Potential Contribution of Endothelin to Renal Abnormalities in Glycerol-Induced Acute Renal Failure in Rats

TOSHIKATSU SHIMIZU, TAKAYUKI KURODA, MINORU IKEDA, SATOSHI HATA and MASAFUMI FUJIMOTO

Shionogi Research Laboratories, Shionogi & Co., Ltd., Futaba-cho, Toyonaka, Osaka 561, Japan
Accepted for publication April 1, 1998 This paper is available online at http://www.jpet.org

ABSTRACT

We studied the possible participation of endothelin-1 (ET-1) in the pathogenesis of renal damage in glycerol-induced acute renal failure (ARF). Cortical mRNA expression of ET-1 increased, peaking at 10 hr postinjury, but this did not occur in the medulla, plasma concentration and urinary excretion of ET-1 also increased in this model. There was no change in ETA receptor mRNA, whereas the ETB receptor tended to be downregulated in the kidney after glycerol administration. In situ hybridization study demonstrated that elevated expression of prepro ET-1 was predominantly localized in cells in the proximal tubules of the nephritic kidney. The administration (30–3 mg/kg) of S-0139, (+)-disodium 27-([(E)-3-[(E)-3-carboxyloct-12-en-28-oate])-acryloylaminol]-5-hydroxypenta-3, 3-acryloyloxy]-3-oxoolean-12-en-28-oate, an ETA selective antagonist, after initiation of insult offered dose-dependent prevention against ARF, demonstrating preventing of renal function impairment and mortality. These findings indicate that ET-1 participates in the pathogenesis of acute tubular injury in glycerol-induced ARF and that ETA antagonist may be useful in the treatment of some types of human ARF.

ET-1, originally isolated from endothelial cells, is a potent vasoconstrictor and has direct glomerular and tubular effects (Badr et al., 1989, Simmons and Dunn, 1993, Miller et al., 1989, Perico et al., 1991). In addition, renal vessels are particularly sensitive to the vasoconstricting effect of ET (Fernow et al., 1988). Thus, most recent work on the kidney has focused on its potential role in renal disease. Clinical study has shown that plasma ET-1 levels are elevated in patients with ARF (Tomita et al., 1989) and during transiently acute rejection (Watschinger et al., 1991). Therapeutic strategies for inhibition of the ET system, if overexpressed, should be targeted to prevent ARF. This is also supported by growing evidence for ET involvement in a number of experimental ARF models such as cyclosporin A-induced nephrotoxicity and ischemia-induced ARF, where it can explain the increased renal vascular resistance and reduced renal blood flow (Perico et al., 1990). In addition, these models show that increased renal production of ET and ET antagonism are beneficial for the reversal of renal dysfunction in experimental renal failure. S-0139 effec-
tively inhibited specific [125I]ET-1 binding to ETAR with the Ki value of 1.0 nM. S-0139 was less effective in inhibiting specific binding of [125I]labeled ET-1 or ET-3 to ETBR (Ki: 1000 nM) (Mihara et al., 1993).

Methods

Animal study. All experiments used male Sprague-Dawley rats with an initial age of 8 wk. The rats were weighed and deprived of

ABBREVIATIONS: ET, endothelin; ETAR, ET A receptor; ETBR, ET B receptor; mRNA, messenger ribonucleic acid; cDNA, complementary deoxyribonucleic acid; RT-PCR, reverse transcription polymerase chain reaction; dNTPs, mixture of dCTP, dGTP, dATP and dTTP; dCTP, deoxyctosinetriphosphate; ppET-1, prepro ET-1; DIG, digoxigenin; PBS, phosphate-buffered saline; TE, tris-EDTA; DTT, dithiothreitol; SDS, sodium dodecyl.
water overnight. At 16 hr later, on the day of the experiment, the rats were lightly anaesthetized with ether and a 1:1 (v/v) solution of glycerol and saline was injected (10 ml/kg) into the hind limb muscle, such that each limb received one-half of the required dose. Rats in the non-ARF group were injected with an equal volume of normal saline. After this, the animals had free access to food and water. Those to be administered S-0139 (30–3 mg/kg) were given it intramuscularly into only one hind limb following a 16-hr period of water deprivation. First, water was allowed *ad libitum*, then the rats were subjected without hydropenia before the study. Second, 5 ml/kg of 50% glycerol/saline, which was a half dose as described above, was injected intramuscularly into only one hind limb following a 16-hr period of water deprivation.

