Attenuation of Pressor Responses to Norepinephrine and Pitressin and Potentiation of Pressor Response to Angiotensin II by Captopril in Human Subjects

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SUMMARY The present study was conducted to investigate the influence of captopril on cardiohemodynamic responses in 38 normal volunteers (20- to 35-year-old men) to exogenously administered vasopressor substances. Norepinephrine (NE), 0.05, 0.1, and 0.2 μg/kg min⁻¹; angiotensin II (AII), 5, 10, and 20 ng/kg min⁻¹; and pitressin (2 mU/kg min⁻¹) were infused for 10 minutes. Each infusion was repeated twice, and the responses were reproducible. Captopril (50 mg by mouth) significantly attenuated the pressor responses to NE and pitressin, but the decrease in heart rate in response to NE and pitressin was almost the same before and after captopril treatment, suggesting that captopril potentiates reflex slowing of the heart. Captopril significantly potentiated the pressor response to AII. Attenuation of pressor response and potentiation of reflex slowing of the heart, in response to NE and pitressin, disappeared when a subdepressor dose of AII (1 ng/kg min⁻¹) was infused in addition to captopril. Infusion of a subdepressor dose of bradykinin (BK), 0.1 μg/kg min⁻¹, had no influence on the pressor response to NE. In the subjects treated with indomethacin (225 mg/54 hrs), captopril still attenuated the pressor response to NE. These results suggest that captopril attenuates the pressor responses to NE and pitressin primarily by depletion of endogenous AII; decreased AII may desensitize the contraction of arterial smooth muscle and may potentiate the compensatory reflex mechanism. (Hypertension 4: 444-451, 1982)

KEY WORDS • blood pressure • heart rate • bradykinin • angiotensin • indomethacin • vascular reactivity • baroreflex • plasma renin activity

Captopril (SQ 14,225), an orally active angiotensin-converting enzyme inhibitor, has been shown to be effective in lowering the blood pressure of hypertensive patients. It is generally assumed that the hypotensive effect of captopril may be due to either suppression of angiotensin II (AII) formation or potentiation of bradykinin (BK), or a combination of both, since angiotensin converting enzyme is identical to kininase II. However, the precise role of the renin-angiotensin and the kallikrein-kinin systems in mediating the hypotensive effect of captopril still remains to be determined. There is documented evidence that captopril lowers blood pressure in some patients with low renin hypertension and in some anephric patients. Additional studies are needed to uncover the mechanism of action of this important therapeutic agent. Okuno et al. recently reported that captopril attenuated the contractile response to norepinephrine (NE) in the rat mesenteric artery. In view of these reports, we put forward a hypothesis that the hypotensive action of captopril is due to a change in vascular reactivity to vasopressor substances and modulation of the baroreflex mechanism. To test this hypothesis, we examined the effect of captopril on cardiohemodynamic responses to several vasoactive substances in normal volunteers.

Materials and Methods

The present study was conducted on 38 male volunteers from 20 to 35 years of age, who were normotensive without any known renal or cardiovascular disease. They gave informed consent before the study.
All subjects were allowed an unrestricted diet (including sodium intake), and underwent the studies either in the morning or the afternoon after a light breakfast or lunch. Each subject was investigated in the recumbent position; blood pressure was measured with an automatic blood pressure recorder (Roche, Arteriosonde Type 1210) and heart rate by a cardio-tachometer, at 1-minute intervals throughout the study. Blood pressure and heart rate of all the subjects became stable during 1 hour of bedrest in the recumbent position. An intravenous infusion of isotonic glucose solution was started via an indwelling venous cannula at a rate of 1 ml/min and continued until the end of the study. Without disturbing the subjects, the drug solution was then infused by constant infusion pump (ATOM, Type 201) superimposed on the glucose infusion.

Drugs used in this study were NE (Noradrenalin, Sankyo), All (Hypertensin, Ciba), pitressin (Parke-Davis), BK (BSR 640, Sandoz), captopril (Squibb-Sankyo), and indomethacin (Inteban SP, Sumitomo). We had previously determined that 1 μU of pitressin (Parke-Davis) was equivalent to 2.5 to 2.7 pg of synthesized arginine vasopressin (unpublished data).

