Endothelin-1 Increases Glomerular Permeability and Inflammation Independent of Blood Pressure in the Rat

Mohamed A. Saleh, Erika I. Boesen, Jennifer S. Pollock, Virginia J. Savin, David M. Pollock

Abstract—Endothelin (ET) 1 is a potent vasoactive peptide implicated in the pathogenesis of hypertension and renal disease. The aim of the current study was to test the hypotheses that ET-1 increases albumin permeability of glomeruli isolated from normal rats and that chronic ET-1 infusion will increase glomerular permeability and inflammation independent of blood pressure. Glomerular permeability to albumin was determined from the change in glomerular volume induced by exposing isolated glomeruli to oncotic gradients. Incubation of glomeruli taken from normal rats with ET-1 at a concentration that did not produce direct glomerular contraction (1 nmol/L) significantly increased glomerular permeability to albumin, reaching a maximum after 4 hours. Chronic ET-1 infusion for 2 weeks in Sprague-Dawley rats significantly increased glomerular permeability to albumin and nephrin excretion rate, effects that were attenuated in rats given an ET<sub>A</sub> receptor antagonist (ABT-627, 5 mg/kg per day). Urinary protein and albumin excretion and mean arterial pressure (telemetry) were not changed by ET-1 infusion. Acute incubation of glomeruli isolated from ET-1–infused rats with the selective ET<sub>A</sub> antagonist significantly reduced glomerular permeability to albumin, an effect not observed with acute treatment with a selective ET<sub>B</sub> antagonist. Chronic ET-1 infusion increased glomerular and plasma soluble intercellular adhesion molecule 1 and monocyte chemoattractant protein 1 and elevated the number of macrophages and lymphocytes in renal cortices (ED-1 and CD3-positive staining, respectively). These effects were all attenuated in rats given an ET<sub>A</sub> selective antagonist. These data support the hypothesis that ET-1 directly increases glomerular permeability to albumin and renal inflammation via ET<sub>A</sub> receptor activation independent of changes in arterial pressure. (Hypertension. 2010;56:942-949.)

Key Words: intercellular adhesion molecule ■ monocyte chemoattractant protein ■ macrophage ■ kidney ■ rat

At a physiological level, endothelin (ET) 1 plays an important role in the control of fluid-volume balance and blood pressure. Specifically, ET-1 promotes diuresis and natriuresis within the collecting duct and action through ET<sub>B</sub> receptors. Systemically, ET<sub>B</sub> receptors clear ET-1 from the circulation and protect against ET<sub>A</sub> receptor–dependent vasoconstriction, cell proliferation, matrix accumulation, and inflammation. Recent clinical studies have suggested that ET<sub>A</sub> antagonists may be a useful therapeutic approach for proteinuric renal disease, but the precise mechanism of action is not known. ET<sub>A</sub> receptors are responsible for a wide range of effects in the kidney including vasoconstriction of renal cortical vessels, mesangial cell contraction and proliferation, stimulation of extracellular matrix production, and inflammation. The ET system has been implicated in a range of effects in the kidney including vasoconstriction of renal cortical vessels, mesangial cell contraction and proliferation, stimulation of extracellular matrix production, and inflammation. The ET system has been implicated in a range of effects in the kidney including vasoconstriction of renal cortical vessels, mesangial cell contraction and proliferation, stimulation of extracellular matrix production, and inflammation. The ET system has been implicated in a range of effects in the kidney including vasoconstriction of renal cortical vessels, mesangial cell contraction and proliferation, stimulation of extracellular matrix production, and inflammation. The ET system has been implicated in a range of effects in the kidney including vasoconstriction of renal cortical vessels, mesangial cell contraction and proliferation, stimulation of extracellular matrix production, and inflammation.

Proteinuria and albuminuria represent early signs of glomerular injury, and their presence predicts not only an elevated risk for nephropathy but also cardiovascular disease in general. The mechanistic pathways of albuminuria in chronic kidney disease have not been resolved. A recent phase III clinical trial in patients with diabetic nephropathy demonstrated that avosentan, a modestly selective ET<sub>A</sub> antagonist, decreased urinary albumin excretion rate after 12 weeks of treatment. This benefit occurred although nearly all of the subjects in this trial were receiving treatment with angiotensin receptor blockers and angiotensin-converting enzyme inhibitors, indicating an independent antiproteinuric effect of ET receptor antagonist. However, the main adverse effect of the new class of drugs was peripheral edema, especially at high dosages of avosentan. Little is known about the specific mechanisms of ET-1 action in chronic kidney disease, and many of the beneficial effects of ET antagonists have not been distinguished from their blood pressure–lowering effect.