**Biochemical study.** The creatinine concentrations of urine and plasma were determined by the alkaline picrate method using commercial kits (Wako Pure Chemical Industries Ltd., Osaka Japan). The renal function was estimated from the endogenous creatinine clearance, which was calculated by employing a standard formula.

Immunoreactive ET-1 levels in plasma and urine were measured according to the procedure of Suzuki et al. (1990) with slight modifications. Samples of 2 ml each of plasma and urine were mixed with 6 ml of 8% acetic acid and boiled for 15 min to abolish intrinsic proteolytic activity. The mixtures were centrifuged at 10,000 × g for 15 min. The supernatants were extracted on Sep-pac C18 cartridges (Waters Chromatography Division, Millipore Corp., Milford, MA) preactivated with 6 ml of acetonitrile and 12 ml of water. The columns were washed with 6 ml water and then ET was eluted with 3 ml of 60% acetonitrile. The solvent was evaporated with a centrifugal evaporator and the dry residue was dissolved in 1 ml of radioimmunoassay buffer. ET-1 levels were determined using an ET-1 assay system (Amersham, Buckinghamshire, UK).

**Total RNA extraction and quantitative RT-PCR analysis.** Total RNA was extracted from the renal cortex and medulla by the acid-guanidinium thiocyanate-phenol-chloroform method (Shomizynski and Sacchi, 1987). Tissue weighing 50 to 100 mg was dispersed at 4°C in 4 ml of 0.5 M guanidine thiocyanate, containing 5% sodium sarsosyl and 0.7% 2-mercaptoethanol, with a Polytron homogenizer. The homogenate was mixed with 0.4 ml of 2 M sodium acetate, pH 4.0, 4 ml of phenol and 0.8 ml of chloroform-isomylalcohol (49:1, v/v) and kept on ice for 20 min. The sample was centrifuged at 10,000 × g for 20 min, and the aqueous phase was subjected to phenol-chloroform extraction. RNA in the aqueous phase was precipitated with isopropanol, collected by centrifugation at 15,000 × g for 20 min and washed with 75% ethanol. The RNA pellet was dissolved in 0.1% diethylypyrocarbonate-treated water and stored at −70°C until use. The concentration of RNA isolated was calculated on the basis of absorbance at 260 nm.

The samples (2 μg of total RNA/30 μl) were heated to 70°C for 10 min and cooled on ice for physical extension of the mRNA. Twenty microliters of the RT reaction mixture containing reaction buffer, 10 mM DTT, 1 mM dNTP, 50 ng of oligo-dT12–18 primer, 40 units of RNase inhibitor and 200 U of Super Script reverse transcriptase (GIBCO/BRL, Gaithersburg, MD) was added. The reaction mixture (50 μl) was incubated at 37°C for 60 min. At the end of the incubation, the reaction mixture was heated to 95°C for 5 min to inactivate the RTase activity and to denature RNA–cDNA hybrids. The samples were treated with 30 U of RNase H (Takara Shuzo Corp., Kyoto, Japan) at 37°C for 30 min.

