Age and Hypertension Promote Endothelium-Dependent Contractions to Acetylcholine in the Aorta of the Rat

Tokushi Koga, Yutaka Takata, Kazuo Kobayashi, Shuichi Takishita, Yoshiaki Yamashita, and Masatoshi Fujishima

This study was undertaken to compare age-related changes in endothelium-dependent vascular responses in both hypertensive and normotensive rats. Aorta from normotensive Wistar-Kyoto (WKY) rats and spontaneously hypertensive rats (SHR) aged 4–6 weeks (young), 3–6 months (adult), and 12–25 months (old) were examined for relaxation to acetylcholine, adenosine 5'-triphosphate (ATP), and sodium nitroprusside. Rubbed (endothelium denuded) aorta from all groups displayed neither relaxation nor contraction to acetylcholine. Maximal relaxation responses to acetylcholine were reduced progressively with increasing age in unrubbed aorta of both SHR and WKY rats. In addition, acetylcholine caused not only dose-dependent relaxations at lower concentrations but also increases in tension at higher concentrations in unrubbed aorta of old WKY rats as well as adult and old SHR. However, indomethacin completely inhibited the tension development. As a result, aorta treated with indomethacin demonstrated similar acetylcholine-induced, endothelium-dependent relaxations in all groups. The thromboxane A2 synthetase inhibitor (E)-7-phenyl-7-(3-pyridyl)-6-heptanoic acid (CV-4151) partially but significantly depressed the increases in tension in aorta of old WKY rats. The degrees of endothelium-dependent relaxations to ATP and endothelium-independent relaxations to sodium nitroprusside were almost similar in all groups. These findings suggest that the release of or vascular responsiveness to endothelium-derived relaxing factor in the aorta is well maintained through senescence in both strains and that, in the aorta of not only SHR but also old normotensive WKY rats, the endothelium releases contracting factors that may be thromboxane A2 and other vasoconstrictor prostanoids. (Hypertension 1989;14:542–548)

The endothelium may play an obligatory role in the local regulation of vascular function, as endothelial cells produce some biologically active substances such as endothelium-derived relaxing factor (EDRF), prostaglandin I2,4 and endothelium-derived contracting factors (EDCF).5–7 It is well known that, in the course of hypertension and aging, the endothelium changes both morphologically and functionally.8–11 It has been demonstrated that endothelium-dependent responses are altered with various types of hypertension.12–15 However, the alterations of endothelium-dependent vascular responses with increasing age are still controversial. Some authors found in the aged animals a decrease in endothelium-dependent relaxation responses of vascular smooth muscles,16–18 whereas others found an increased response.19 In addition, there are only a few reports comparing the influences of age on the regulatory action of endothelium in the vascular responses between normotensive and hypertensive rats.

The present study was designed to elucidate whether age could alter endothelium-dependent responses in aorta of both spontaneously hypertensive rats (SHR) and normotensive Wistar-Kyoto (WKY) rats.

Materials and Methods

Young (age 4–6 weeks), adult (age 3–6 months), and old (age 12–25 months) male SHR and WKY rats that were used for the study had been maintained in the Institute of Experimental Animals in Kyushu University and had been fed a commercial diet containing approximately 250 mg sodium and 800 mg potassium/100 g. The average age and weight of SHR and WKY rats in each group were:
were fixed in half-Kalnousky fixatives, and the
were determined by scanning electron microscopy.

Basal tension and norepinephrine-
induced contractions were not significantly affected
by these inhibitors.

tranylcypromine (10^{-4} M) was incubated in the
solution 30 minutes before and during the response
(10^{-5} M) or prostaglandin I_2 synthetase inhibitor
(triphasic) and thromboxane A_2 synthetase inhibitor (E)-7-
phenyl-7-(3-pyridyl)-6-heptanoic acid (CV-4151).

The solution was aerated with 95% O_2 and 5%
CO_2, and the pH was maintained at 7.2-7.3. The
tissues were allowed to equilibrate for at
least 60 minutes.