Chemokines such as monocyte chemoattractant protein-1 (MCP-1) and soluble (s) intercellular adhesion molecule-1 (sICAM-1) were demonstrated to be elevated in the urine of patients with diabetic nephropathy. These chemokines are known to attract monocytes and lymphocytes to the kidney and to stimulate the production of proinflammatory cytokines. In addition, ET-1 stimulates the expression of ICAM-1 on the surface of endothelial cells, facilitating the migration of monocytes and lymphocytes into the renal interstitium. These findings suggest that ET-1 may contribute to the development of glomerular injury and inflammation in diabetic nephropathy.

Inflammation plays a crucial role in the development and progression of renal disease in models of these disorders. For example, inflammation has been shown to be a key factor in the pathogenesis of diabetic nephropathy, which is characterized by glomerular inflammation, proteinuria, and eventual loss of renal function. The role of inflammation in diabetic nephropathy is supported by the observation that therapies that target inflammatory pathways, such as angiotensin-converting enzyme inhibitors and angiotensin II receptor blockers, are effective in reducing proteinuria and slowing the progression of renal disease in clinical trials. This suggests that targeting the inflammatory response may be an effective strategy for the prevention and treatment of renal disease.

In conclusion, the present study demonstrates that ET-1 promotes glomerular permeability and inflammation independent of blood pressure. These effects appear to be mediated by ET<sub>A</sub> receptors and are associated with the recruitment of inflammatory cells to the kidney. These findings highlight the potential role of ET-1 in the development and progression of renal disease and suggest that targeting ET<sub>A</sub> receptors may be a useful therapeutic approach for the treatment of proteinuric renal disease.

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ICAM-1 are important in attracting inflammatory cells and in their attachment to the endothelium, thus facilitating the early process of macrophage and lymphocyte infiltration into the kidney. MCP-1 may contribute to the development of diabetic nephropathy by facilitating the formation of tubulo-interstitial lesions through macrophage recruitment and activation. Increased ICAM-1 expression along with increased leukocyte trafficking has been described in experimental models of nephropathy. ET-1 has been demonstrated to possess a chemoattractant role for renal and blood macrophages and lymphocytes in an ETα receptor–dependent manner.

The current study was designed to determine the direct actions of ET-1 in promoting changes in glomerular permeability and renal inflammation. We hypothesized that chronic ET-1 infusion would stimulate ETα receptors to increase expression of inflammatory mediators with subsequent infiltration of inflammatory cells into the kidney. We also proposed that ET-1 has a direct effect on glomeruli to increase permeability to albumin.

Methods

Intravenous Infusion of ET-1

All of the surgical and experimental procedures were performed according to the guidelines for the care and use of animals established by the Medical College of Georgia and was approved by the Institutional Animal Care and Use Committee. Male Sprague-Dawley rats (Harlan Laboratories), 225 to 250 g, were housed under conditions of constant temperature and humidity and exposed to a 12:12-hour light-dark cycle. ET-1 (2 pmol/kg per minute, American Peptide, Inc) or saline vehicle (0.9% NaCl) was infused intravenously for 14 days via an osmotic minipump (model 2ML2, Alza Scientific) connected to a catheter (phycocerythrin 50) placed in the jugular vein, implanted under sodium pentobarbital (50 mg/kg IP) anesthesia. Three groups of rats were studied (n=5 to 9): (1) saline infusion; (2) ET-1 infusion; and (3) ET-1 infusion plus ABT-627 (5 mg/kg per day, Abbott Laboratories) in the drinking water. An additional subset of rats was also given ABT-627 in the drinking water without any ET-1 infusion (n=4). ABT-627 is a selective ETα receptor antagonist at this dose in vivo; the dosing was identical to many previous studies. Blood pressure was measured by telemetry as described previously. Treatment with ABT-627 was initiated on the same day as ET-1 infusion. During the final 2 days of infusion (days 13 and 14), rats were placed in metabolic cages to collect urine for determination of the excretion rates of protein, albumin, and nephrin.