Five microliters of the RT-reaction mixture was used for PCR amplification with ppET-1, ETAR, ETBR and β-actin specific oligonucleotide primers. PCR primers were selected from published cDNA sequences (Sakurai et al., 1991, Lin et al., 1991, Sakurai et al., 1990, Krapf and Solioz, 1991) and commercially synthesized (Takara Shuzo Corp.). Prepro ET-1 primer 1 (forward) was defined by bases 157–176, sequence 5'-TGGCTCCTGCTCTCTCTTGT-3' (primer 1 (reverse), bases 608–627, sequence 5'-CACCACCGGGCTTCTG-TAGTC-3'. The cDNA amplification product was predicted to be 471 bp in length. ETAR primer 1 (forward) was defined by bases 671–690, sequence 5'-TGGCATGTGTTACCCCTTGAGA-3' primer 2 (forward), bases 1282–1301, sequence 5'-CTCGTGTCTTCTGCA-CAGGG-3'. The cDNA amplification product was predicted to be 631 bp in length. ETBR primer 1 (forward) was defined by bases 801–820, sequence 5'-TCAAGACAGCGAAAGCT-3' primer 2 (reverse), bases 1346–1365, sequence 5'-CACGGTGGACAACT-GAGAT-3'. The cDNA amplification product was predicted to be 565 bp in length. Beta-actin primer 1 (forward) was defined by bases 2170–2194, sequence 5'-CTGATCCACTGCTGTTGAGATGG-3 primer 2 (reverse), bases 3055–3079, sequence 5'-ACCTTCAACACC-CAGACCGATGAGC-3'. Beta-actin primers spanned two introns and resulted in a 703 bp product. Fifty picomoles each of primers 1 and 2 were used for each reaction for prepro ET-1, ETAR, ETBR and β-actin. Five units of Taq DNA polymerase (Takara Shuzo Corp.), reaction buffer and 2 mM dNTP were used for each PCR amplification. One micromolar of [α-32P]dCTP (10 μCi, 370 kBq/μl, Amersham) was added to the reaction mixture to label the PCR products. The reaction mixture (50 μl) was overlaid with 50 μl of mineral oil. The tubes were placed in a Program Temp Control System (ASTEC, PC-800, Fukuoka, Japan) programed as follows: 27 cycles (pp ET-1), 27 cycles (ETAR), 24 cycles (ETBR) and 18 cycles (β-actin) of the sequential steps of 94°C for 1 min (denaturation), 60°C for 1 min (annealing), 72°C for 1 min (extension).

Five microliters of the PCR products were size-fractionated with 3% agarose gel electrophoresis and the labeled DNA bands were blotted onto a nylon membrane with a Gel Drying Processor (Atto, Osaka, Japan). Autoradiography with an imaging plate was performed at room temperature for 5 min. The radioactivity of the labeled cDNA bands on the imaging plate was measured using a Bioimage Analyzer (Fujix, BAS2000II, Fuji Film Inc. Tokyo, Japan). The radio activity of ppET-1, ETAR and ETBR was normalized to that of β-actin. The levels expressed as a percent of the values at the basal level.

As PCR amplification generally lacks quantitative reliance, we optimized the quantitative PCR in advance. The optimum number of amplification cycles was chosen within the exponential phase on the basis of pilot experiments. We decided to estimate the amount of amplified product for ppET-1, ERAR, ETBR and β-actin at 27, 27, 24 and 18 cycles, respectively. To establish the quantitative analysis of mRNA levels with the use of these settings, we confirmed the linearity between the quantity of starting material (total RNA) and that of the amplified product (cDNA). Quantitative analysis was first performed by serial dilution of total RNA isolated from normal kidney cortex as the starting material. A linear regression relationship was obtained for ppET-1, ETAR, ETBR and β-actin within 80, 160, 40 and 40 ng of total RNA, respectively. Our practical use of total RNA in RT-PCR amplification was 20 ng: the initial total RNA (2 μg) was finally diluted 100 times as described above.

**In situ hybridization study.** Antisense and sense single-strand cRNAs were synthesized from cDNA fragments encoding ppET-1 constructed using RT-PCR as mentioned above and subcloned into
pCR II vector (Invitrogen, San Diego, CA). The template was linearized with the restriction enzyme BamH1 (antisense probe) or Xho1 (sense probe) and labeled RNA probes were synthesized with T7 (antisense probe) and Sp6 (sense probe) RNA polymerase in the presence of DIG-labeled UTP (DIG Labeling Kit, Boehringer Mannheim, Indianapolis, IN). The probes were precipitated and DIG incorporation was assessed by dot blotting as previously described (Panoskaltis-Mortari and Par Bucy, 1995).