In preliminary experiments, the dose-response
relations to norepinephrine (10^{-9} to 10^{-5} M) were
constructed, and the doses of norepinephrine causing
a 60-70% maximal contractile response were
estimated to be 3x10^{-7} M.

Acetylcholine chloride, adenosine 5'-triphosphate,
norepinephrine hydrochloride, and sodium nitroprus-
side (all obtained from Sigma Chemical Co., St.
Louis, Missouri) were dissolved in distilled water.
Indomethacin (Sigma Chemical Co.) was dissolved in
ethanol and CV-4151 (Takeda Chemical Industries,
Osaka, Japan) in dimethyl sulfoxide. At the concentra-
tions used in these experiments, ethanol or dime-
ethyl sulfoxide alone had no effect on basal tension or
contractile responses to norepinephrine (3x10^{-7} M)
in aortic rings. Drug concentrations are expressed as
final molar concentrations in the bath solutions.

Results are given as mean±SEM. Statistical analy-
ses were done by repeated measures of analysis of
variance and unpaired Student’s t test. A p value
less than 0.05 was considered significant.

Blood Pressure

The systolic blood pressures of SHR and WKY
rats at three different ages were as follows: 113±6
and 109±4 mm Hg for the young group; 207±4 and
127±4 mm Hg for the adult group; and 207±5 and
125±5 mm Hg for the old age group, respectively.
The systolic pressures of the adult and old SHR were
significantly higher than those of the young
SHR (p<0.001) and also those of the corresponding
WKY rats (p<0.001).

Morphological Findings

Histological examinations after completion of the
experiment revealed that all aortic rings with endo-
thelium (n=127), except the regions pressed by
wires, had a normal endothelial covering whereas
the aortic vessels subjected to mechanical rubbing
(n=36) had no endothelial cells.

Vascular Responses to Acetylcholine

Significant differences in relaxation responses to
acetylcholine of vessels with intact endothelium
were apparent among the three different age groups
in both SHR (young vs. adult p<0.01, young vs. old
p<0.001, and adult vs. old p<0.01) and WKY rats
(young vs. adult p<0.05, young vs. old p<0.001,
and adult vs. old p<0.005) as shown in Figure 1. Acetylcholine produced dose-dependent relaxa-
tions in young SHR and young and adult WKY
rats as well. In adult and old SHR and in old WKY
rats, however, higher doses (10^{-6} and 10^{-5} M) of
acetylcholine increased vascular tone instead of
dose-dependent relaxations (Figures 1 and 2). The
maximal relaxation responses to acetylcholine
significantly decreased in both SHR and WKY rats
with increasing age (SHR: young vs. adult p<0.001,
adult vs. old p<0.01; WKY: adult vs. old p<0.001).
Responses of either relaxation or contraction to
acetylcholine completely disappeared among all
groups after removal of the endothelial cells
(Figure 2).
FIGURE 1. Line graphs showing endothelium-dependent responses to acetylcholine in aorta with endothelium of spontaneously hypertensive rats (SHR) (left panel) and Wistar-Kyoto (WKY) rats (right panel) at three different ages that were precontracted with norepinephrine \((3 \times 10^{-7} \text{ M})\). Responses were significantly different among three age groups in both SHR (young vs. adult \(p<0.01\), young vs. old \(p<0.001\), and adult vs. old \(p<0.01\)) and WKY rats (young vs. adult \(p<0.05\), young vs. old \(p<0.001\), adult vs. old \(p<0.005\)).

The endothelium-dependent relaxations to acetylcholine were not altered by treatment with indomethacin in young SHR and in young and adult WKY rats; whereas in old WKY rats as well as adult and old SHR, the increases in tone at the high concentration of acetylcholine were abolished and the relaxations enhanced dose dependently (Figure 3). As a result, acetylcholine-induced relaxations were almost equal in all groups during treatment with indomethacin. In rings with endothelium from the old WKY rats, CV-4151 (KT 5 M) partially but significantly depressed the tension development evoked by high doses of acetylcholine (Figure 4). However, tranylcypromine \((10^{-4} \text{ M})\) did not significantly affect these vascular responses in old WKY rats.