Isolation of Glomeruli

Details of glomeruli isolation are available in the online Data Supplement (please see http://hyper.ahajournals.org). Briefly, glomeruli were isolated by gradual sieving, as described previously. Glomeruli were homogenized, and total protein was determined in the supernatant using the Bradford assay.

Measurement of Glomerular Albumin Permeability

Please see the online Data Supplement for details of glomerular albumin permeability (Pab) measurement. In brief, the rationale for the determination of albumin permeability has been described in detail previously. Pab is measured via calculating the volume change created by the oncotic pressure induced by switching the surrounded medium from 5% to 1% BSA. This volume change is mathematically translated into Pab.

Immunohistochemical Analysis

Details of the immunohistochemical methods are available in the online Data Supplement. Briefly, harvested renal tissue from each group of rats was prepared and evaluated for CD68- and CD3-positive immunoreactivity for analyses of macrophages and T cells, respectively.

Plasma and Urinary Analyses

Commercially available kits for rat sICAM-1 and ET-1 (Quantikine sICAM-1 and QuantiGlo ET-1 Immunoassay, respectively, R&D Systems) and MCP-1 (RayBioTech, Inc) were used for accurate determination of these 2 cytokines in plasma and glomerular homogenates (1 μg of total protein loaded). Nephrit concentration was determined in urine via ELISA kit (Exocell, Inc). Urinary protein concentrations were determined using the Bradford colorimetric method (Bio-Rad Laboratories) according to the manufacturer’s instructions. Urinary concentrations of albumin were measured using enzyme immunoassay kits from Cayman Chemical (Cayman Chemical).

Transmission Electron Microscopy

Details of the transmission electron microscopy in this study are available in the online Data Supplement. Briefly, renal cortical tissue from each group of rats was prepared, and 4 to 5 sections were analyzed. Ten glomeruli per section were evaluated.

Statistical Analysis

All of the data are presented as mean±SEM. Data were compared using unpaired Student’s t test or 1-way ANOVA. Differences were considered statistically significant with P<0.05. Analyses were performed using GraphPad Prism version 5.0 software (GraphPad Software Inc).

Results

Acute Effects of ET-1 on Isolated Glomeruli

The addition of ET-1 to the 5% BSA incubation medium elicited a significant concentration-dependent contraction of glomeruli isolated from normal rats observed within 5 minutes. The lowest concentration of ET-1 that elicited identifiable contraction (2.7±0.3%) was 10 nmol/L (Figure 1A). No glomerular contraction was observed when 1 nmol/L of ET-1 was added for 5 minutes. Because the calculation of glomerular permeability relies on glomerular volume differences on switching the medium from 5% to 1% BSA, we chose a dose of 1 nmol/L to study the effects of ET-1 on glomerular permeability to preclude volume changes attributed to contractile effects of ET-1 affecting our results.

Incubation of glomeruli with ET-1 (1 nmol/L) caused a time-dependent increase of Pab. As shown in Figure 1B, there was a slight increase in Pab after 15 minutes (0.10±0.08) compared with controls (0 nmol/L ET-1; 0.00±0.02), but the increase in Pab was not statistically significant until 30 minutes of incubation (0.26±0.10) and was sustained at 4 hours (0.57±0.07).

Pab in Chronic ET-1–Infused Rats

ET-1 infusion (2 pmol/kg per minute; IV) for 2 weeks did not affect the mean arterial pressure (measured continuously by telemetry; Figure 2). Pab was significantly increased in glomeruli isolated from ET-1–infused rats (P<0.05; Figure 3A). However, there was no effect on protein or albumin excretion (Figure 3C and 3D, respectively). Separate groups of rats were infused with ET-1 and given either normal
drinking water or the ET_A receptor antagonist, ABT-627, in the drinking water for 2 weeks. As depicted in Figure 3B, chronic ABT-627 treatment significantly attenuated the elevation of Palb in glomeruli isolated from ET-1–infused rats (0.18 ± 0.02 versus 0.4 ± 0.03; \( P < 0.05 \)). Glomeruli from non–ET-1–infused rats given ABT-627 maintained normal Palb (0.03 ± 0.04; \( n = 4 \)).