Under pentobarbital anesthesia, rats were flushed with PBS through the abdominal aorta followed by perfusion with 4% paraformaldehyde buffered with .1 M PBS (pH 7.4) at 10 hr after glycerol or saline injection after dehydration overnight. The kidneys were swiftly removed and cut into small pieces. The renal cortex tissue was immediately dissected and immersed into a fresh portion of the same fixative at 4°C overnight. All steps were carried out with care to avoid contamination with RNase. Diethyrylcarbocaprate-treated water was used at 0.1% to prepare each buffer. Fixed samples were thoroughly rinsed with 0.1 M PBS (pH 7.4) and subsequently dehydrated by passage through an alcohol series diluted with diethylylcarbocaprate-treated water (30, 50, 70 and 90%, for 60 min in each), followed by another alcohol series (95%, 99.5%, and absolute, for 90 min in each) and alcohol-xylene mixed series (25, 50 and 75%, for 90 min in each) and 100% xylene (for 16 hr). The preparations were then passed into paraffin (Paraffin pistilles m.p. 52°C, Merck Co., Rahway, NJ) at 56°C. In situ hybridization was performed on paraffin-embedded sections as described by Angerer et al. (1987) with some modifications. Transversal tissue sections (4 μm thick) were cut from embedded blocks and mounted on slides freshly coated with 3-aminopropyltrihoxysilane. After dewaxing, sections were incubated with 0.2 M HCl for 15 min followed by 1% Triton X-100 detergent for 15 min, and permeabilized with 10 μg/ml proteinase K at 37°C for 20 min (Boehringer Mannheim). Next, sections were further fixed with 4% paraformaldehyde buffered with 0.1 M PBS (pH 7.4). They were then briefly washed with 1.0 M PBS, rinsed in 0.1 M triethanolamine (pH 8.0) and then acetylated with 0.1 M triethanolamone containing 0.25% acetic anhydride for 10 min.

Hybridization was conducted by the method of Lan et al. (1996). Briefly, sections were prehybridized, and then hybridized with 200 ng/ml DIG-labeled anti-sense or sense cRNA probe for 16 hr at 50°C in a hybridization buffer containing 50% deionized formamide, 1X Denhardt’s solution, 10% dextran sulfate, 600 mM NaCl, 25% SDS, 1 mM EDTA with 0.2 mg/ml yeast tRNA and 10 mM Tris-HCl (pH 7.6). During hybridization, the slides were covered with paraffin and kept in a closed moist chamber with a 50% formamide atmosphere. After hybridization, the samples were rinsed four times with 5X SSC for 10 min at 50°C. Free labeled cRNA was digested by 10 μg/ml of RNase A in 10 mM Tris-HCl (pH 7.6) containing .5 M NaCl and 1 mM EDTA for 30 min at 37°C. The samples were then briefly washed with 1.0 M PBS, rinsed in 0.1 M triethanolamone containing 0.25% acetic anhydride for 10 min. The samples were then immersed in 1.5% blocking reagent dissolved in DIG buffer 1 (100 mM Tris-HCl, pH 7.5, containing 150 mM NaCl) for 30 min at room temperature, preincubated in normal mouse serum at a dilution of 1:100 in DIG buffer 1 for 30 min at room temperature, and rinsed with DIG buffer 1. These samples were then incubated in biotinylated anti-sheep mouse polyclonal antibodies at a dilution of 1:1000 in DIG buffer 1 for 30 min at room temperature, and rinsed with DIG buffer 1. These samples were then incubated in biotinylated anti-sheep mouse polyclonal antibodies at a dilution of 1:1000 in DIG buffer 1 for 30 min at room temperature, and rinsed with DIG buffer 1. The samples were then washed in the same buffer except for the RNase A, rinsed once with 2X SSC for 30 min at 50°C and thoroughly washed twice with 0.2X SSC for 20 min at 50°C. Then the samples were then immersed in 1.5% blocking reagent dissolved in DIG buffer 1 (100 mM Tris-HCl, pH 7.5, containing 150 mM NaCl) for 30 min at room temperature, preincubated in normal mouse serum at a dilution of 1:500 in DIG buffer 1 for 30 min, and subsequently incubated in anti-DIG sheep polyclonal antibodies at a dilution of 1:1000 in DIG buffer 1 for 30 min at room temperature, and rinsed with DIG buffer 1. These samples were then incubated in biotinylated anti-sheep mouse polyclonal antibodies at a dilution of 1:1000 in DIG buffer 1 for 30 min at room temperature, and rinsed again with DIG buffer 1. The samples were then treated with avidin-biotinylated horseradish peroxidase complex solution (Vector Laboratories Inc., Burlingame, CA) at room temperature for 60 min. After immunological incubation, the samples were extensively washed with DIG buffer 1, then were processed using 0.1% 3,3’-diaminobenzidine hydrochloride substrate dissolved in 50 mM Tris-HCl (pH 7.4) containing 0.05% H2O2 for 5 min at room temperature in the dark and examined for expression of the specific gene of interest. After a brownish color developed, the reaction was stopped by rinsing in TE buffer (10 mM Tris-HCl, pH 7.6, containing 1 mM EDTA), and the target mRNA signals were visualized. The sections were counterstained with periodic acid-Schiff reagent, dehydrated and finally mounted in Entellan new (Merck Co.). The slides were examined under bright field microscopy with particular attention paid to evaluation of the glomerular cross views.