The term “basal” used in the present study refers to a value obtained just prior to the administration of vasopressor substances (average of five readings). The term “control” used in the present study refers to responses to vasoactive substances before captopril treatment or BK infusion. The response was defined as the difference between the “basal” value and the average of five readings for each dose of vasoactive substance given. In the cases of NE and All, the final five readings were averaged, while in the case of pitressin, the five readings from the 3rd to 7th minute in the course of a 10-minute infusion were averaged, since tachyphylaxis was found easily during the infusion of pitressin. Blood samples for the measurement of plasma renin activity (PRA) were taken just prior to the infusion of vasoactive substances and with and without captopril treatment; PRA was measured radio-immunologically as described previously.10

Study Groups

Ten groups for 10 different studies were designed. One-half of the subjects were studied twice in different study protocols. The second study was performed at least 1 week after the first one. In all groups except Groups 3, 6, and 9, the changes in heart rate in response to vasopressor substances were expressed as the value obtained with the highest dose. Reproducibility of Cardiohemodynamic Responses to Norepinephrine (Group 1), Angiotensin II (Group 2), and Pitressin (Group 3)

Norepinephrine in doses of 0.05, 0.1, and 0.2 μg/kg min−1; All in doses of 5, 10, and 20 ng/kg min−1; and pitressin in a dose of 2 mU/kg min−1 were infused into three different groups (Groups 1, 2, and 3, each with five subjects). These infusions were repeated two times to determine the reproducibility of the responses to these vasoactive substances. Norepinephrine, All, and pitressin solutions were diluted to concentrations of 50 μg/ml, 5 μg/ml, and 0.5 U/ml, respectively, using physiological saline. At least 1 hour was allowed to elapse between the first and the second infusion. Three doses of NE or All were infused for 10 minutes each. The effects of pitressin were studied using only one dose, since tachyphylaxis and urge for defecation occurred.

Effect of Captopril on the Cardiohemodynamic Responses to Norepinephrine (Group 4), Angiotensin II (Group 5), and Pitressin (Group 6)

Seven (Group 4), six (Group 5), and five (Group 6) normal volunteers were examined to determine the effect of captopril on the responses to vasopressor substances. A control response to the vasopressor substances was obtained, and 1 hour later captopril in a dose of 50 mg was administered orally. One hour later, the vasopressor substances were infused again. Doses of the drugs were the same as in Groups 1, 2, and 3.

Effect of Combined Treatment with Captopril and a Subdepressor Dose of Angiotensin II on the Cardiohemodynamic Responses to Norepinephrine (Group 7) and Pitressin (Group 8)

Five normal volunteers were examined in Groups 7 and 8. The subdepressor dose of All was determined by extrapolation of the dose-response curve obtained in Group 2. One hour after obtaining the control pressor responses to NE and pitressin, infusion of All at a rate of 1 ng/kg min−1 was started in addition to the oral administration of captopril in a dose of 50 mg. The second responses to NE and pitressin were tested during the infusion of All at a low rate. Doses of the drugs were the same as in Groups 1 and 3.

Effect of Infusion of Subdepressor Dose of Bradykinin on the Cardiohemodynamic Responses to Norepinephrine (Group 9)

Five normal volunteers were examined in Group 9. The responses to NE were examined with only one dose (0.1 μg/kg min−1 for 10 minutes). One hour after the control responses to NE were obtained, BK was infused in a dose of 0.1 μg/kg min−1 for 20 minutes; the BK solution was diluted to a concentration of 50 μg/ml using physiological saline. Ten minutes after the start of BK infusion, NE in a dose of 0.1 μg/kg min−1 was infused.

