in length was prepared. The preparation was set up in a small chamber with a capacity of 0.9 ml through which the test solution was superfused rapidly by a jet of solution entering at one end and by simultaneous suction with a water pump from the other end. Both ends of the preparation were fixed between pieces of Scotch double stick tape (3M Co., St Paul, MN), and isometric tension was recorded by means of a mechanotransducer (Nihon Kohden, MZ3A) (Itoh, Kuriyama & Suzuki, 1981).

Normal Krebs solution contained (mM): Na^+ 137.4, K^+ 5.9, Ca^{2+} 2.5, Mg^{2+} 1.2, HCO_3^- 15.5, H_2PO_4 1.2, Cl^- 134.0 and glucose 11.5. This solution was bubbled with 97% O_2 and 3% CO_2 and the pH was kept at 7.2–7.3. The K^+-rich solution was prepared by replacing NaCl with equivalent amounts of KCl. The values of the measured parameters of the muscle membrane are expressed as the mean value ± s.d. The following drugs were used at the molar concentrations described in the results; noradrenaline (NA; Sigma), phentolamine (Ciba), yohimbine (Tokyo Kasei), clonidine (Tokyo Kasei), prazosin (Pfizer), tetrodotoxin (TTX, Sankyo), guanethidine (Tokyo Kasei), isoprenaline and propranolol (Sumitomo) and dopamine (Sigma). The solutions containing the final concentrations of drugs were freshly prepared for each experiment. When the effects of adrenoceptor agonists were studied in the presence of adrenoceptor antagonists, the antagonist was applied at least 10 min before addition of the agonist.

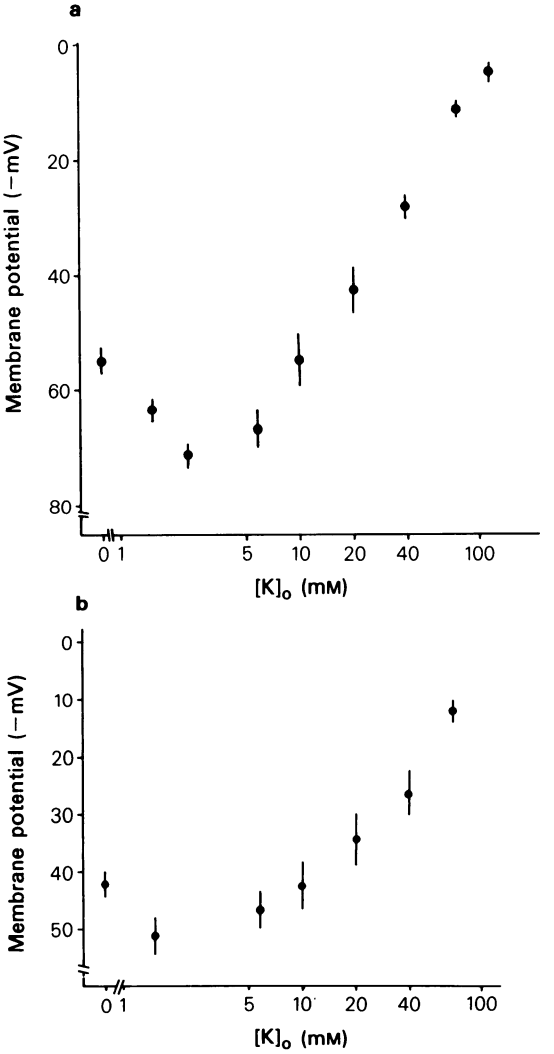

Figure 1 The membrane potentials of the guinea-pig renal artery and vein in the presence of various concentrations of $[K]_o$. Vertical bars indicate 2 × s.d. ($n = 15–20$). (a) artery, (b) vein.

Results

Membrane properties of smooth muscle cells of the renal arteries and veins

Smooth muscle cells of the renal artery and vein were electrically quiescent and the resting membrane potentials were -66.8 ± 2.8 mV (s.d., $n = 80$) in the renal artery and -46.8 ± 3.2 mV ($n = 62$) in the renal vein.

