Angiotensin II Type 2 Receptor Blockade Amplifies the Early Signals of Cardiac Growth Response to Angiotensin II in Hypertrophied Hearts

Jozef Bartunek, MD, PhD; Ellen O. Weinberg, PhD; Minori Tajima, MD, PhD; Susanne Rohrbach, BA; Beverly H. Lorell, MD

Background—We have previously shown that the acute molecular growth response of new protein synthesis and protein kinase C activation in response to angiotensin II (Ang II) is altered in left ventricular (LV) hypertrophy compared with normal hearts. We have also shown an upregulation of Ang II type 2 (AT₂) receptors in hypertrophied hearts relative to controls. Activation of AT₂ receptors is proposed to counteract growth effects of AT₁ receptor in response to Ang II. Thus, we tested the hypothesis that in hypertrophied hearts, the AT₂ receptor mediates inhibitory effects on the new cardiac protein synthesis in response to acute Ang II stimulation.

Methods and Results—Flaccid buffer-perfused adult normal and hypertrophied rat hearts were perfused with Ang II 10⁻⁸ mol/L plus prazosin 10⁻⁷ mol/L or Ang II plus the AT₂ blocker PD 123319 5×10⁻⁷ mol/L. New protein synthesis was measured by the rate of [³H]phenylalanine incorporation into the LV proteins. In normal hearts, Ang II (n=8) increased the rate of [³H]phenylalanine incorporation by 74±27% (P<0.05 versus no drug). Treatment with PD123319 (n=8) did not increase protein synthesis compared with Ang II alone (32±11% versus Ang II alone, P=NS). In hypertrophied hearts, Ang II alone (n=6) increased the rate of [³H]phenylalanine incorporation only by 23±13% (P=NS versus no drug). In contrast, treatment with PD123319 (n=7) induced a 76±21% increase in new LV protein synthesis compared with Ang II alone (P<0.05). AT₂ receptor blockade in Ang II–stimulated hypertrophied hearts was associated with enhanced membrane protein kinase C translocation and reduced LV cGMP content.

Conclusions—These data support the hypothesis that in adult hypertrophied rat hearts, inhibition of cardiac AT₂ receptors, which are upregulated in chronic LV hypertrophy, amplifies the immediate LV growth response to Ang II. This appears to be related to augmented Ang II–stimulated PKC activation and suppression of cGMP signaling. (Circulation. 1999;99:22-25.)

Key Words: angiotensin ■ hypertrophy ■ signal transduction

In neonatal cardiac myocytes and intact adult hearts, angiotensin (Ang) II stimulates early signals of the cardiac growth, such as new cardiac protein synthesis, independently of the load. This response depends on translocation of protein kinase C (PKC)-ε from cytosol to membrane fraction and is blocked by the specific Ang II type 1 (AT₁) receptor antagonist losartan. In contrast with neonatal myocytes, early signals of the cardiac growth response to Ang II in adult rat hearts do not involve the induction of proto-oncogenes, which occurs in response to load. We have also shown that the acute cardiac growth response of new cardiac protein synthesis and PKC translocation in response to Ang II is blunted in hypertrophied hearts with aortic stenosis relative to normal hearts. Recent observations suggest that this may be mediated by the Ang II type 2 (AT₂) receptor. We and others have demonstrated an upregulation of LV AT₂ receptors in hypertrophied hearts. Similar upregulation of AT₂ receptors was reported in human failing myocardium. Several studies have proposed that downstream signaling related to the AT₂ receptor differs strikingly from signaling of the AT₁ receptor and involves kinin/cGMP signaling rather than the PKC pathway. Transgenic experiments suggest that the AT₂ receptor signaling cascade has distinct biological roles compared with AT₁ receptor–mediated signaling. Consistent with this hypothesis, recent studies in vascular smooth muscle cells and endothelial cells demonstrated that the AT₂ receptor exerts antiproliferative effects counteracting the growth-promoting effects of the AT₁ receptor. In contrast, the role of AT₂ receptor–mediated signaling in cardiac growth of the intact adult heart is not known. Thus, in the present study, we tested the hypothesis that in hypertrophied hearts, the AT₂ receptor mediates inhibitory effects on the new cardiac protein synthesis and PKC activation in response to acute Ang II stimulation.
Methods