Incubation of glomeruli isolated from ET-1–infused rats in vitro for 15 minutes at 37°C also significantly reduced the elevated Palb (Figure 4A). However, in vitro incubation of glomeruli from ET-1–infused rats with A-192612, a selective ET_B antagonist, did not produce any significant changes in Palb (Figure 4B).

Representative transmission electron micrographs of kidneys showing glomerular structures from saline- and ET-1–infused rat glomeruli are depicted in Figure 5A and 5B, respectively. ET-1 infusion appeared to cause some detachment of podocytes and foot process effacement in glomerular tufts relative to saline-infused control rats, suggesting that ET-1 mediates podocyte injury and increases glomerular permeability. We also observed that ET-1 infusion increases nephrin shedding from the glomeruli into the urine. Nephrin is a filtration slit protein expressed in glomerular epithelial cells (podocytes) and acts as a size- and charge-selective filtration barrier. Shedding of nephrin into the tubular fluid and urine is considered a sign of reduced glomerular permeability and, thus, glomerular injury. Nephrin excretion was significantly increased in ET-1–infused rats compared with saline-infused control rats (\( P < 0.05 \); Figure 5C). Chronic treatment of ET-1–infused rats with ABT-627 significantly decreased urinary nephrin excretion (Figure 5C).

Consistent with efficient clearance of ET-1 from the circulation, plasma ET-1 levels were not significantly changed by chronic ET-1 infusion with or without treatment with ABT-627: 1.06 ± 0.17 pg/mL (\( n = 6 \)) in saline-infused rats, 0.88 ± 0.25 pg/mL (\( n = 7 \)) in ET-1 rats, and 1.42 ± 0.51 pg/mL (\( n = 5 \)) in the ET-1+ABT-627 group. Furthermore, there was no change in 24-hour ET-1 excretion: 0.28 ± 0.03 mg/day.
days after saline infusion, ET-1 infusion, or ET-1 infusion plus ABT-627 treatment. The density of cells expressing the macrophage-specific CD68 antigen and T-cell–specific CD3 antigen in the renal cortex was very low in saline-infused rats (Figure 7A and 7D) and markedly increased in ET-1–infused rats (Figure 7B and 7E). ABT-627 treatment reduced the number of both CD68- and CD3-positive cells in ET-1–infused rats (Figure 7C and 7F). Finally, there were no significant differences in kidney weight between saline and ET-1–infused animals (1.23±0.03 and 1.22±0.02 g, respectively).

**Discussion**

Since the discovery of ET-1, the mechanisms by which ET-1 contributes to chronic kidney disease have been slow in being resolved. In various animal models of hypertension, ET-1 has been shown to exert proinflammatory, promitogenic, and profibrotic actions in the kidney, which may be at least partially attributable to the hypertensive effects of ET-1. In the present study, we demonstrated that ET-1 induces systemic and local glomerular inflammation, as well as increases in glomerular permeability independent of effects on blood pressure.

In the present study, we showed in vitro that concentrations of ET-1 >1 nmol/L produced glomerular contraction in a dose-dependent manner. The contractile effect of ET-1 is potentially attributable to mesangial cell contraction, as reported by Simonson and Dunn. At lower concentrations, we observed a fairly rapid increase in P_ab after only 30 minutes and a further increase during the 5-hour incubation period. The normal podocyte has a highly organized cytoskeleton with microfilaments including actin, α-actinin-4, and myosin that are also in association with focal adhesion-related proteins, such as αiβi integrins. Together, these results have led us to hypothesize that disruption of structural organization by ET-1 may play a role in alterations of normal podocyte function leading to increased glomerular permeability.

Consistent with our previous study, we found that infusion of ET-1 at 2 pmol/kg per minute IV for 2 weeks had no effect on mean arterial pressure. In a similar dose range (1 to 5 pmol/kg per minute), others have also reported no effect of

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**Figure 4.** Ex vivo effect of ABT-627, a selective ET_A receptor antagonist (A), or A-192621, a selective ET_B receptor antagonist (B), on P_ab of glomeruli isolated from 2-week ET-1–infused rats. n=4 rats, 10 to 15 glomeruli per rat. *P<0.05 vs ET-1 alone.

