Kidney results physiologically from a balance of opposing vasodilator systems such as nitric oxide (NO) and prostaglandins, and vasoconstrictor systems. These latter include, besides sympathetic nervous system, the 2 potent vasoactive properties of ET-1 are mediated by 2 receptor subtypes, ETA and ETB, both leading to vasoconstriction in vascular smooth muscle cells, whereas activation of ETB in endothelial cells may cause vasodilation through the release of prostacyclin and NO. At the kidney level, however, studies in both dogs and humans have indicated the ET A receptor as the main mediator of the vasoconstrictor effect of ET-1.

A considerable body of evidence has shown that ET-1, although it is the most potent endogenous vasoconstrictor, assumes a major hemodynamic role and contributes to the end-organ damage, mainly under experimental and clinical pathophysiological conditions. Furthermore, a number of interactions have been recognized between Ang II and ET-1, such as an ET-1-mediated vasoconstriction from Ang II infusion, a marked stimulation by Ang II of ET-1 synthesis and release, and a synergistic effect of nonhypertensive amounts of ET-1 to induce a pressor action of otherwise nonpressor doses of infused Ang II. ET-1 is also known to contribute substantially through its hypertrophic and mitogenic effect to the functional and structural abnormalities of both the cardiovascular system and the kidney in experimental, salt-sensitive, hypertension because of low-dose Ang II infusion. Thus, ET-1 is now considered as a powerful mediator of Ang II–dependent vasoconstriction and organ damage.

Conversely, the role of ET-1 by itself and of its numerous interactions with Ang II in the maintenance of systemic and renal hemodynamics in humans under physiological conditions is much less clarified.

Systemic pharmacological blockade of the primarily vasoconstricting ETA receptor may produce vasodilation in patients suffering from diseases with an activated ET-1 system and markedly elevated plasma ET-1, such as chronic heart failure.
failure (CHF) and liver cirrhosis. In healthy humans, systemic ET \(_\alpha\) blockade prevents or markedly blunts systemic and renal vasoconstriction due to either infusion of exogenous ET-1 or NO synthesis inhibition by systemic infusion of N\(^\text{\textregistered}\)-nitro-L-arginine methylester (L-NAME). However, when doses of ET \(_\alpha\) antagonists, such as those used under experimental or pathophysiological conditions, have been administered systemically in healthy humans, only minor effects on systemic circulation and no changes in baseline renal hemodynamics have been detected.\(^8\) Even when selective ET \(_\alpha\) blockade has been performed by infusing drugs locally in the forearm of normal subjects, conflicting results have been obtained, ranging from no changes\(^17\) to a 40% increase in baseline blood flow.\(^18\)

On the other hand, studies in both normal dogs and rats undergoing simultaneous systemic blockade of renin-angiotensin system (RAS) with either ACE inhibitors (ACEI)\(^4,5\) or AT\(_1\) receptor antagonists (AIIRA)\(^19\) have shown that hypertension and, primarily, marked renal vasoconstriction resulted from ET \(_\alpha\) or mixed ET\(_{\alpha/\beta}\) blockade. For instance, Berthold et al.\(^4,5\) have reported that, in dogs receiving both ACEI trandolapril and ET \(_\alpha\) blocker LU135252, renal blood flow (RBF) increased to an extent 3 to 4 times larger than that observed with ET \(_\alpha\) blockade alone. Thus, the hypothesis may be advanced that a substantial, ET \(_\alpha\) receptor–mediated contribution of ET-1 in the maintenance of systemic and, principally, renal hemodynamics takes place when RAS activity is blunted by ACE inhibition or AT\(_1\) blockade. In addition, because renal vasoconstriction under combined ACE inhibition and ET \(_\alpha\) blockade was prevented in dogs by NO synthesis inhibition,\(^5\) intrarenal NO production seems to be involved in renal vasoconstriction due to ET \(_\alpha\) blockade.

The aim of the present study was to investigate whether and to what extent ET \(_\alpha\) activity and NO regulate renal hemodynamics in normal humans undergoing RAS blockade.

