Brain Angiotensin II
New Insights Into Its Role in Sympathetic Regulation
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Since its discovery, the renin-angiotensin II system (RAS) has intrigued physiologists and clinicians. Angiotensin II (Ang II), an ancient peptide, evolved to carry out a variety of biological functions, in order to meet the needs of diverse organisms. The negative feedback nature of the RAS enables it to participate in hemodynamic, endocrine, neural, behavioral, and excretory functions. It is truly a peptide to which the survival of most species is closely linked.

Over the past 20 years, blockade of the RAS has become a prime target for pharmacotherapy in a variety of diseases. Either blockade of Ang I conversion to Ang II or blockade of the Ang II type I receptor (AT1) has been used to treat hypertension and heart failure. Administration of these agents are effective in ameliorating disease and enhancing survival, even in patients without augmented levels of circulating Ang II. This observation has led investigators to focus on the tissue RAS as a mechanism by which organ function is both controlled and, in disease states, impaired. Although the kidney is the only organ that stores renin in granular form, the components of the RAS have been found in tissues from several other organs. These include the heart, liver, lung, and brain. The regulation of the RAS system in the brain is especially intriguing because Ang II can act as both a neurotransmitter and a vasoconstrictor.

It has been known for some time that the brain expresses the genes that code for angiotensinogen, renin, converting enzyme, and all of the subtypes of the AT1 and AT2 receptors. The actions of Ang II in the central nervous system include promotion of thirst behavior and salt appetite, the regulation of vasopressin secretion, the regulation of sympathetic outflow, and modulation of the sensitivity of the arterial baroreflex, as well as many other important cardiovascular reflexes (Figure). The modulation of sympathetic outflow is a critical regulatory action of central Ang II because both chronic heart failure and some forms of hypertension are characterized by sympathoexcitation. The precise nature by which the brain RAS participates in the regulation of sympathetic outflow is still not completely understood. A major step forward in our understanding of the role of the RAS in blood pressure regulation has come from the study of Lazartigues et al. reported in this issue of Circulation Research. These investigators developed a new and novel transgenic mouse that selectively overexpresses brain AT1 receptors. To develop this model, they took advantage of splicing the gene for the AT1 receptor with that of the neuron-specific enolase (NSE). The resulting animals (NSE-AT1) overexpressed the AT1 receptor in neurons in a wide variety of brain areas but not in glial cells or peripheral tissues (except for the adrenal medulla). Interestingly, these animals had normal resting arterial blood pressure, a finding not predicted based on other experiments in which arterial pressure was lowered in hypertensive animals by blockade or genetic manipulation of the central RAS. Although the arterial pressure of the NSE-AT1 was normal, these animals responded with an exaggerated increase in arterial pressure after central administration of Ang II. These two observations are important because they strongly suggest that overexpression of AT1 receptors in normal animals does not alter arterial pressure and, most likely, sympathetic outflow. These data also relate to the issue of baroreflex resetting, which has been shown to be influenced by nonpressor doses of Ang II. In order to minimize decreases in baroreflex sensitivity after an increase in arterial pressure, the baroreflex operating point may shift closer to the elevated pressure. The study by Lazartigues et al adds support for the notion that central AT1 receptors may participate in the resetting process.

The role of Ang II in the sympathoexcitatory process of disease states such as chronic heart failure has been an active area of investigation. For instance, it has been shown that central and peripheral administration of the AT1 receptor antagonist losartan enhances baroreflex sensitivity, which may contribute to sympathoinhibition. In addition, it appears that central Ang II participates in the sympathoexcitatory process of the heart failure state by virtue of sensitization of reflexes that are sympathoexcitatory in nature, such as the cardiac sympathetic afferent reflex. This reflex too can be normalized by blockade of the AT1 receptor in the brain or more specifically in discrete regions of the central nervous system such as the paraventricular nucleus.

The genetic manipulation of the AT1 receptor offers a unique opportunity to develop new therapeutic strategies in the treatment of hypertension, heart failure, and other states characterized by sympathoexcitation. The strategy described in the article of Lazartigues et al is but one possibility. Another method to implicate overexpression or hyperactivity of the AT1 receptor in disease states is the use of antisense oligonucleotide administration to reduce transcription of the mRNA for the AT1 receptor in both hypertension and heart failure. These studies point to a potential pivotal role of...
the AT1 receptor in the mechanism of the sympathoexcitation in these disease states. Finally, overexpression of the renin gene has proved to be an important model to implicate the brain RAS in the pathogenesis of hypertension.\textsuperscript{10,27} Hopefully, it will be possible to construct target-specific overexpression in order to identify specific sites in the regulation of Ang II–mediated responses.

Although the observations relating to the manipulation of the central RAS suggest that Ang II and the AT1 receptors may be important in blood pressure regulation, there is also a large amount of evidence showing that these elements operate in concert with other endocrine and paracrine factors. For instance, nitric oxide (NO) may modulate the action of Ang II and expression of AT1 receptors in various sites.\textsuperscript{28} In fact, central infusion of Ang II has been shown to decrease nNOS gene expression in conscious animals only after increasing plasma (and most likely brain) levels of Ang II.\textsuperscript{29} Therefore, one could envision the use of the NSE-AT1 model as a tool to investigate the role of other substances produced in the central nervous system that are modulated by Ang II, such as NO.

In summary, there are now several transgenic and knockout rodent models in which the brain RAS has been manipulated. Indeed, in a recent report from the laboratory of one of the coauthors of the article by Lazartigues et al,\textsuperscript{15} the human renin gene was overexpressed in the mouse.\textsuperscript{9} These models will undoubtedly be important for a comprehensive understanding of the role played by, and the regulation of, Ang II in the brain. The application of integrative physiology to these models will help to mesh this novel molecular biology with pathology to better treat patients with sympathoexcitatory syndromes.

References


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