**Figure 5.** Transmission electron microscopy of the glomerular filtration barrier in saline (n=3; A) or ET-1–infused rats (n=3; B). Arrows indicate glomerular basement membrane (i) and podocytes (ii). Nephrin excretion in rats receiving saline (n=6), ET-1 (n=9), or ET-1+ABT-627 (n=5) for 2 weeks (C). *P<0.05 vs saline and †P<0.05 vs ET-1 alone.
chronic ET-1 infusion on arterial pressure in rats. However, Sedeek et al and Yao et al reported that chronic ET-1 infusion elevates arterial pressure in rats on a normal salt diet. Therefore, we took care to choose a dose of ET-1 that would allow us to examine the effects of ET-1 independent of hypertension and used telemetry to verify the lack of an effect on arterial pressure. Dao et al reported pressure-independent actions of ET-1 in this model by infusing ET-1 at 1 and 5 pmol/kg per minute for 28 days and observing hypertrophy and small artery hyperplasia, respectively. Therefore, it appears that variations of local ET-1 concentrations are sufficient to produce blood pressure-independent cellular responses in vivo.

Ours is not the first study to report blood pressure-independent effects of ET-1 on renal pathology. Hocher et al demonstrated that transgenic overexpression of the human ET-1 gene in mice resulted in glomerulosclerosis and interstitial fibrosis without the presence of systemic hypertension. In the same animal model, Hocher et al showed that ET-1 induced recruitment of inflammatory cells into the kidney, which contributed progressively to the fibrosis independent of blood pressure. In their study, blood pressure was similar in 3-month-old ET-1 transgenic mice and their corresponding littermates. However, ET-1 transgenic mice exhibit chronic renal inflammation characterized by infiltration of CD4+ T cells and macrophages. Such findings suggest that an activated renal ET system could be a blood pressure-independent risk factor for the progression of renal fibrosis to end-stage renal disease. However, we cannot rule out the possibility of alterations of intraglomerular capillary pressure and small artery hyperplasia, respectively. Therefore, it appears that variations of local ET-1 concentrations are sufficient to produce blood pressure-independent cellular responses in vivo.

Our study is not the first to report blood pressure-independent effects of ET-1 on renal pathology. Hocher et al. demonstrated that transgenic overexpression of the human ET-1 gene in mice resulted in glomerulosclerosis and interstitial fibrosis without the presence of systemic hypertension. In the same animal model, Hocher et al. showed that ET-1 induced recruitment of inflammatory cells into the kidney, which contributed progressively to the fibrosis independent of blood pressure. In their study, blood pressure was similar in 3-month-old ET-1 transgenic mice and their corresponding littermates. However, ET-1 transgenic mice exhibit chronic renal inflammation characterized by infiltration of CD4+ T cells and macrophages. Such findings suggest that an activated renal ET system could be a blood pressure-independent risk factor for the progression of renal fibrosis to end-stage renal disease. However, we cannot rule out the possibility of alterations of intraglomerular capillary pressure during chronic ET-1 elevation. Moreover, our data indicate that a nonpressor 2-week infusion of ET-1 does not induce proteinuria or albuminuria in normal Sprague-Dawley rats. These data are in agreement with findings in ET-2 transgenic rats and human ET-1 transgenic mice that display glomerulosclerosis with the absence of proteinuria. The absence of albuminuria suggests that the changes in permeability determined in isolated glomeruli are not sufficient to translate into measurable albuminuria. Recent studies have renewed interest in the role of proximal tubular uptake of albumin in protecting against albuminuria.

ETα receptor antagonism using ABT-627 attenuated Pab in glomeruli isolated from ET-1–infused rats even when glomeruli were treated ex vivo for only 15 minutes, confirming the role of endogenous ET-1 and ETα receptor activity within the glomerulus influencing permeability to albumin. It is unlikely that changes in expression (mRNA or protein) of glomerular filtration barrier molecules (ie, nephrin, CD2AP, and podocin) can explain the rapid effect of ETα receptor blockade on Pab. Rather, ETα receptor-mediated cytoskeletal rearrangement is a more likely mechanism of reduced Pab. This hypothesis is supported by previous studies by Morigi et al showing that F-actin redistribution and gap formation occurred when exogenous ET-1 was added to cultured podocytes. Intervention with LU-302146, a selective ETα receptor antagonist, prevented F-actin redistribution and decreased