Vascular responses to acetylcholine in the absence of preconstriction by norepinephrine were examined in aortic segments from old WKY rats. Cumulative addition of acetylcholine caused a slight but significant contraction in a dose-dependent manner in unrubbed aortic rings. At the highest concentration of acetylcholine \((10^{-5} \text{ M})\), the magnitude of force development was approximately 10% of the force developed in response to \(3 \times 10^{-7} \text{ M}\) norepinephrine. Indomethacin completely abolished these contractions evoked by acetylcholine. After removal of the endothelium, dose-dependent contractile responses to acetylcholine were not recognized.

**Vascular Relaxations to Adenosine 5'-Triphosphate**

In all rats, ATP was effective in evoking dose-dependent relaxation in the presence of an intact endothelium (Figure 5), although after removal of endothelium, ATP-induced relaxation was almost abolished (young: SHR \(p<0.05\) \([n=6]\), WKY rats \(p<0.05\) \([n=6]\); adult: SHR \(p<0.001\) \([n=5]\), WKY rats \(p<0.001\) \([n=7]\); old: SHR \(p<0.001\) \([n=5]\), WKY rats \(p<0.001\) \([n=7]\)). ATP-induced relaxations in SHR were almost similar to those in WKY rats at any age (young: SHR \([n=6]\) vs. WKY \([n=6]\) \(p>0.05\) NS; adult: SHR \([n=5]\) vs. WKY rats \([n=7]\) \(p<0.05\); old: SHR \([n=5]\) vs. WKY rats \([n=7]\) \(p>0.05\) NS). In addition, the degree of relaxations by ATP was not altered by aging in both SHR and WKY rats.

**Vascular Relaxations to Sodium Nitroprusside**

Sodium nitroprusside produced dose-dependent relaxation of aortic rings, which was not altered by removal of the endothelium. The number of unrubbed and rubbed (in parentheses) aorta from SHR and WKY rats used was 6 (5) and 7 (6) from the young, 6 (5) and 6 (7) from the adult, and 7 (7) and 7 (6) from the old age group. The degree of relaxation by sodium nitroprusside did not differ significantly either between SHR and WKY rats or among the three different age groups (Figure 6).
Discussion

The present study demonstrates that maximal endothelium-dependent relaxations to acetylcholine were decreased with advancing age in both SHR and WKY rats, and the tensions at higher doses of acetylcholine were increased in adult and old SHR and in old normotensive WKY rats. However, these tension developments were abolished by treatment with indomethacin, and relaxations were enhanced dose dependently resulting in identical acetylcholine-induced relaxations in all groups. These findings suggest that the increases in tension observed at higher concentrations of acetylcholine are mediated by a cyclooxygenase-dependent contracting factor. Moreover, since both vascular relaxant and contractile responses to acetylcholine were abolished by removal of the endothelium in all preparations, acetylcholine-induced contractions in unrubbed rings of old WKY rats as well as those of SHR are dependent on the endothelium. Similarly, Lüscher and Vanhoutte observed previously that adult SHR aorta generates endothelium-dependent contraction to acetylcholine and that indomethacin blocked this contraction. The existence of endothelium-dependent contraction in the present study was also supported by the appearance of the small but significant dose-dependent contractile responses to acetylcholine in quiescent rings with endothelium from old WKY rats.

It has been reported that adult SHR aorta or renal artery stimulated by acetylcholine, canine femoral artery or porcine pulmonary artery...
were partially inhibited by CV-4151 but not by (left panels) rat aorta with (lower panels) hypertension rat (SHR) and Wistar-Kyoto (WKY) rats. We found that the release of or vascular response to EDRF by purinergic stimulation might not differ in either strains or age groups. Hongo et al39 demonstrated that ATP-induced relaxations in the carotid artery from WKY rats decreased with advancing age.39 This difference from our observation may be because of the different region of origin of the blood vessels. Thus, it is possible that the generation of EDRF or its response in rat aorta is generally maintained independent of effects of age or hypertension.