Figure 1 shows the membrane potential in various concentrations of external potassium, $[K]_o$, in the renal artery and vein. Increased $[K]_o$ depolarized the membrane and with concentrations over 20 mM $[K]_o$, the relationship between the membrane potential and $[K]_o$, plotted on a logarithmic scale, was almost linear. The maximum slope of the depolarization given by a 10 fold increase in $[K]_o$ plotted on a logarithmic scale was 46 mV ($n = 3$) in the renal artery and 39 mV ($n = 3$) in the renal vein. A reduction of $[K]_o$ from 5.9 mM to 2.4 mM hyperpolarized the membrane to -71.4 ± 1.4 mV ($n = 13$) (control membrane potential: -66.8 ± 2.8 mV, $n = 13$) in the renal artery. In the renal vein, the reduction of $[K]_o$ from 5.9 mM to 1.5 mM hyperpolarized the membrane to -51.2 ± 3.2 mV ($n = 15$) (control membrane potential; -46.8 ± 3.2 mV $n = 15$). In K-free solution, the muscle membranes of artery and vein depolarized to -55.0 ± 1.8 mV ($n = 16$) and -40.4 ± 2.2 mV ($n = 16$), respectively. Ouabain (10^{-5} M) depolarized the membrane to much the same level as observed with K-free solution in the renal artery and vein.

To investigate whether the cable equation (Hodgkin & Rushton, 1946) is applicable for measuring the membrane resistance in the presence or absence of catecholamines in these tissues, passive membrane properties of the smooth muscle were measured by application of electrical stimulation using the partition stimulating method (Abe & Tomita, 1968). Figure 2a shows the current-voltage relationships recorded at four different distances from the stimulating electrode in the renal artery. Application of inward current pulses with various intensities produced a linear current-voltage relationship, whereas rectification was apparent with outward current. Figure 2b shows the relationship between the amplitude of electrotonic potential produced by the constant intensity of inward current pulse (1.5 s pulse duration) plotted on a logarithmic scale and the distance from the stimulating electrode. The decay of the electrotonic potential against the distance from the stimulating electrode is linear, indicating that the tissue possesses a cable-like property. The mean value of the space constant (λ) calculated from the decay of the electrotonic potential from $\lambda = e^{-1}$ was 0.54 ± 0.07 mm ($n = 6$). The time constant of the membrane (τm) could be calculated from the relationship between the time required to reach the half amplitude of electrotonic potential and the distance from the stimulating electrode. The relationship is linear and the slope of this line is given as $\tau m/2\lambda$ (Hodgkin & Rushton, 1946). The mean value of the calculated time constant is 240 ± 50 ms ($n = 4$).

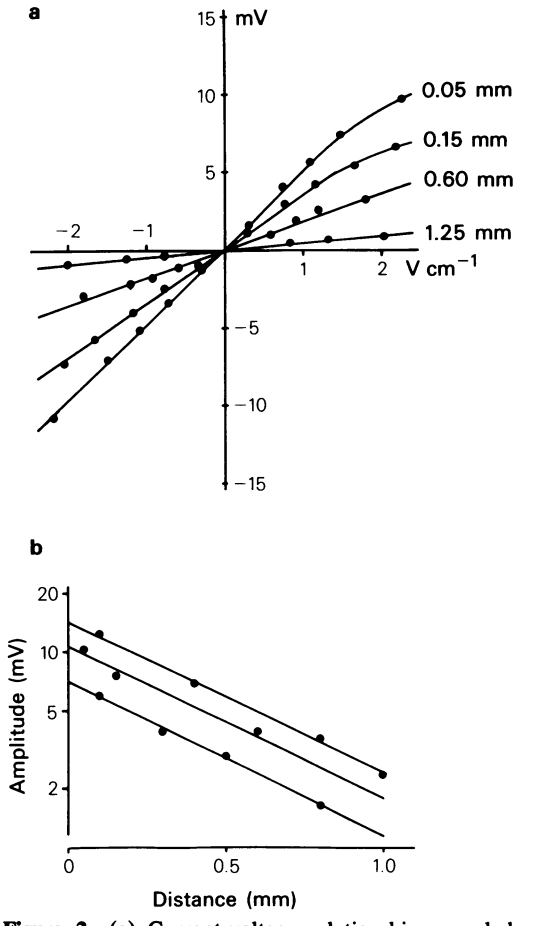

Figure 2 (a) Current-voltage relationship recorded from smooth muscle cells at a distance of 0.05, 0.15, 0.6 or 1.25 mm from the stimulating electrode. (b) The relationship between the amplitude of electrotonic potential plotted on a logarithmic scale against distances from the stimulating electrode. Horizontal axis: distances from the stimulating electrode, Vertical axis: the amplitude of electrotonic potential. Different experiments under conditions of three different intensities were superimposed.