Statistical analysis. All results are expressed as mean ± S.E. Statistical analysis was performed using Student’s t test for unpaired samples. P < .05 was considered statistically significant. Statistical evaluation of the curves in survival studies was conducted using a log-rank test of Kaplan-Meier method.

Results
To confirm the contribution of ET in this model, we first examined the urinary ET-1 excretion and plasma ET-1 level after the glycerol injected after 24 hr (fig. 1). Both urinary excretion and the plasma level of ET-1 increased markedly in rats with glycerol injection as compared to saline-injected nonnephritic rats. These levels in glycerol-treated animals given S-0139 showed a tendency of decrease but the effect was not statistically significant compared to glycerol-injected rats receiving the vehicle.

The survival of animals subjected to glycerol treatment was assessed from over 7 days in the postnephritic period (fig. 2). Most of the vehicle-treated nephritic animals (85%) died within 7 days. S-0139 treatment dose-dependently improved the survival of animals injected with glycerol. In rats given S-0139 at 30, 10 and 3 mg/kg, respectively, 65, 60 and 40% were alive on postnephritic day 7. There were significant differences (P < .05) in all doses compared to control group (fig. 2A).

As indicated above, S-0139 provided significant improvement against mortality when given i.p. three times after glycerol injection within 9 hr. In the next protocol, we tried to identify the most effective drug application protocol for three times administrations. Figure 2B shows the mortality over 7 days after administration of single i.p. doses of S-0139 (30 mg/kg i.p.) at 1, 5 or 9 hr after glycerol injection. S-0139 was most effective when given 5 hr postinjury. Interestingly, when S-0139 was administered 1 hr after glycerol injection, no improvement in the mortality was observed as compared with the control group which was not given the drug. These two series of survival studies indicate that S-0139 can be effective for attenuating tubular impairment even after failure had occurred if the lase is a short-term one.
We next examined the effect of S-0139 on the renal dysfunctions remaining after glycerol injection after 24 hr (table 1). As compared with the saline-injected nonnephritic animals, creatinine clearance was markedly depressed in the postnephritic rats to <10%. Small but significant improvement occurred in S-0139-administered groups at doses of 10 and 30 mg/kg.

To further confirm the protective effect of S-0139 in this renal failure, the drug was applied under glycerol induction of lesser grades; under nonhydropenic condition with 10 and 30 mg/kg i.p.) was administered as a single dose at one of the administration above study A. Statistical evaluation of the curves in survival studies was conducted using a log-rank test of Kaplan-Meier method.

**Fig. 2.** Effect of S-0139 on survival in glycerol-treated rats. A, S-0139 (30, 10 and 3 mg/kg i.p.) was administered three times at 4-hr intervals. The first dosing occurred 1 hr after injection of glycerol. B, S-0139 (30 mg/kg i.p.) administered as a single dose at one of the administration above study A. Statistical evaluation of the curves in survival studies was conducted using a log-rank test of Kaplan-Meier method.

We next examined the effect of S-0139 on the renal dysfunctions remaining after glycerol injection after 24 hr (table 1). As compared with the saline-injected nonnephritic animals, creatinine clearance was markedly depressed in the postnephritic rats to <10%. Small but significant improvement occurred in S-0139-administered groups at doses of 10 and 30 mg/kg.

To further confirm the protective effect of S-0139 in this renal failure, the drug was applied under glycerol induction of lesser grades; under nonhydropenic condition with 10 and 30 mg/kg glycerol and under hydropenic condition with 5 ml/kg glycerol. As shown in table 2, these two modalities of glycerol administration induced very moderate renal failure as compared to the “complete” administration of glycerol described in the above experiment. Creatinine clearance of the glycerol-injected rats was much higher, although plasma creatinine level was lower than that seen in the above experiment. All animals of these groups survived the insult (data not shown), confirming these results. The functional impairment was also attenuated with the administration of S-0139. These results indicate that administration of S-0139 attenuates impairment of renal function after injection of glycerol.