Effect of Combined Treatment with Indomethacin and Captopril on the Cardiohemodynamic Responses to Norepinephrine (Group 10)

Five normal volunteers were examined in Group 10. Indomethacin in a dose of 25 mg was administered orally every 6 hours for 54 hours; then, 1 hour after the final administration, the control responses to NE were examined. One hour later, captopril in a dose of 50 mg was administered orally. After another hour, the responses to NE were examined again to deter-
determine the effect of the combined treatment with indomethacin and captopril on the responses to NE.

Calculation and Analytical Methods

The mean arterial blood pressure (MAP) was calculated from systolic and diastolic blood pressure in the conventional way. The values in the text, table, and figures are means ± SEM. The dose response curves for NE and All within a group and those between groups were analyzed by one-way analysis of covariance. It was determined whether the slopes of the linear regression and the corrected means for a few groups of data on pressor response to vasopressor substance were different from each other. The pressor responses to pitressin within a group were analyzed by Student's t test for paired comparison, and those between groups were analyzed by analysis of variance.

Results

Table 1 shows the basal MAP and heart rate before and after captopril or BK administration. In all studies, no statistically significant difference was found between the MAP before and after captopril or BK administration.

Pressor Responses to Norepinephrine, Angiotensin II, and Pitressin

Figure 1 (upper) shows changes in MAP produced by NE infusion in 17 subjects before captopril. Arterial pressure was increased by NE with time and with doses. Figure 1 (center) shows similar changes in MAP produced by infusion of All in 11 normal subjects. With infusion of pitressin (fig. 1 lower), MAP increased rather rapidly and attained a peak 4 minutes after the start of infusion, but failed to remain elevated and returned toward preinfusion level.

Reproducibility of the Cardiohemodynamic Responses to Norepinephrine, Angiotensin II, and Pitressin (Groups 1, 2, and 3)

As shown in figures 2 (left, 3 left, and 4 left), the pressor response to each dose of vasopressor substances obtained from the first administration was not significantly different from that obtained from the second administration. The pressor responses to NE, All, and pitressin were reproducible. The reflex slowing of the heart in response to NE and pitressin was also reproducible. The decrease in heart rate with NE was -10.9 ± 1.8 bpm (first administration) and -8.7 ± 2.9 bpm (second administration), and -4.9 ± 1.5 and -6.5 ± 1.1 bpm with pitressin. The chronotropic effect of All was also reproducible, the change in heart rate being -2.9 ± 1.8 and -1.2 ± 1.5 bpm respectively, although the chronotropic effect of All was variable depending upon individuals in such a way that the heart rate was increased in one, decreased in three, and unchanged in the remaining subject.

Effect of Captopril on the Cardiohemodynamic Responses to Norepinephrine, Angiotensin II, and Pitressin (Groups 4, 5 and 6)

Captopril did not reduce MAP in normal men (table 1). However, the dose-response curve for NE after captopril was located on the right of the control curve (fig. 2 center); the slopes of both curves were not significantly different from each other. There was a significant difference between the corrected means of data on pressor responses to NE before and after captopril (p < 0.005); in other words, captopril

<table>
<thead>
<tr>
<th>Group no.</th>
<th>No. of subjects</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Basal MAP (mm Hg)</th>
<th>Basal heart rate (beats/min)</th>
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<td>Control period</td>
<td>Second period</td>
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<tr>
<td>1 5</td>
<td>22.2 ± 1.3</td>
<td>62.4 ± 2.1</td>
<td>84.2 ± 2.3</td>
<td>81.6 ± 2.6</td>
<td>55.5 ± 3.5</td>
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<td>2 5</td>
<td>23.8 ± 3.4</td>
<td>67.2 ± 3.0</td>
<td>83.9 ± 5.1</td>
<td>84.8 ± 5.3</td>
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<td>3 5</td>
<td>22.4 ± 1.3</td>
<td>62.4 ± 2.1</td>
<td>84.3 ± 1.3</td>
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<td>60.6 ± 2.4</td>
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<td>4 7</td>
<td>25.7 ± 2.1</td>
<td>62.5 ± 2.3</td>
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<td>61.4 ± 2.3</td>
<td>83.2 ± 2.2</td>
<td>82.8 ± 2.6</td>
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<td>62.8 ± 0.5</td>
<td>86.5 ± 2.2</td>
<td>88.6 ± 2.0</td>
<td>64.8 ± 1.1</td>
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<td>83.9 ± 5.0</td>
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<td>64.4 ± 3.6</td>
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<td>10 5</td>
<td>23.8 ± 1.5</td>
<td>67.2 ± 3.0</td>
<td>82.1 ± 5.6</td>
<td>80.1 ± 2.9</td>
<td>63.9 ± 5.0</td>
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In Groups 1, 2, and 3, no pretreatment was carried out in the second period. In Groups 4, 5, 6, and 10, captopril was given in the second period. In Groups 7 and 8, captopril and a subpressor dose of angiotensin II were given in the second period. In Group 9, bradykinin was infused in the second period. In Group 10, indomethacin was given in the control and the second periods.
significantly attenuated the pressor response to NE. The control dose-response curves in Groups 1, 4, and 7 were not significantly different from each other. The dose-response curve after captopril in Group 4 was significantly different from the control curves in Groups 1 and 7 \((p < 0.01)\).