Apart from being relevant in normal physiology, this issue also may be of importance in view of the proposed beneficial effects of ET \(_\alpha\) receptor blockade in a number of human cardiovascular and renal diseases.\(^20,21,22,23\) Because pharmacological blockade of RAS with ACEI or AIIRA is now one of the most generally accepted therapies, just in such a broad clinical spectrum, the demonstration of a physiological mechanism by which RAS blockade unmask a substantial, nonvasoconstricting dose of NO-synthesizing enzyme L-NAME.

### Materials and Methods

**Participants**

Six healthy volunteers, 3 men and 3 women, chosen from among the medical staff of Dipartimento di Scienze Cliniche at the University of Parma, after written informed consent, participated in the study, which was conducted according to the ethical protocols of our institution. Their ages were 30 ± 1 years, heights 166 ± 7 cm, body weights 66.7 ± 2.0 kg, body surface areas 1.71 ± 0.05 m\(^2\). None had evidence or history of heart, liver, kidney, or endocrine diseases, had abused alcohol or drugs, or were currently under medical treatment. Before the study, all participants had a clinical examination, a blood pressure measurement, and an ECG. A laboratory screening showed normal values for urinalysis, blood hematocrit, and plasma creatinine, Na, K, uric acid, total cholesterol, and triglycerides.

**Experimental Procedure**

Participants underwent 4 infusion studies in a randomized order, each preceded by 5 days of a controlled diet that provided 250 mmol Na, 80 mmol K, and 1800 Kcal.\(^16,24\) The washout period between infusions was approximately 2 weeks for males and 4 weeks for females, who were studied during the follicular phase of the menstrual cycle. In 3 studies ET \(_\alpha\) blocker BQ 0.2 mmol·Kg \(^{-1}\)·min \(^{-1}\) was infused after pretreatment with either PL, 1 mg·Kg·day \(^{-1}\), TELM, or TELM as well, but with co-infusion of both BQ and 0.5 mg·Kg·min \(^{-1}\)·L-NAME. The fourth infusion was made with 0.5 g·Kg·min \(^{-1}\)·L-NAME alone preceded by PL. Such a dose of L-NAME, which is one-half the lowest amount infused up to now in human studies of systemic NO synthesis inhibition,\(^25\) was adopted in the assumption that, in this way, we would still produce a substantial degree of NO synthesis inhibition without significant renal hemodynamic changes. PL or TELM single oral doses were given for 3 days before the study at 10:00 PM. Each participant therefore received the last dose of TELM 10 hours before the study to avoid systemic and renal hemodynamic changes as a result of acute drug administration. Long-acting AIIRA TELM\(^26\) was chosen because a substantial AT\(_1\) blockade would be maintained until the following morning, as indicated by the finding of a prolonged, near maximal inhibition of pressor effect of exogenous Ang II in normal humans even after a 40 mg single dose.\(^27\)

After an overnight fast, experiments were initiated at 8.00 AM with the participant in a sitting position. A plastic indwelling catheter was placed into a cubital vein, a priming dose of 3000 mg · 1.73 m\(^2\) body surface area of inulin and 600 mg · 1.73 m\(^2\) of para-aminohippuric acid (PAH) was injected, and an infusion of PAH and inulin was initiated and continued throughout the entire study using a 50 mL syringe precision pump (Perfusion Secura, Braun) to obtain plasma levels of approximately 1.5 mg·dL \(^{-1}\) for PAH and 20 mg·dL \(^{-1}\) for inulin. A second indwelling catheter for blood sampling was placed immediately at the controlateral arm and kept patent by pump infusion of saline solution 1.0 mL·h \(^{-1}\). After 60 minutes of equilibration (~45 minutes time), participants emptied their bladders, then a 45-minute baseline clearance period was initiated. At 45 minutes, after voiding, a pump infusion of either BQ, L-NAME, or BQ plus L-NAME in order to control renal perfusion. Two 45-minute clearance periods were performed (0 to 45 minutes and 45 to 90 minutes, respectively); then the experiment was stopped. A 300-ml tap water load was administered hourly throughout the study to ensure an appropriate urine flow. Blood pressure and pulse rate were measured every 5 minutes using an automatic oscillometric monitoring device (TM 2421, A and D Co Ltd). Samples from urine of each clearance period were taken for excretion rate of Na (UaNaV). Samples were drawn for plasma PAH and inulin every 15 minutes during the entire study.