Weanling male Wistar rats (75 to 90 g, Charles River Breeding Laboratories, Wilmington, Del) underwent ascending aortic stenosis as previously described (n=44).2,3,9 Age-matched animals served as a control group (n=45). At 7 to 9 weeks after the banding, the isolated flaccid hearts were perfused by modified Krebs-Henseleit buffer at 37°C as previously described.2,3,7–9 For measurements of protein synthesis, the buffer contained 0.05% albumin and a mixture of amino acids as previously described.2,3,8,9

To investigate the effects of AT1 blockade on Ang II–induced new cardiac protein synthesis, normal and hypertrophied hearts were perfused with no drug (n=4), with Ang II 10−6 mol/L plus 10−7 mol/L prazosin (n=6 to 8), and with Ang II plus the selective AT2 blocker PD 123319 (Parke-Davis, 5 mol/L prazosin (n=7 mol/L, n=5 per group). LV cGMP levels were determined by enzymatic assay (Amersham, Life Sciences) and expressed as mol/mg protein.

All data are presented as mean±SEM. Two-way ANOVA followed by Fisher’s exact test for post hoc analyses was used for multiple comparisons. Significance was accepted at P<0.05.

Results

Characteristics of Hypertrophied and Normal Hearts

<table>
<thead>
<tr>
<th>Weight and Hemodynamics of Isolated Hypertrophied and Normal Hearts</th>
<th>Normal Hearts</th>
<th>LVH Hearts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Drug</td>
<td>Ang II</td>
</tr>
<tr>
<td></td>
<td>(n=4)</td>
<td>(n=8)</td>
</tr>
<tr>
<td>Body weight, g</td>
<td>344±3</td>
<td>370±15</td>
</tr>
<tr>
<td>LV weight, g</td>
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<td>0.89±0.03</td>
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<tr>
<td>LV/body weight, mg/g</td>
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<td>2.39±0.05</td>
</tr>
<tr>
<td>Coronary flow, mL·min−1·g−1</td>
<td>23.2±2.1</td>
<td>20.9±0.9</td>
</tr>
</tbody>
</table>

Figure 1. LV protein synthesis assessed by [3H]phenylalanine incorporation in normal and hypertrophied hearts. In normal hearts (left), Ang II induced a significant increase in rate of [3H]phenylalanine incorporation. In normal hearts, Ang II–induced cardiac protein synthesis did not significantly increase further during AT2 blockade. In hypertrophied hearts (right), Ang II alone did not promote an increase in new LV protein synthesis compared with hearts perfused with no drug. In contrast, Ang II–stimulated LV protein synthesis was markedly amplified by selective AT2 receptor blockade in hypertrophied hearts.

The rate of [3H]phenylalanine incorporation into proteins in the absence of drug was similar in normal and hypertrophied hearts (Figure 1). Corroborating our previous findings,2 Ang II–induced phenylalanine incorporation increased in normal hearts but did not in hypertrophied hearts. In normal hearts stimulated with Ang II, the rate of phenylalanine incorporation did not increase further during AT2 receptor blockade. In contrast, in hypertrophied hearts stimulated with Ang II, phenylalanine incorporation was increased by AT2 receptor blockade.