Contrariwise, captopril slightly but significantly \((p < 0.01)\) potentiated the pressor response to All, as shown in figure 3 right. The control dose-response curves in Groups 2 and 5 were significantly different from each other. The dose response curve after captopril in Group 5 was significantly different from the control curve in Group 2.

As shown in figure 4 center, captopril significantly attenuated the pressor response to pitressin \((p < 0.01)\). The control pressor responses to pitressin in Groups 3, 6, and 8 were not significantly different from each other. The pressor responses in control in Groups 3, 6, and 8 were pooled and compared with that after captopril in Group 6. There was significant difference between these responses \((p < 0.02)\).

Although the increases in blood pressure caused by NE and pitressin were significantly attenuated by captopril, the decreases in heart rate caused by these pressor substances after captopril were similar to those before captopril. With NE, the decrease in heart rate was \(-11.0 \pm 1.2\) bpm before and \(-11.4 \pm 1.5\) bpm after captopril. With pitressin, the decrease in heart rate was \(-4.0 \pm 1.4\) bpm before and \(-5.5 \pm 1.1\) bpm after captopril. The change in heart rate caused by All after captopril \((-5.2 \pm 2.4\) bpm) was almost similar to that before \((-4.6 \pm 3.3\) bpm).

**Effect of Captopril on the Cardiohemodynamic Responses to Norepinephrine and Pitressin during Infusion of Subdepressor Dose of Angiotensin II (Groups 7 and 8)**

Infusion of All in a dose of 1 ng/kg min\(^{-1}\) in addition to captopril caused no significant change in MAP or heart rate (table 1). With the infusion of All, the attenuation by captopril of the pressor responses to NE (fig. 2 right) and pitressin (fig. 4 right) disappeared.

The changes in heart rate caused by NE \((-8.8 \pm 1.3\) bpm) and pitressin \((-4.5 \pm 1.3\) bpm) during combined treatment with captopril and All were not significantly different from those in the control period \((-10.1 \pm 1.7\) bpm and \(-2.9 \pm 0.8\) bpm respectively).

**Effect of Infusion of a Subdepressor Dose of Bradykinin on the Cardiohemodynamic Responses to Norepinephrine (Group 9)**

Infusion of BK in a dose of 0.1 \(\mu\)g/kg min\(^{-1}\) did not decrease the MAP (table 1). In three of the five subjects, BK infusion in a dose of 0.1 \(\mu\)g/kg min\(^{-1}\) caused a slight tachycardia and burning sensation. The pressor response to NE during BK infusion \((14.1 \pm 4.7\) mm Hg) was almost identical to the control pressor response \((15.0 \pm 2.8\) mm Hg). The bradycardia caused by NE was significantly less during BK infusion \((-3.3 \pm 0.8\) bpm) than in the control \((-6.8 \pm 1.0\) bpm, \(p < 0.05)\).
Figure 2. Reproducibility of the pressor response to norepinephrine (left), modification of the pressor response to norepinephrine by captopril (center), and the effect of combined treatment with captopril and a subdepressor dose of angiotensin II on the pressor response to norepinephrine (right). •—• control pressor response; •—• pressor response to the second administration (left graph); △—△ pressor response after captopril (center); ◻—◆ pressor response during combined treatment (right). ΔMAP = change in mean arterial pressure. **Significant difference from control dose-response curve (p < 0.01).