Similar measurements were made using the renal vein. With applications of outward current pulse, smooth muscle cells of the renal vein have the rectifying property, and the relationship between the amplitudes of negative electrotonic potential evoked by

the constant intensity of inward current and the distance from the stimulating electrode indicated they had cable-like properties. The mean value of the space constant was 0.43 ± 0.1 mm ($n = 3$) and that of time constant was 98 ± 40 ms ($n = 3$).

Effects of catecholamines on the membrane property of renal vascular beds

The effects of NA, phenylephrine, isoprenaline and dopamine on the membrane potential and elec-

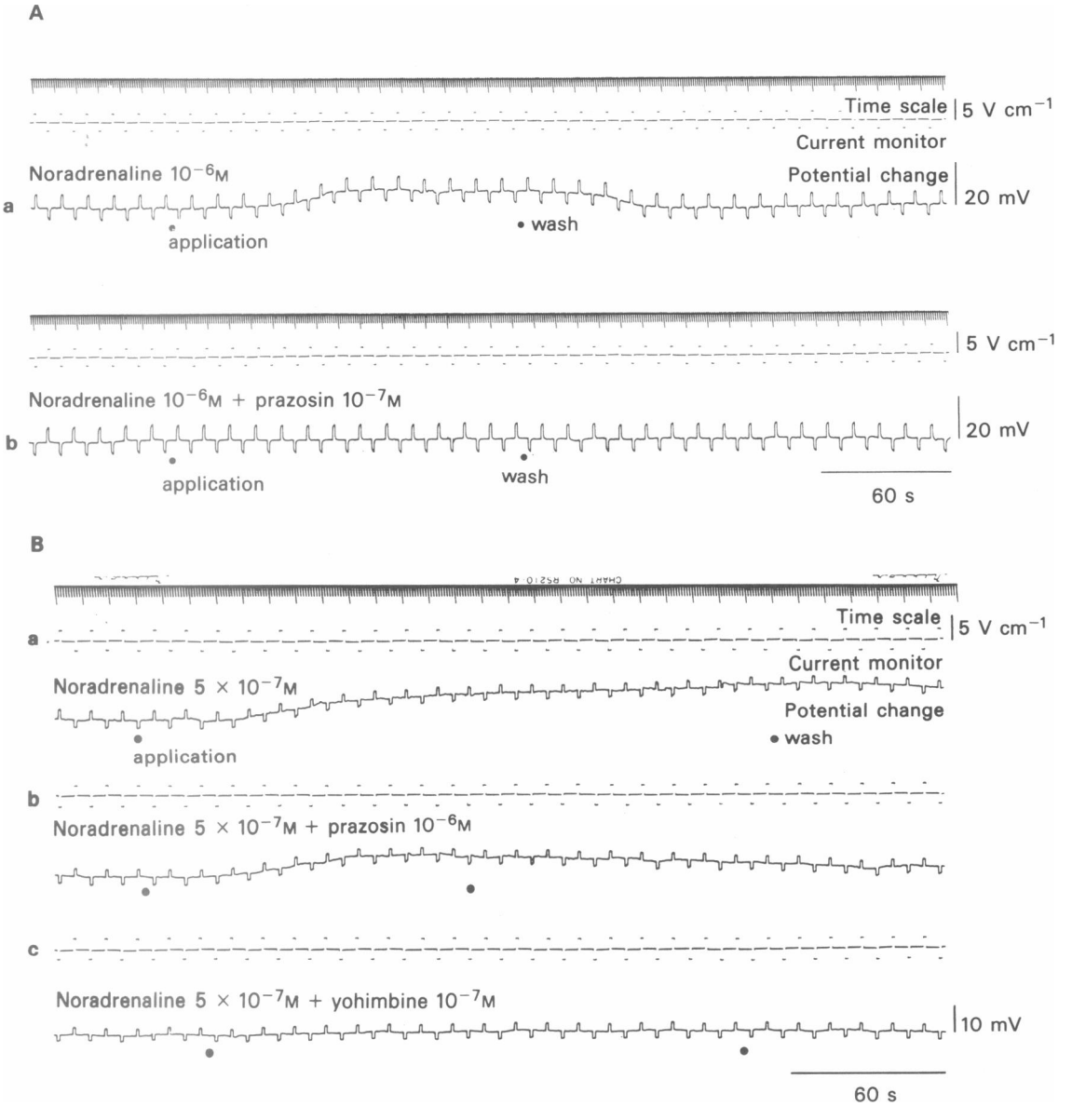

Figure 3(A) Effects of prazosin on the noradrenaline (NA)-induced depolarization in smooth muscle cells of the renal artery. (a); NA (10^{-6} M) (b); NA (10^{-6} M) during treatment with prazosin (10^{-7} M). Dots indicate the application and removal of agents. (B) Effects of yohimbine on the NA-induced depolarization in smooth muscle cells of the renal vein: (a) NA (5×10^{-7} M); (b) Simultaneous treatment with NA (5×10^{-7} M) and prazosin (10^{-6} M); (c) Simultaneous treatment with NA (5×10^{-7} M) and yohimbine (10^{-7} M). Dots indicate the application and removal of agents.