Figure 6. Effect of ET-1 infusion (A through D) with or without concurrent treatment with ABT-627 (E through H) on glomerular and plasma sICAM-1 and MCP-1 concentrations. n=5 to 9 per group. *P<0.05 vs saline and †P<0.05 vs ET-1 alone.
intercellular gap formation induced by Shigatoxin 2. Moreover, the same group has reported that inhibition of Rho kinases, which are crucial for the formation of stress fibers, resulted in a significant inhibition of F-actin rearrangement in response to ET-1.20 Treatment of non–ET-1 infused rats with ABT-627 had no effect on Palb as one might expect because Palb was no different from 0 in these rats.

Our data further support a specific role for the ET\textsubscript{A} receptor in control of Palb because ETB receptor antagonism did not alter the increase in Palb induced by ET-1. This is consistent with relatively low expression of ET\textsubscript{B} receptors in glomeruli compared with ET\textsubscript{A} receptors.33 It is important to note, however, that this does not exclude a role for the ET\textsubscript{B} receptor in modulating the progression of glomerular injury and renal disease. Studies by Tazawa et al34 and Pfab et al35 have demonstrated that rats lacking a functional ET\textsubscript{B} receptor develop more severe renal dysfunction, proteinuria, and renal injury in response to subtotal nephrectomy and streptozotocin-induced hyperglycemia. In these studies, the rat lacking functional ET\textsubscript{B} receptors also developed disease-induced elevations in blood pressure that could account for the increased proteinuria. These findings, taken together with our current results, suggest that the protective role of ET\textsubscript{B} receptors is through hemodynamic mechanisms rather than direct ET\textsubscript{B}-dependent effects on permeability, which we were unable to observe in the permeability experiments.

We observed that chronic ET\textsubscript{A} receptor activation increased the excretion of nephrin into the urine, again suggesting that ET\textsubscript{A} receptors influence podocyte function and Palb. Collino et al36 identified a mechanism of nephrin loss that may account for the enhanced glomerular permeability in preeclampsia. These investigators provided evidence for a factor(s) present in serum from preeclamptic patients who trigger production of ET-1 from glomerular endothelial cells and that ET-1, in turn, may induce shedding of nephrin from the surface of podocytes. They went on to conclude that ET-1 activates the podocyte cytoskeleton and modifies surface expression of nephrin, thus depleting it from the plasma membrane and excretion into the urine. Others have shown that upregulation of ET-1 production by podocytes is induced by protein overload, resulting in cytoskeletal changes associated with foot-process effacement, a hallmark of chronic glomerular disease.37 ET-1 released by podocytes thus may contribute to glomerular barrier dysfunction by direct effects on podocytes themselves. Because ET-1 also increases reactive oxygen species,13 ET-1 may elevate glomerular perme-
ability in chronic settings via superoxide-mediated enhancement of gelatinase synthesis by mesangial cells, reduction of de novo synthesis of proteoglycans, and degradation of the glomerular basement membrane.38

We also observed that infusion of ET-1 for 2 weeks significantly increased glomerular sICAM-1, MCP-1, and plasma MCP-1 levels independent of hypertension or loss of glycemic control (euglycemic clamp test, unpublished observations). These data agree with previous work published by Amiri et al,39 who reported that transgenic mice that overexpress human preproendothelin 1 in endothelial cells exhibit various vascular inflammatory responses, including macrophage infiltration, transcription factor activation (activator protein-1 and nuclear factor-κB), and increases in VCAM-1 expression independent of blood pressure elevation. These data suggest that ET-1 directly triggers the initial phase of renal inflammation through upregulation of systemic MCP-1 and local glomerular ICAM-1 and MCP-1. These inflammatory molecules are known to participate in macrophage infiltration into the kidney.8 Future studies are needed to explore the mechanism of ET-1–induced glomerular ICAM-1 and MCP-1 upregulation. The proinflammatory effects of ET-1 were also blocked by ABT-627 consistent with the proinflammatory effects of ET-1 being ETₐ receptor mediated. We have observed previously that ETA blockade in intact rats has no effect on indices of inflammation.12 One challenge will be to determine whether the inflammatory effects of ET-1 contribute to changes in glomerular permeability and, furthermore, proteinuria.