Figure 3. Reproducibility of the pressor response to angiotensin II (left), and modification of the pressor response to angiotensin II by captopril (right). •—• control pressor response; •—• pressor response to the second administration (left); △—△ pressor response after captopril (right). Otherwise the same as figure 2.

Figure 4. Reproducibility of the pressor response to pitressin (left), modification of the pressor response by captopril (center), and the effect of combined treatment with captopril and a subdepressor dose of angiotensin II (right). **Significant difference from control (p < 0.01). • control pressor response; • pressor response to the second administration (left); △ pressor response after captopril (center); ◻ pressor response during combined treatment (right). ΔMAP = change in mean arterial pressure.
Effect of Captopril on the Cardiohemodynamic Responses to Norepinephrine during Indomethacin Treatment (Group 10)

The pressor response to each dose of NE in the group treated with indomethacin was not significantly different from that of the group without indomethacin (fig. 5 left). However, as shown in figure 5 right, the dose-response curves for NE was still attenuated by captopril (p < 0.01) even in the presence of indomethacin. The reflex bradycardia during combined treatment with captopril and indomethacin (−11.0 ± 2.5 bpm) was similar to that in the control (−10.8 ± 1.8 bpm).

Effect of Captopril on Plasma Renin Activity

The PRA recorded just prior to the second infusion of NE (3.1 ± 0.9 ng/ml · 6 hrs⁻¹, n = 5) was not significantly different from that obtained just prior to the first infusion of NE (3.0 ± 0.8 ng/ml · 6 hrs⁻¹). The PRA obtained 1 hour after captopril administration and just prior to the infusion of NE (15.5 ± 5.2 ng/ml · 6 hrs⁻¹, n = 7) was significantly higher than that obtained just prior to the infusion of NE in the control period (3.8 ± 0.7 ng/ml · 6 hrs⁻¹, p < 0.05).

Discussion

The influence of captopril on the pressor response to NE has been investigated in animal experiments. However, the results are conflicting. In vivo experiments showed that captopril scarcely affected the pressor response to NE in rabbits 12 and rats. 13 Recently, Spertini et al. 14 reported that in normotensive anesthetized rats acute converting enzyme blockade by captopril did not blunt the pressor response to NE and vasopressin, although chronic blockade blunted the pressor response to NE. Rubin et al. 15 reported that captopril, in vitro, had little effect on the contractile response of NE in the rat portal vein and rabbit thoracic aorta, whereas some authors reported that captopril attenuated the vasoconstrictor effect of NE in the rat mesenteric artery 4 or rat isolated kidney. 16 Our investigation presented here is the first report that describes the effect of an angiotensin converting enzyme inhibitor on the responses to exogenous vasopressor substances in humans. In the present study, captopril, 50 mg by mouth, attenuated the pressor responses to NE and pitressin in normal human subjects. The question arises as to what mechanism is involved for the attenuation of pressor responses to vasopressor substances. Since captopril attenuated the pressor responses to two vasopressor substances (NE and pitressin), it is unlikely that the attenuation was brought about by some specific mechanisms such as adrenergic alpha-receptor blockade. Since AI converting enzyme and kininase II are the same enzyme, 4 captopril potentiates a vasodepressor or a vasodilator action of BK. Thus, it is possible that the attenuation of the pressor responses to NE and pitressin might be due to counteraction of endogenous BK. However, the pressor response to NE was not attenuated by a subdepressor dose of BK, even though this dose was sufficient to cause symptoms such as slight tachycardia and/or a burning sensation. 18 Therefore, it is unlikely that the attenuation of pressor responses to the two vasopressors by captopril was caused by an accumulation of BK.