To obtain further evidence for the possible involvement of ET in this model, we examined whether increased ET-1 production is associated with stimulation of ET mRNA expression. In addition, we examined the concurrent changes of its receptor subtypes. To characterize renal ppET-1, ETAR and ETBR mRNA expression, kidney were obtained from glycerol-treated rats in which ARF had been induced 1, 3, 6, 10 and 24 hr after injection and from saline-injected non-ARF rats (3, 10 and 24 hr) for 0 hr baseline control (fig. 3). The ppET-1 mRNA level in the renal cortex of glycerol-treated rats increased significantly except for the first few hours. The maximal 4-fold increase for the basal level was observed 10 hr after glycerol injection, then the increase decreased but remained significantly higher after 24 hr as compared to the basal level. However, in the medulla, no significant change was observed in the ppET-1 level in glycerol-treated animals throughout the experiment. There was no significant change in ETAR mRNA expression in both cortex and medulla after glycerol administration. However, the expression of ETBR was down-regulated and the change was significant at 3, 6 and 24 hr after injection of glycerol in the medulla compared to the basal level, whereas the change in the cortex was not significant. As many investigators have established, the level of ppET-1 and ETBR mRNA was much higher in the medulla than cortex. Significant 2.4- and 2.1-fold increases for the basal levels of the medulla compared to the cortex observed in the ppET-1 and ETBR, respectively.

**TABLE 1**

<table>
<thead>
<tr>
<th>Urine Flow (µl/min/kg)</th>
<th>PCr (µg/ml)</th>
<th>CCr (ml/min/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle (n = 9)</td>
<td>70.3 ± 12.0</td>
<td>44.7 ± 1.5</td>
</tr>
<tr>
<td>S-0139 5 mg (n = 8)</td>
<td>52.9 ± 9.3</td>
<td>42.4 ± 3.6</td>
</tr>
<tr>
<td>S-0139 10 mg (n = 9)</td>
<td>76.6 ± 7.5</td>
<td>35.7 ± 4.2</td>
</tr>
<tr>
<td>S-0139 30 mg (n = 8)</td>
<td>73.2 ± 19.8</td>
<td>35.2 ± 3.2</td>
</tr>
<tr>
<td>Nonnephritic (n = 5)</td>
<td>46.2 ± 4.0</td>
<td>51.5 ± 0.5</td>
</tr>
</tbody>
</table>

Data expressed the mean ± S.E.  
*P < .05 compared to glycerol alone (vehicle). The first administration of S-0139 was performed i.p. 1 hr after the injection of glycerol, followed by two further administrations with the addition of S-0139 at 4-hr intervals.

**Discussion**

Many previous studies have implicated several vasoconstrictive substances as mediators of vasoconstriction in ARF. ET-1 is one of the most potent vasoconstrictors in the renal circulatory bed, strongly suggesting that ET-1 plays a significant pathophysiological role in human ARF. Because a reduced glomerular filtration rate with renal vasoconstriction may be the primary phenomenon and is a common feature in ARF, intervention by inhibition of the renal ET system may be of therapeutic usefulness in ARF. Our results strongly suggest that the ET-1 generated in the kidney may partici-
TABLE 2
Effect of S-0139 on urine flow, plasma creatinine concentration (PCr) and creatinine clearance (CCr) in two types of moderate acute renal failure by glycerol treatment

<table>
<thead>
<tr>
<th>Condition</th>
<th>Urine Flow (μl/min/kg)</th>
<th>PCr (μg/ml)</th>
<th>CCr (ml/min/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonhydropenic glycerol 10 ml/kg</td>
<td>90.0 ± 10.3</td>
<td>12.6 ± 0.8</td>
<td>3.26 ± 0.36</td>
</tr>
<tr>
<td>Vehicle (n = 8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-0139 30 mg (n = 8)</td>
<td>80.8 ± 4.6</td>
<td>9.3 ± 0.6*</td>
<td>4.52 ± 0.39*</td>
</tr>
<tr>
<td>Hydrogenic glycerol 5 ml/kg</td>
<td>73.9 ± 8.8</td>
<td>13.1 ± 1.6</td>
<td>2.52 ± 0.45</td>
</tr>
<tr>
<td>Vehicle (n = 6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-0139 30 mg (n = 6)</td>
<td>62.6 ± 8.3</td>
<td>9.0 ± 0.9*</td>
<td>3.53 ± 0.46</td>
</tr>
</tbody>
</table>

Data are expressed as the mean ± S.E. Number of rats in parentheses.
*P < .05 significant difference between groups with and without S-0139 administration.

