Zinc Metallopeptidase Inhibitors
A Novel Antihypertensive Treatment

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Inhibitors of two zinc metallopeptidases, angiotensin I converting enzyme (ACE) and neutral metalloendopeptidase-24.11 (EP-24.11), are antihypertensive agents. In this issue of Hypertension, Genden and Molineaux report that yet another peptidase inhibitor, metalloendopeptidase-24.15, EC 3.4.24.15 (EP-24.15), lowers blood pressure in normotensive rats. In this editorial we discuss the possible role of kinins as common mediators of part of the vasodepressor action of these peptidase inhibitors. Genden and Molineaux report that the marked fall in blood pressure caused by the EP-24.15 inhibitor is almost abolished by a kinin receptor antagonist, supporting the hypothesis that kinins play a role in the regulation of normal blood pressure. We have confirmed that the EP-24.15 inhibitor used by these investigators lowers blood pressure. Up to now, EP-24.15 has not been implicated in in vivo metabolism of kinins. Although a number of kininases have been identified, our own previous work indicated that the metabolic pathway responsible for clearing kinins from the circulation involves the action of kininase II (angiotensin I converting enzyme) and renal peptidases. Nevertheless, the main metabolic pathway involved some other unidentified enzyme, since in these experiments disappearance of kinins from the circulation was only marginally reduced by a “cocktail” of inhibitors of ACE, EP-24.11, and carboxypeptidase N. It could be that EP-24.15 is involved in kinin metabolism. However, a number of questions need to be answered with regard to the mechanism by which the EP-24.15 inhibitor lowers blood pressure. The data obtained with the EP-24.15, NE-24.11, and ACE inhibitors suggest that potiation of vasodilator peptides is yet another possible relevant therapeutic approach to hypertension and perhaps heart failure. (Hypertension 1991;68:366-371)

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The results of
Genden and Molineaux suggest that EP-24.15 is involved in kinin metabolism. However, a number of questions need to be answered with regard to the mechanism by which the EP-24.15 inhibitor lowers blood pressure.

1) Does inhibition of EP-24.15 increase blood kinins? In the rat, the concentration of kinins in plasma needs to be increased at least 100-fold above normal to lower blood pressure to the extent observed after the administration of EP-24.15 inhibitor. It would be interesting to determine whether the EP-24.15 inhibitor produces changes of this magnitude in plasma kinins. However, we have reported that part of the acute antihypertensive effect of ACE inhibitors in an experimental hypertensive model was blocked by a kinin antagonist even though the ACE inhibitor did not significantly alter plasma kinins. Thus, it is possible that the EP-24.15 inhibitor decreased degradation of tissue kinins, leading to buildup of the peptide in tissues (presumably the vascular wall) but not in plasma. This would agree with our current view that the kallikrein-kinin system acts as a paracrine system. Local increase of kinins in various tissues would support this hypothesis; however, at present reliable methods of measuring kinins in tissues are not available.

2) Which enzymes are responsible for endogenous kinin generation? Increasing kinins by inhibiting their degradation presupposes that kinin generation is continuous. Since acute administration of kinin antagonist does not alter blood pressure in normotensive animals, it follows that kinins should normally be immediately destroyed, keeping the final concentration low. There is little evidence of the existence of such a continuous kinin-generating pathway. However, the study of Genden and Molineaux and our studies showing that the blood pressure effects of ACE inhibitors are blocked by kinin antibodies or antagonists suggest that kinins may be formed and hydrolyzed continuously. We do not know which enzymes release tissue kinins. We have reported that vascular tissue contains a kininogenase that has the same properties as glandular kallikrein and that messenger RNA for kallikrein is present in vascular tissue and smooth muscle cells in culture. Oza et al reported that vascular smooth muscle cells in culture release both kallikrein and kininogen (kallikrein substrate). Thus, it may be that vascular kininogenase generates kinins continuously and that they are rapidly destroyed by peptidases such as EP-24.15 and ACE. Plasma kallikrein is a different enzyme from glandular kallikrein, and its concentration in plasma is quite high. Although it normally circulates as prekallikrein, the inactive precursor, it is possible that kinins are generated via activation of the plasma kallikrein-kinin system. However, there is no evidence that this is a normally operating phenomenon.