trotonic potentials evoked by alternately applied inward and outward current pulses (1.3 s pulse duration) with constant intensity were determined in the renal artery. As the tissue possessed a cable-like property, the microelectrode was inserted into the cell within 0.1 mm from the stimulating electrode to measure the membrane potential and membrane resistance. NA depolarized the membrane at concentrations over 5×10^{-7} M with a slight decrease in the amplitude of electrotonic potential (0.96 times the control, $n = 5$) i.e. the relative membrane resistance was, therefore, 0.92 times the control, calculated from the equation introduced by Hodgkin & Rushton 1946). NA 5×10^{-7} M depolarized the membrane from -65.2 ± 3.1 mV ($n = 25$) in Krebs solution to -60.3 ± 1.8 mV ($n = 25$). Figure 3A shows the effect of prazosin on NA-induced depolarization of the membrane. NA 10^{-6} M depolarized the membrane from -65.2 ± 3.1 mV to -57.4 ± 2.1 mV ($n = 15$, $P < 0.05$), but this depolarization was completely blocked by the application of prazosin 10^{-7} M. Phenylephrine 5×10^{-7} M depolarized the membrane from -64.8 ± 2.8 mV ($n = 15$) to -59.8 ± 3.2 mV ($n = 15$, $P < 0.05$), with a slight decrease in the amplitude of electrotonic potential (0.94 times the control, $n = 5$). Isoprenaline and dopamine did not modify the membrane potential and resistance at concentrations up to 10^{-6} M (the control membrane potential was -65.1 ± 1.8 mV, while in isoprenaline 10^{-6} M it was -66.4 ± 2.1 mV ($n = 13$) and in dopamine 10^{-6} M it was -64.6 ± 2.0 mV ($n = 15$)).