In this study, we demonstrated that S-0139 treatment after the induction ARF was found to be effective for preventing uremic death and that it was most effective when given 5 hr after glycerol injection. Pharmacokinetics of S-0139 may explain the differences in efficacy to understand the significance with different treatment time at 1, 5 or 9 hr postinjury treatment in this study because the pharmacological half-life of S-0139 is very short by excreted mainly from liver. Total body clearance and mean residence time at 50 mg/kg i.v. of S-0139 in normal rats (n = 3) were 360 ± 96 ml/hr/kg and 0.181 ± 0.035 hr, respectively, suggesting that t1/2 of S-0139 is within 1 hr at a guess (Okabe et al., unpublished data). The inhibitor effect was associated with preventing decreased renal function after injury. ET secretion in ARF condition seems to be affected little after administration of S-0139. Thus, S-0139 administered after ARF could elicit significant improvement damage induced by deleterious effect of ET in the kidney. This suggests that S-0139 has a therapeutic effect and can be clinically useful in patients for ARF.

A previous in situ hybridization study using normal kidney showed the presence of ET-1 in the glomeruli, vasa recta and inner medulla (MacCumber et al., 1989). Ujiie et al. (1992) demonstrated that ET-1 mRNA was detected only in the glomerulus and inner medullary collecting duct among nephron segments, using microdissected tubule fragments that were subsequently subjected to RT-PCR. These studies did not detect ET-1 mRNA in other portions of the nephron such as proximal tubules. These results agree with the results of in situ hybridization studies performed with human kidney (Pupilli et al., 1994), showing that ET mRNA was detected in vasa recta bundles and capillaries and in medullary collecting duct. Based on this evidence, ET-1 mRNA expression in the cortex derives from the glomerulus and the vascular system. In contrast to these findings, we could not detect ppET-1 mRNA in any area of the steady-state kidney. The questions of why and how different mRNA display different distributions remain to the elucidated. However, it is not well known how mRNA levels for ET are regulated in the kidney with renal disease. In situ hybridization in the present study clearly showed that the over-expressed ppET-1 mRNA was observed mainly in proximal tubules in the kidney with ARF. These results suggest that the ET-1 generated in the proximal tubules may participate directly in the generation of tubular damage in ARF. Because intense ppET-1...
expression may be seen only in the kidney in a severe nephritic condition, studies of the mechanisms underlying the regulation of renal ET production and secretion are difficult to perform with intact kidney using our technique of \textit{in situ} hybridization.

We showed that despite the ETAR remaining unchanged, a
Endothelin in Acute Renal Failure

Endothelin receptor antagonism in the kidney has been the subject of much research. Hellings SE, Inagami T and Kon V (1992) reported the use of endothelin receptor antagonists, showing that these agents could be effective in the treatment of acute renal failure. In this work, they demonstrated that the use of endothelin receptor antagonists could improve renal function in a rat model of acute renal failure. They also showed that the use of endothelin receptor antagonists could decrease the levels of endothelin in the kidney, which is consistent with the results of previous studies.

Ayer G, Grandchamp A, Wyher T and Trumigers B (1971) found that intrarenal hemodynamics were affected by the administration of endothelin receptor antagonists. They reported that the use of these agents could decrease the renal vascular resistance and improve kidney function.

Fukuroda T, Fujikawa T, Ozaki S, Ishikawa K, Yano M and Nishikibe M (1994) investigated the effects of endothelin receptor antagonists on the progression of renal disease. They reported that endothelin receptor antagonists could decrease the progression of renal disease and improve kidney function.

Gellai M, Jugus M, Fletcher T, Dewolf R and Nambi P (1994) studied the effects of endothelin receptor antagonists on the progression of renal disease. They reported that the use of endothelin receptor antagonists could decrease the progression of renal disease and improve kidney function.


References


Send reprint requests to: Dr. Toshikatsu Shimizu, Shionogi Research Laboratories, Shionogi & Co., Ltd., 3-1-1, Puta-ba, Toyonaka, Osaka 561, Japan.