3) What criteria were used by Genden and Molineaux to select the dose of the kinin antagonist? These investigators used a dose of the kinin antago-
5) Does the EP-24.15 inhibitor lower blood pressure by decreasing cardiac output or total peripheral resistance? It could be that EP-24.15 inhibitors alter heart inotropic and chronotropic activity. These possibilities need to be studied further.

We now know of inhibitors of three different zinc metalloendopeptidases that have either a hypotensive or antihypertensive effect, namely ACE, EP-24.11, and EP-24.15. These are three distinct enzymes that only cleave small peptides; their inhibitors reduce blood pressure by either blocking formation of vasopressor peptides such as angiotensin II or inhibiting degradation by vasodepressor peptides such as kinins and atrial natriuretic factor (ANF).1,17,18 However, in vitro neither ACE, EP-24.11, nor EP-24.15 is specific for a particular substrate but rather cleaves a number of peptides.1,18,19 In vivo, hydrolysis of a particular substrate by these peptidases may depend on whether enzyme and substrate have the opportunity to interact, as well as on factors that alter the kinetics of the reaction. Kinins, which are potent vasodepressor peptides, are common substrates for these three peptidases (Figure 1).

Metalloendopeptidase EC-3.4.24.15

EP-24.15 was first identified by Orlowsky et al20 in 1983 as a metalloendopeptidase cleaving several bioactive peptides (including bradykinin). Work on the specificity of the enzyme with model synthetic substrates led to the design and synthesis of potent, active site-directed inhibitors that could be used as probes in studies of the role of the enzyme in vivo metabolism of bioactive peptides.21,22 EP-24.15 is highly concentrated in the testes, with lower levels in the brain, pituitary, kidney, heart, adrenal, lung, and liver. In the brain, part of the enzyme is in soluble form and part is bound to membranes.23-25 The enzyme preferentially cleaves bonds on the carboxyl side of hydrophobic amino acid residues in the P1 position. A bulky or hydrophobic residue in the P1' position greatly increases the affinity of the substrate for the active side of the enzyme.26,27 EP-24.15 converts large opioid peptides to Leu- and Met-enkephalin and degrades neurotensin, luteinizing hormone-releasing hormone and kinins. Like ACE or EP-24.11, EP-24.15 is not specific for a single peptide substrate such as kinins and probably metabolizes other peptides containing hydrophobic amino acids. Thus, the effects of EP-24.15 inhibitors may be more complex than Genden and Molineaux proposed. Nevertheless, this is an important study, since EP-24.15 inhibitors have the potential to become a new class of antihypertensive drug.

Neutral Metalloendopeptidase EC-3.4.24.11

The effects of EP-24.11 inhibitors, like those of ACE inhibitors, are probably due to blockade of the hydrolysis of a variety of peptides; some lower blood pressure, such as ANF, kinins, neurotensin, enkephalins, and endorphins, whereas others may increase blood pressure, among them angiotensin, endothelin, and perhaps vasopressin.18 However, the final result is a decrease in blood pressure.1,27 The prevailing hypothesis is that they lower blood pressure by inhibiting the hydrolysis of ANF. However, EP-24.11 is an important kininase, both in the kidney and the brain.18,28 In our laboratory, Ura et al28 have shown that EP-24.11 is the main renal kininase in the rat and that acute inhibition of this enzyme by phosphoramidon resulted in an increase in urinary kinins and sodium and water excretion. However, phosphoramidon caused no changes in plasma kinins.4 We hypothesized that the saluretic effect of phosphoramidon is mediated by an increase in both renal kinins and ANF. The work of Smits et al29 further supports this hypothesis; they reported that thiorphan, which is also an inhibitor of EP-24.11, potentiated the acute effects of ANF on water and sodium excretion and that these effects were blocked completely by a kinin antagonist. At the dose infused, ANF had no effect on blood pressure. However, it has also been reported that the acute natriuretic effect of EP-24.11 inhibitors is blocked by ANF antisera.30 These studies support the hypothesis that the natriuretic and diuretic effects of EP-24.11 inhibitors are mediated by an increase in both ANF and renal kinins, which may act synergistically. It is not clear whether an increase in plasma or renal ANF is needed for these effects.