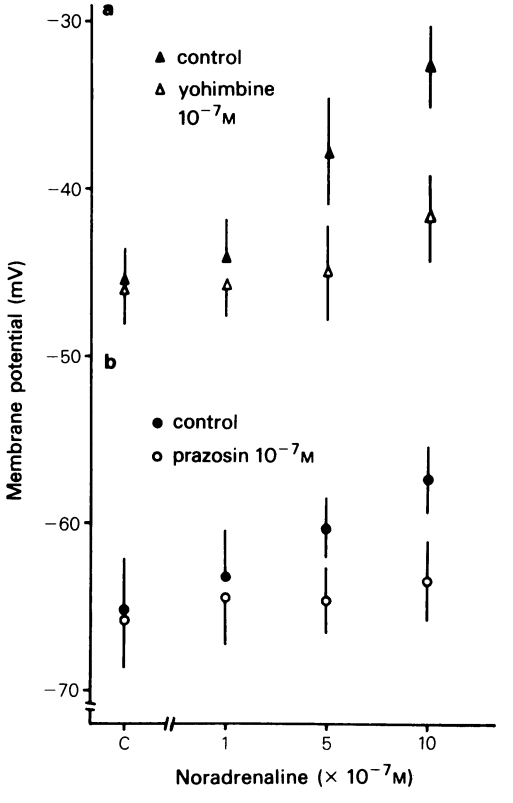

Figure 4 Effects of prazosin and yohimbine on the noradrenaline-induced depolarization in smooth muscle cells of the renal vein (a) and artery (b). In (a), (▲) = control; (△) = yohimbine 10^{-7} M; in (b), (●) = control; (○) = prazosin 10^{-7} M. Vertical bars indicate 2 × s.d. ($n = 10$–16).

The effects of NA, α-adrenoceptor antagonists, isoprenaline and dopamine on the membrane potential, and resistance in the renal vein were also observed. The membrane potential was -45.6 ± 2.1 mV ($n = 12$) in Krebs solution, while in NA 5×10^{-7} M, it was -37.8 ± 3.2 mV ($n = 12$) and the membrane resistance was reduced to 0.73 times the control ($n = 5$). While prazosin 10^{-6} M had no effect, yohimbine 10^{-7} M completely antagonized the NA (5×10^{-7} M)-induced membrane depolarization (Figure 3B). Isoprenaline and dopamine at concentrations up to 10^{-6} M did not modify the membrane potential and resistance (the membrane potential was -46.4 ± 2.8 mV ($n = 15$) in Krebs solution, while the values of -45.1 ± 2.4 mV ($n = 15$) were seen with isoprenaline 10^{-6} M, and with dopamine 10^{-6} M, the values were -45.8 ± 2.6 mV ($n = 15$)). When 10^{-6} M phenylephrine was applied, no depolarization of the membrane was observed (-47.1 ± 1.9 mV, $n = 15$). These findings with the renal vein are different from the effects of phenylephrine in the renal artery.

Figure 4 summarizes the effects of prazosin (for arteries) or yohimbine (for veins) on the NA-induced membrane potential changes. Prazosin but not yohimbine inhibited the NA-induced depolarization in the smooth muscle membrane of the renal artery, while yohimbine but not prazosin inhibited those changes in the renal vein.

In the renal artery and vein, NA depolarized the membrane and induced the contraction. The minimum concentration of NA required to produce the contraction was 5×10^{-7} M in the artery and 10^{-7} M in the vein, respectively, and the maximum contraction was observed at a concentration of 5×10^{-6} M NA, in both tissues. In the renal artery, prazosin, at concentrations over 10^{-9} M, antagonized the NA-induced contraction. The dose-response curves are shown in Figure 5. The contractile response of the renal vein varied greatly so that the dose-response curve could not be determined. However, yohimbine 5×10^{-6} M consistently inhibited the NA-induced contraction in the renal vein.

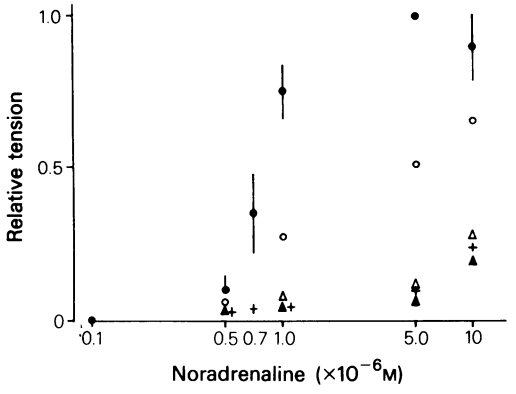

Figure 5 Effects of prazosin on the noradrenaline (NA)-induced contraction of the guinea-pig renal artery. The amplitude of the NA-induced contraction evoked by 5×10^{-6} M NA was registered as a relative tension of 1.0. Vertical bars indicate 2 × s.d. ($n = 3-6$). NA alone = (●); NA plus prazosin 10^{-9} M = (○), plus prazosin 10^{-8} M = (△), plus prazosin 10^{-7} M = (+) and plus prazosin 10^{-6} M = (▲).