Perspectives

The use of ETₐ selective and ETₐ/β receptor antagonists is under consideration for treatment of proteinuric renal disease,7,40 but we have little knowledge of how they may confer benefit. We observed that ETₐ receptor activation results in overexpression of circulating and glomerular inflammatory mediators, as well as changes in glomerular permeability to albumin independent of blood pressure. Our results provide mechanistic support for the use of ETₐ selective blockade in chronic kidney disease, but, thus far, the clinical data indicate frequent fluid retention problems of uncertain origin. Future studies are needed to specifically investigate receptor subtype-specific actions in the human kidney.

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Disclosures

None.


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In the *Hypertension* article by Saleh et al (Saleh MA, Boesen EI, Pollock JS, Savin VJ, Pollock, DM. Endothelin-1 Increases Glomerular Permeability and Inflammation Independent of Blood Pressure in the Rat. *Hypertension*. 2010;56:942–949), 2 transposition errors were made by Dr Saleh in (1) the entry of data in the text listing 24-hour ET-1 excretion rate for the 3 groups of rats, and (2) the units for nephrinuria (Figure 5C). While there were no differences between the 3 groups as reported, actual values presented were urine ET-1 concentrations, not excretion rates. The actual excretion rate values were 9.2±1.6, 8.5±0.9, 7.3±1.0 pg/d for the saline, ET-1, and ET-1+ABT-627 groups, respectively. In Figure 5C, nephrinuria should be presented as μg/day, not ng/day.

All data in the remainder of the manuscript are correct as published.

The authors apologize for the errors in the original manuscript.

These corrections have been made to the current online version of the article, which is available at http://hyper.ahajournals.org/cgi/content/full/56/5/942.
Endothelin-1 increases glomerular permeability and inflammation independent of blood pressure in the rat

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Supplemental Methods

Isolation of glomeruli
Rats were anesthetized with sodium pentobarbital (50 mg/kg; i.p). A blood sample was taken from the abdominal aorta for determination of both plasma sICAM-1 and MCP-1 as outlined below. Kidneys were removed, decapsulated and placed in ice-cold phosphate-buffered saline (PBS; pH 7.4) containing phenylmethylsulfonylfluoride (PMSF, 1mM). Glomeruli were isolated by gradual sieving as described previously. The isolated glomeruli were re-suspended in 1 ml PBS and the final glomerular pellet was snap frozen in liquid nitrogen and stored at -80°C.

Glomeruli were re-suspended in lysis buffer (20 mM HEPES, pH 7.4, 10 mM NaCl, 5 mM EDTA, 0.2% Triton X-100, 10 mM sodium fluoride, 1 mM sodium ortho-vanadate, 1 mM PMSF, 1 μg/ml leupeptin and 1 μg/ml pepstatin) and homogenized by ultrasonic homogenizer (20 s). After centrifugation at 10000 × g for 10 min, the supernatant was used for protein determination using the Bradford assay and subsequent analysis of glomerular expression of both sICAM-1 and MCP-1 by ELISA as outlined below.

Measurement of glomerular albumin permeability (P_{alb})
For measurement of \( P_{alb} \), glomeruli were isolated from the renal cortex in medium containing 5% bovine serum albumin (BSA), 115 mM NaCl, 5 mM KCl, 10 mM sodium acetate, 1.2 mM dibasic sodium phosphate, 25 mM sodium bicarbonate, 1.2 mM magnesium sulphate, 1 mM calcium chloride and 3.5 mM glucose, pH 7.4, at room temperature. The rationale and methodology for the determination of albumin permeability has been described in detail previously. In brief, images of 10–15 glomeruli per kidney preparation (i.e., per rat) were captured using a digital camera through an inverted microscope before and after a medium change from 5% BSA to 1% BSA. The medium exchange creates an oncotic gradient across the basement membrane resulting in a glomerular volume change \( (\Delta V = \frac{V_{final} - V_{initial}}{V_{initial}}) \), which was measured off-line by an image analysis program (Digimizer, MedCalc Software bvba, Mariakerke, Belgium). The computer program determines the average radius of the glomerulus in two-dimensional space, and the volume is derived from the formula \( V = \frac{4}{3}\pi r^3 \).