Bradykinin is well known to promote the synthesis of prostaglandins. 17, 18 It is proposed that a decrease in blood pressure after captopril treatment in the rat was the result of vasodilation produced through the interaction of angiotensin-bradykinin-prostaglandin system. 19 Recently, some authors have suggested that the potentiation of the prostaglandin system may contribute to the antihypertensive action of captopril. 5, 20 Therefore, it is also possible that a prostaglandin system activated by increased BK might attenuate the pressor responses. However, attenuation of the pressor response to NE by captopril also occurred even though this dose was sufficient to cause symptoms such as slight tachycardia and/or a burning sensation. 18 Therefore, it is unlikely that the attenuation of pressor responses to vasopressor substances. Since captopril attenuation was brought about by some specific actions such as adrenergic alpha-receptor activation. In the present study, captopril, 50 mg by mouth, attenuated the pressor responses to NE and pitressin in normal human subjects. The question arises as to what mechanism is involved for the attenuation of pressor responses to vasopressor substances. Since captopril attenuated the pressor responses to two vasopressor substances (NE and pitressin), it is unlikely that the attenuation was brought about by some specific mechanisms such as adrenergic alpha-receptor activation. Since AI converting enzyme and kininase II are the same enzyme, captopril potentiates a vasodepressor or a vasodilator action of BK. Thus, it is possible that the attenuation of the pressor responses to NE and pitressin might be due to counteraction of endogenous BK. However, the pressor response to NE was not attenuated by a subdepressor dose of BK, even though this dose was sufficient to cause symptoms such as slight tachycardia and/or a burning sensation. Therefore, it is unlikely that the attenuation of pressor responses to the two vasopressors by captopril was caused by an accumulation of BK.

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The attenuation of pressor responses to NE and pitressin does not depend on the specific change in the arteriole by captopril, since it did not occur with the other pressor agent, AII. In the present study, the attenuation of the pressor responses to NE and pitressin by captopril was abolished by infusion of a subdepressor dose of AII. This suggests that the depletion of endogenous AII by captopril may have some relationship to the attenuation of the pressor responses to vasopressor substances. Recently, Moulds and Worland reported that AII potentiated vasoconstrictor effects of NE, KCl, BaCl2, and 5-HT in human vasculature. Thoenen et al. reported that AII enhanced excitation-contraction coupling of vascular smooth muscle. Day and Moore provided evidence that AII may potentiate the effects of NE and other vasopressor substances by inhibiting the active extrusion of sodium from the vascular smooth muscle cells, thereby causing a nonspecific sensitization. If so, depletion of endogenous AII by captopril may lead to the diminution of pressor responses to vasopressor substances. The attenuation of the pressor responses to NE and vasopressin by captopril observed in the present study could be an expression of the loss of the sensitizing effect of endogenous AII.

In our present study, the pressor response to AII was potentiated after captopril. It is reported that the nonapeptide teprotide and captopril potenti ate the pressor response to exogenous AII. Thurston and Laragh postulated that the potentiation of the pressor response to exogenous AII observed during converting enzyme inhibition results from decreased competition for receptor sites to endogenous AII and increased availability of vascular receptor site to exogenous AII.

Reflex compensation mediated through the baroreceptors to acute elevation of arterial pressure could be an important contributor to the homeostasis of blood pressure. In the present study, the decrease in heart rate in response to NE and pitressin after captopril was almost similar to that in control, while the pressor responses to both vasopressor substances were lower with captopril than in control. Therefore, the dose of captopril, 50 mg by mouth, used in the present study could be sufficient to block angiotensin converting enzyme. However, the PRA was clearly increased. This reflects the blocking of the negative short-feedback mechanism of AII by angiotensin converting enzyme inhibitor.

In conclusion, the attenuation of pressor responses to captopril may be explained by its inhibition of angiotensin formation; decreased AII may desensitize the contraction of arterial smooth muscle and may potentiate the compensatory reflex mechanism.

Acknowledgments

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