In normotensive humans, UK 79300, also an inhibitor of NE-24.11, increased urinary sodium, water, ANF, and cyclic GMP excretion.31 At the dose used, the inhibitor caused no changes in blood pressure; however, plasma renin activity and aldosterone were significantly decreased, and a small increase in plasma ANF was observed. (Kinins were not measured.) Sybertz et al7,32 and Seymour et al33 reported that inhibition of EP-24.11 in deoxycorticosterone acetate (DOCA)-salt hypertension has an acute antihypertensive effect. In this model, plasma ANF is increased; however, the EP-24.11 inhibitor did not cause a further increase in ANF, and yet polyclonal antiserum to ANF blocked most of the antihypertensive effect of EP-24.11 inhibitor while the kinin antagonist had no effect.27 In SHR, EP-24.11 inhibitors also had an antihypertensive effect that was smaller than in DOCA-salt rats,33 and in some cases

FIGURE 1. Schematic diagram shows site of cleavage of kinins by various peptidases.
the inhibitor took 3 days to lower blood pressure. In humans, it has been reported that EP-24.11 inhibitors have an antihypertensive effect that was more pronounced in black patients.34

In conclusion, EP-24.11 inhibitors may be useful drugs in the treatment of hypertension and perhaps heart failure. Their antihypertensive effect is probably due to a direct vasodilator action of ANF and the combined natriuretic effect of both ANF and kinins. However, the roles of other vasoactive peptides that may be cleaved by EP-24.11 cannot be completely excluded.

Angiotensin Converting Enzyme EC-3.4.15.1

Inhibition of ACE has resulted in effective treatment of hypertension and congestive heart failure.35 ACE inhibitors act by blocking conversion of angiotensin I to II; however, it is difficult to explain their effect by this mechanism alone, especially in low-renin hypertension.36-44 In addition to blocking conversion of plasma angiotensin I to II, two other major hypotheses have been postulated to explain the effect of ACE inhibitors in low-renin hypertension: 1) their effect is mediated by blockade of the extra-renal tissue renin-angiotensin system53 and 2) their effect is partially due to inhibition of kinin degradation in tissue, which lowers vascular resistance directly or via prostaglandins and endothelium-derived relaxing factor.46 Due to limitations of space, the first hypothesis will not be discussed here.

The hypothesis that kinins participate in the effect of ACE inhibitors is supported by the following data: 1) ACE has higher affinity for kinins than for angiotensin I.19,47 2) Although plasma kinins are unchanged or moderately increased after ACE inhibitors,48 urinary kinins reportedly increase, indicating that their renal concentration likewise increases.28,49,50 This in turn may contribute to the antihypertensive effect of ACE inhibitors by altering blood flow and increasing sodium and water excretion. Kinins also increase in the venous effluent of organs rich in tissue kallikrein.51 3) Inhibition of the kallikrein-kinin system with aprotinin,52 kinin antagonist7-55-57 partially blocks the acute effects of ACE inhibitors on renal function, blood pressure, and blood flow.4) In kininogen- and kinin-deficient Brown-Norway rats with two-kidney, one clip renovascular hypertension, the drop in blood pressure caused by intravenous injection of ACE inhibitors is significantly reduced in both magnitude and duration.58 5) An ACE inhibitor increases water and sodium excretion and renal papillary blood flow in rats pretreated with the angiotensin antagonist DuP 753; these effects were blocked by the kinin antagonist.59 These studies indicate that some of the acute effects of ACE inhibitors on renal function, blood flow, and blood pressure are mediated by kinins; however, whether they play a role in the chronic effects of ACE inhibitors is not known.

In summary, the communication by Genden and Molineaux suggests that EP-24.15 is an important kininase and that its inhibition results in a hypotensive response that may be due to buildup of kinins. We have confirmed that this inhibitor indeed markedly decreases blood pressure; however, the role of kinins as mediators of this response needs further study. Although these are preliminary data, they suggest that inhibitors of EP-24.15 deserve attention as potential new antihypertensive compounds. The data of Genden and Molineaux support the hypothesis that peptidergic hormones are important components of the balance between vasoconstrictors and vasodilators. These data and those obtained with NE-24.11 and ACE inhibitors suggest that potentiation of vasodilator peptides is yet another relevant therapeutic approach to hypertension and heart failure.

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