Neuromuscular transmission in the smooth muscle cells of the renal vascular beds

Figure 6 shows the effects of perivascular nerve stimulation on smooth muscle cells of the renal artery. Repetitive stimulation of perivascular nerves (0.1 ms pulse duration, 50 Hz, 5 shocks) produced a small depolarization of the membrane; however, a single stimulus was ineffective. As stimulus frequencies or the number of the stimuli increased, the amplitude of the small depolarization also increased. This depolarization was suppressed completely by treatment with tetrodotoxin 3×10^{-7} M (Figure 6a) or guanethidine 10^{-6} M. It could therefore be regarded as an excitatory junction potential (e.j.p.). NA (below 10^{-7} M) modified neither the membrane potential nor the membrane resistance, yet after pretreatment of 10^{-7} M NA, the amplitude of e.j.p. generated by perivascular nerve stimulation decreased, as shown in Figure 6a.

To observe further the effects of catecholamines on the neuromuscular transmission in this tissue, the effects of several α-adrenoceptor agonists or antagonists on the amplitude of e.j.p. were investigated. Figure 6b shows the effects of prazosin, phentolamine, clonidine and yohimbine on the e.j.p. amplitude. These agents did not modify the membrane potential or resistance of muscle membrane at concentrations below 10^{-6} M, but they had different actions on the e.j.p. amplitude: prazosin (10^{-7} M), phentolamine (5×10^{-7} M), yohimbine (5×10^{-7} M) enhanced the e.j.p. amplitude, while clonidine (5×10^{-7} M) reduced it (Figure 6b).

Prazosin had a dual effect on the e.j.p. amplitude. At a concentration of 10^{-7} M, it enhanced the e.j.p. amplitude, but with concentrations over 10^{-5} M, a slight reduction was observed with no change in the property of muscle membranes. However, further increased concentrations of prazosin did not abolish the e.j.p. Similar results were observed with phentolamine i.e. at concentrations below 10^{-6} M, phentolamine enhanced the amplitude of the e.j.p., while in concentrations over 10^{-5} M, phentolamine reduced the amplitude; yohimbine (10^{-5} M) still increased the amplitude of the e.j.p..

In this artery, the appearance of m.e.j.ps was noted in most preparations (about 80% of preparations), but it was often transient. In only 1% was there

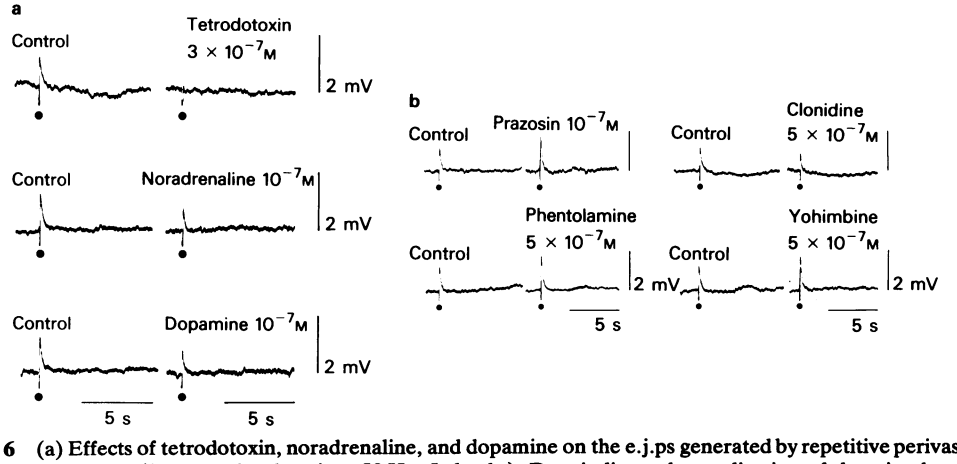

Figure 6 (a) Effects of tetrodotoxin, noradrenaline, and dopamine on the e.j.ps generated by repetitive perivascular nerve stimulation (0.1 ms pulse duration, 50 Hz, 5 shocks). Dots indicate the application of the stimulus. (b) Effects of prazosin, clonidine, phentolamine and yohimbine on the e.j.ps. Stimulus conditions were the same as in (a).