The magnitude of \( \Delta V \) was related to the albumin reflection coefficient, \( \sigma_{alb} \), by the following equation: \( (\sigma_{alb})_{experimental} = \frac{(\Delta V)_{experimental}}{(\Delta V)_{control}} \); the \( \sigma_{alb} \) of the control glomeruli was assumed to be equal to 1. \( P_{alb} \) is defined as \( (1 - \sigma_{alb}) \), and describes the movement of albumin consequent to water flux. When \( \sigma_{alb} \) is zero, albumin moves across the membrane with the same velocity as water, and \( P_{alb} \) is 1.0. Conversely, when \( \sigma_{alb} \) is 1.0, as in control glomeruli, albumin cannot cross the membrane with water, and \( P_{alb} \) is zero.

Immunohistochemical Analysis
Kidneys were perfused with 4% paraformaldehyde in 100 mM dibasic sodium phosphate buffer and immersed in 4% paraformaldehyde solution overnight at room temperature, transferred to 70% ethanol for 24 h, and paraffin embedded. The kidneys were sectioned at a thickness of 4 μm onto Superfrost plus slides. Slides were incubated overnight in the absence or presence of primary antibody to CD68 or monocytes/macrophages (ED-1; Serotec, Kidlington, Oxford, UK) or CD3 (Santa Cruz Biotechnology, Santa Cruz, CA) for T cells in humidity chambers at 4°C, followed by incubation for 30 min with peroxidase-conjugated goat anti-mouse
IgG (Serotec, Kidlington, Oxford, UK) at room temperature. Positive staining was detected with
diaminobenzamidine (DakoCytomation, Carpinteria, CA) and counterstained with Mayer’s
hematoxylin. The stained sections were viewed on bright-field setting with an Olympus BX40
microscope (Olympus America, Melville, NY) fitted with a digital camera (Olympus DP70;
Olympus America). For quantification of T cell and monocytes/macrophage number, CD3 and
CD68 positive cells respectively were counted in the entire cortex of a given kidney
(magnification x40) in a blinded fashion. Cortical sections were all of similar size.4

Transmission electron microscopy
Renal cortical tissue sections were fixed in 2% glutaraldehyde in 0.1 M sodium
cacodylate (NaCac) buffer, pH 7.4, and post fixed in 2% osmium tetroxide in NaCac, stained en
bloc with 2% uranyl acetate, dehydrated with a graded ethanol series and embedded in Epon-
Araldite resin. Thin sections were cut with a diamond knife on a Leica EM UC6 ultramicrotome
(Leica Microsystems, Inc, Bannockburn, IL), collected on copper grids and stained with uranyl
acetate and lead citrate. Cells were observed in a JEM 1230 transmission electron microscope
(JEOL USA Inc., Peabody, MA) at 110 kV and imaged with an UltraScan 4000 CCD camera &
First Light Digital Camera Controller (Gatan Inc., Pleasanton, CA).

References
1. Misra RP. Isolation of glomeruli from mammalian kidneys by graded sieving. Am J Clin
Pathol. 1972;58:135-139.
2. Bradford MM. A rapid and sensitive method for the quantitation of microgram quantities
R. Mycophenolate mofetil reduces renal injury in the chronic nitric oxide synthase
Correction

In the *Hypertension* article by Saleh et al (Saleh MA, Boesen EI, Pollock JS, Savin VJ, Pollock, DM. Endothelin-1 Increases Glomerular Permeability and Inflammation Independent of Blood Pressure in the Rat. *Hypertension*. 2010;56:942-949), 2 transposition errors were made by Dr. Saleh in (1) the entry of data in the text listing 24-hour ET-1 excretion rate for the 3 groups of rats, and (2) the units for nephrinuria (Figure 5C). While there were no differences between the 3 groups as reported, actual values presented were urine ET-1 concentrations, not excretion rates. The actual excretion rate values were 9.2±1.6, 8.5±0.9, 7.3±1.0 pg/d for the saline, ET-1, and ET-1+ABT-627 groups, respectively. In Figure 5C, nephrinuria should be presented as µg/day, not ng/day.

All data in the remainder of the manuscript are correct as published.

The authors apologize for the errors in the original manuscript.