Effects of AT2 Blockade on Ang II–Induced PKC-e Translocation in Adult Rat Hearts

In normal and hypertrophied hearts with no drug, the membrane fraction of PKC composed 41.6±2.7% and 46.3±1.3% of total PKC content (P=NS). Normal hearts stimulated with Ang II demonstrated a significant increase in membrane fraction of PKC (24.9±8.6% versus no drug, P<0.05) that was not further modified by AT2 receptor blockade. In contrast, in hypertrophied hearts, Ang II alone did not cause a significant increase in membrane translocation of PKC (8.8±4.1% versus no drug, Figure 2,
right). In the presence of AT2 blockade, however, Ang II significantly increased the membrane fraction of PKC compared with hypertrophied hearts with no drug (15.4±4.7% versus no drug, P<0.05).

**Effects of AT2 Blockade on LV cGMP Content**

In both normal and hypertrophied hearts stimulated with Ang II, selective AT2 blockade significantly depressed LV cGMP levels (98.6±7.6 versus 64.7±6.1 fmol/mg protein, P<0.05, and 75.5±11.9 versus 45.8±6.2 fmol/mg protein, P<0.05, respectively).

**Discussion**

In the present study using a well-characterized intact buffer-perfused adult heart model, we directly examined the role of upregulated LV AT2 receptors on new cardiac protein synthesis in response to Ang II in adult hypertrophied rat hearts. Consistent with previous observations,2 3,11 Ang II failed to cause an increase in new protein synthesis or PKC translocation in hypertrophied hearts. In normal hearts with a predominance of LV AT1 receptors,9,10 Ang II–induced new cardiac protein synthesis did not increase further during selective AT2 blockade. In contrast, in hypertrophied hearts, AT2 receptor blockade increased Ang II–induced LV protein synthesis and PKC translocation. Thus, these data support the hypothesis that AT2 receptor activation mediates inhibitory effects on acute growth response to Ang II in adult intact hearts with LV hypertrophy.

Recent studies suggested that AT2 receptor–related biological effects are due to activation of kinins and intracellular cGMP signaling.13–17 Our data corroborate these findings by demonstrating that AT2 blockade causes a decrease in LV cGMP content in intact hearts stimulated by Ang II. In addition, AT2 blockade amplified PKC translocation in hypertrophied hearts stimulated with Ang II. Of note, this effect was absent in normal hearts. The presence of cross talk between PKC translocation and selective AT2 blockade in hypertrophied hearts with upregulated AT2 receptors9–12 is consistent with a report of Yamada et al.24 who demonstrated that AT2 receptor activation inhibits mitogen-activated protein kinase. In addition, several authors proposed that AT2 receptor activation may enhance apoptotic cell death.17,24 These hypotheses merit future studies in the present aortic stenosis model of chronic LV hypertrophy and failure.

The present study has several limitations. First, the isolated-perfused heart model does not allow investigation of later components of the growth response, namely myocyte hypertrophy. Second, it does not distinguish whether changes in protein synthesis or PKC translocation are localized predominantly to cardiac myocytes or also to matrix cells that express Ang II receptors.

In summary, the present study shows that AT2 receptor blockade amplifies new cardiac protein synthesis in response to Ang II in hypertrophied hearts. This appears to be related to both augmented PKC activation by Ang II and suppression of cGMP signaling. Thus, these data suggest for the first time that the AT2 receptor upregulation in chronic LV hypertrophy may blunt the acute LV growth response to Ang II. The beneficial or detrimental effects of chronic AT2 receptor blockade on hypertrophic remodeling and the transition to failure in pressure-overload hypertrophy remain to be investigated.

**Acknowledgments**

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**References**


**Figure 2.** Membrane translocation of PKC-ε in normal and hypertrophied rat hearts. Left, Ang II induced a significant increase in membrane fraction of PKC compared with normal hearts with no drug. This increase in membrane fraction was not further modified by AT2 blockade. Right, In hypertrophied hearts, Ang II alone did not cause a significant increase in membrane translocation of PKC compared with no drug. However, stimulation with Ang II in presence of AT2 blockade significantly increased membrane fraction of PKC compared with no drug. M indicates membrane; C, cytosol.


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