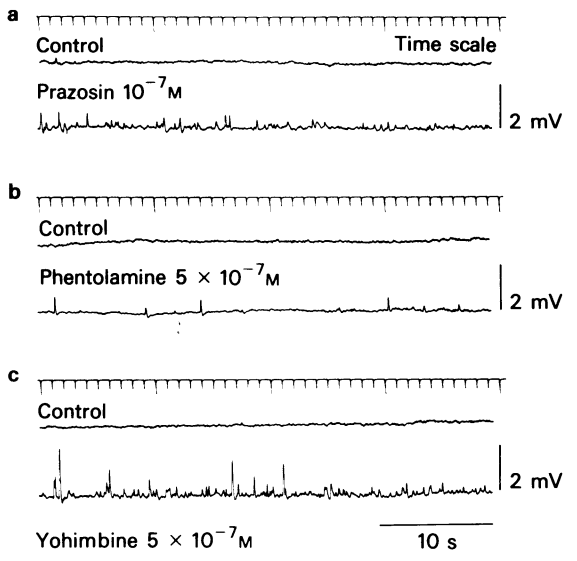

Figure 7 Effects of prazosin, phentolamine and yohimbine on the miniature e.j.ps recorded from smooth muscle cells of the renal artery. The records were taken 5 min after the application of drugs.

relative continuity. M.e.j.ps occurred once or twice for several minutes in the presence of TTX (3×10^{-7} M). Furthermore, these m.e.j.ps were blocked by higher concentrations of phentolamine ($> 10^{-4}$ M) or an adrenergic neurone blocker such as guanethidine (10^{-7} M). Therefore, we concluded that they do not result from the nerve excitation, but rather reflect the spontaneous noradrenaline release from the nerve terminals. Figure 7 shows the effects of prazosin (10^{-7} M), phentolamine (5×10^{-7} M) and yohimbine (5×10^{-7} M) on m.e.j.ps. All of these agents increased the frequency of m.e.j.ps with no change in the passive membrane properties. Some of the large but not all m.e.j.ps were accompanied by small hyperpolarizations.

In the renal vein, repetitively applied perivascular nerve stimulation generated neither small depolarizations nor m.e.j.ps.

Discussion

Membrane potentials of the guinea-pig renal artery and vein were approx. −67 mV and −47 mV, respectively. This value in the case of the renal artery was much the same as that in other muscular arteries (Kuriyama & Suzuki, 1981; Karashima & Kuriyama, 1981: Fujiwara, Itoh & Suzuki, 1982), and that of the renal vein was smaller than that of the renal artery. The smooth muscle cells of both the renal artery and vein had cable-like properties. The length and the time constants were slightly smaller than those of the guinea-pig mesenteric or cerebral arteries (Kuriyama & Suzuki, 1981; Karashima & Kuriyama, 1981).

The maximum slope of the K-induced depolarization plotted on a logarithmic scale was low, in both renal artery and vein. K-free solution or ouabain depolarized the membrane to the same extent, by about 10 mV in the renal artery and 6 mV in the renal vein. This means that the Na-K pump may partly contribute to the maintenance of the resting membrane potential, as observed in the guinea-pig mesenteric and coronary arteries and also in the portal vein (Kuriyama, Ohshima & Sakamoto, 1971; Harder & Sperelakis, 1978).

The responses of the vascular smooth muscle to catecholamine differs markedly with location and species (Ito, Kitamura & Kuriyama, 1979; Fujiwara *et al.*, 1982; Hirst, Neild & Silverberg, 1982). In the guinea-pig renal artery and vein, NA depolarized the membrane and slightly reduced the membrane resistance. On the other hand, the nature of the α-adrenoceptors differed in the renal artery and vein, namely, in the artery, prazosin, an α_1-antagonist, inhibited, while in the vein, yohimbine, an α_2-antagonist, inhibited the NA-induced depolarization. Therefore, it is suggested that the smooth muscle cells of this artery seem to possess α_1-adrenoceptors while those of the vein have α_2-adrenoceptors. The effects of phenylephrine observed in both tissues support this idea. Isoprenaline and dopamine had no effects on the membrane properties in either the renal artery or vein. These findings are consistent with the reports that renal vessels are fairly sensitive to constrictor and rather refractory to dilator actions of several agents in *in vivo* experiments (Vapaatalo & Säynävälammi, 1980).