The degree of relaxation by sodium nitroprusside was similar at all ages of both SHR and WKY rats, whether with or without endothelium. Shirasaki et al49 demonstrated that relaxation responses to sodium nitroprusside in the aorta of adult and old rats were increased by removal of the endothelium. This report is in contrast with our experiments. Yanagisawa et al36 reported the existence of endothelin, a potent vasoconstrictor peptide produced by vascular endothelial cells.36 However, EDCF in our experiments may be different from endothelin because endothelin-induced vasoconstrictions are not blocked by indomethacin.36

Lüscher and Vanhoutte6 suggest that the reduction of acetylcholine-induced relaxation in adult SHR aorta may be due to the release of EDCF in vascular endothelium of hypertensive animals at higher concentrations of acetylcholine. Also, in the present study, reduction of the vasorelaxation effect of acetylcholine with increasing age may be attributed to the appearance of endothelium-dependent contraction. Our findings that, in the presence of indomethacin, the acetylcholine-induced relaxations were identical in both strains and among three ages suggest that the releases of or vascular responsiveness to EDRF stimulated by acetylcholine in rat aorta are well maintained regardless of senescence or high level of blood pressure. In addition, the similarity of ATP-induced endothelium-dependent relaxations in all groups indicates that the release of or vascular response to EDRF by purinergic stimulation might not differ in either strains or age groups. Hongo et al39 demonstrated that ATP-induced relaxations in the carotid artery from WKY rats decreased with advancing age.39

Previous reports have demonstrated different EDCF's such as 1) vasoconstrictor prostanoids like thromboxane A2,7,31-34 2) angiotensin II,35 3) endothelin,36 4) oxygen-derived free radicals,37 and 5) unidentified substances.5,6,27-30 Because acetylcholine-induced contractions in our model were partially inhibited by CV-4151 but not by tranylcypromine, the findings in the present study suggest, like the previously reported findings,7,31-33 that thromboxane A2 contributes but cannot fully explain endothelium-dependent contraction. In other words, the cyclooxygenase pathway may produce EDCF only in some branches of the pathway (i.e., thromboxane formation, formation of prostanoids other than prostaglandin I2). In addition, it has been demonstrated that oxygen-derived free radicals, which are generated by activation of endothelial cyclooxygenase,38 may mediate endothelium-dependent contraction in the basilar artery of the dog.37 We cannot exclude the participation of oxygen-derived free radicals in endothelium-dependent contractions in our experiments. Yanagisawa et al36 reported the existence of endothelin, a potent vasoconstrictor peptide produced by vascular endothelial cells.36 However, EDCF in our experiments may be different from endothelin because endothelin-induced vasoconstrictions are not blocked by indomethacin.36

Figure 6. Line graphs showing dose-dependent relaxations to sodium nitroprusside in spontaneously hypertensive rat (SHR) (upper panels) and Wistar-Kyoto (WKY) rat (lower panels) aorta with (left panels) and without (right panels) endothelium at various ages.

Exposed to hypoxia, and stretched canine basilar artery30 generate endothelium-dependent contractions. In the present study, acetylcholine-induced, endothelium-dependent contraction was identified in the aorta of not only adult and old SHR but also old normotensive WKY rats. We found that the aorta of old WKY rats also elaborate EDCF despite the absence of hypertension, suggesting that age may also promote endothelium-dependent contraction regardless of the level of blood pressure and also that the development of genetic hypertension accelerates the occurrence of endothelium-dependent contraction.
We conclude that EDCF is released with increasing age independently of the level of blood pressure, resulting in attenuation of endothelium-dependent relaxation. In hypertensive rats, EDCF is synthesized at a younger age as compared against findings in normotensive rats. These contracting factors are thromboxane A₂ and other cyclooxygenase products other than prostaglandin I₂.

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T Koga, Y Takata, K Kobayashi, S Takishita, Y Yamashita and M Fujishima

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