In the renal artery, perivascular nerve stimulation produced e.j.ps, which were generated by chemical transmitter release from the nerve terminals. Morphological and histochemical studies revealed that the renal artery is innervated by adrenergic nerves and that its chemical transmitter is NA (Dieterich, 1974; Moffat, 1979).

E.j.ps are recorded in many vascular smooth muscles. In some vascular smooth muscles, e.j.ps are very resistant to α-adrenoceptor antagonists (Suzuki & Kuriyama, 1980; Holman & Surprenant, 1980; Hirst, *et al.*, 1982; Kou, Kuriyama & Suzuki, 1982; Asada, Nanjo, Itoh, Suzuki & Kuriyama, 1982; Kuriyama & Makita, 1983). The intra-junctional adrenoceptor related to the neuromuscular transmission is of a different nature from the adrenoceptor present in the smooth muscle membrane (Hirst & Neild, 1980a; Kuriyama & Makita, 1983) and has been termed the γ-receptor by Hirst & Neild (1980b; 1981). According to the effects of several α-

adrenoceptor agonists and antagonists, α-adrenoceptors can be classified into three subtypes in the guinea-pig mesenteric artery i.e. intra-junctional adrenoceptor (γ-adrenoceptor), extra-junctional α_1-adrenoceptor and presynaptic α_2-adrenoceptor.

In the guinea-pig renal artery, application of phentolamine or prazosin had a dual action on e.j.ps. In concentrations below 10^{-6} M, phentolamine enhanced the e.j.p. amplitude, whilst application of a higher concentration of phentolamine (over 10^{-5} M) reduced the e.j.p. amplitude. Much the same effects were observed with prazosin. If presynaptic nerve terminals possess α_2-adrenoceptors, clonidine, an α_2-adrenoceptor agonist, should suppress the e.j.p. amplitude and yohimbine, an α_2-adrenoceptor antagonist, should enhance the e.j.p. amplitude. In this study, these agents acted as expected on the amplitude of e.j.ps. These actions of α_2-agonist and antagonist indicate that the renal artery has a negative feedback system of transmitter release through the presynaptic α_2-adrenoceptor, as was suggested in the case of the guinea-pig mesenteric artery (Kuriyama & Makita, 1983). The presence of the adrenoceptors which differ from α_2-adrenoceptors was also assumed from actions of prazosin on e.j.ps in the renal artery.

Spontaneously generated m.e.j.ps sometimes occurred. These potential changes ceased following treatment with guanethidine. Prazosin, yohimbine and phentolamine all increased the frequency of m.e.j.ps while clonidine and NA did not. The underlying mechanism of the increased m.e.j.p. generation cannot be adequately explained from the present data. In the renal artery, some of the large m.e.j.ps were accompanied by a small hyperpolarization. Presumably, activation of the muscle membrane could result from increased generation of m.e.j.ps, following treatment with α-adrenoceptor blockers.

In the guinea-pig renal vein, even repetitive perivascular nerve stimulation failed to generate the e.j.ps; therefore, the sympathetic innervation would be either very sparse or have no physiological significance.

In conclusion, the renal artery is innervated by sympathetic nerves which produce e.j.ps in the smooth muscle cells, while in the renal vein, sympathetic innervation seems to be sparse. Postsynaptic adrenoceptors differ in the renal artery and vein, i.e. the renal artery possesses α_1-and intra-junctional (γ)-adrenoceptors and the renal vein possesses α_2-adrenoceptors on the smooth muscle membrane. In the renal artery, presynaptic adrenoceptors are mainly α_2-adrenoceptors and presynaptic adrenoceptors which differ from α_2-adrenoceptors may also contribute to regulation of NA releases.

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