### Calculations

A satisfactory steady-state of plasma concentration of PAH and inulin was obtained with our infusion technique.\(^26,24\) Because variability in plasma PAH and inulin measured throughout infusion was comparable to that found in a duplicate analysis of single plasma samples (2.4% for PAH and 3.6% for inulin), effective renal plasma flow (ERPF) and glomerular filtration rate (GFR) were estimated without measuring urinary PAH and inulin using a constant-infusion technique.\(^28\) Such a procedure was preferred rather than standard urinary clearance because an unethical bladder catheterization should be necessary to avoid errors in urine collection, potentially of the same order of magnitude as that of measured changes in renal

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hemodynamics.\textsuperscript{16,24} Constant infusion technique already has been shown to detect in humans rapid changes in renal hemodynamics as a result of administration of different substances such as nifedipine,\textsuperscript{29} L-NAME\textsuperscript{16,24} and Ang II.\textsuperscript{30} PAH and inulin concentrations were measured in the infusate, then multiplied for the volume of infused solution per minute. The resulting infusion rate of PAH or inulin was divided for each measured plasma concentration, thus obtaining 4 clearance values in the baseline period and 3 in each drug period for both ERPF and GFR.\textsuperscript{16,24} The mean values were used in the expression of data for each period. Filtration fraction (FF) was calculated from GFR and ERPF, RBF was calculated from ERPF and hematocrit, and renal vascular resistances (RVR) from MAP and RBF.

**Study Drugs**

PAH (20% solution) and inulin (10% solution) were purchased from J. Monico, Ltd, Venice, Italy. A commercially available TELM preparation of 40- and 80-mg tablets was used, while pharmaceutical grade L-NAME.HCl and BQ were obtained from Clinalfa.

**Analytical Methods**

Na was measured by flame photometry. Plasma and infusate PAH and inulin were measured as previously described.\textsuperscript{16,24} Statistical Methods

Data are expressed as the mean±SEM. Time-dependent effects of each infusion were analyzed by one-way ANOVA. Differences between various infusions were analyzed by two-way ANOVA followed by post hoc multiple comparisons with the Student-Newman-Keuls test. Differences at the 5% level or less were considered to be statistically significant.

**Results**

The results of MAP, renal hemodynamics (GFR, RBF, RVR, and FF), and Na excretion (UNaV) are summarized in Table 1. Data of RBF also are represented in Figure 1.

**Acute ET\textsubscript{A} Blockade Does Not Affect Baseline Renal Hemodynamics**

Acute ET\textsubscript{A} blockade alone, as performed with BQ infusion after PL, did not produce any change in MAP, RBF, GFR, RVR, and UNaV.

**Renal Vasodilation Follows the Acute ET\textsubscript{A} Blockade Superimposed to AT\textsubscript{1} Receptor Blockade**

Pretreatment with AIIRA TELM did not significantly affect either baseline renal hemodynamics or UNaV. Quite surprisingly, baseline MAP was slightly, although not significantly, higher after TELM. When ET\textsubscript{A} blockade with BQ followed pretreatment with TELM, MAP showed a slight fall from baseline. However, statistical comparison of absolute changes in MAP did not show significant differences among the various treatments. RBF (Figure 1) increased significantly with TELM+BQ (+14.3%, P<0.001 versus any other treatment). GFR did not change and, by consequence, FF fell by 14.0% (P<0.001). RVR also declined significantly (from 89±7 mm Hg · min · L\textsuperscript{-1} at baseline to 74±5 at 45 to 90 minutes, −16.8%, P<0.001 versus any other treatment).

**Inhibition of Intrarenal NO Synthesis Abolishes ET\textsubscript{A} Blockade-Induced Renal Vasodilation**

Infusion of 0.5 μg · Kg · min\textsuperscript{-1} L-NAME alone did not produce, as expected, any detectable change in MAP and renal hemodynamics. However, when such a microdose of L-NAME was co-infused with BQ after TELM, it prevented any change in RBF (Figure 1) and RVR. In addition, a 30% to 33% decrease in UNaV took place when L-NAME was infused, either alone or with TELM+BQ.

**Discussion**

In the present human study, ET\textsubscript{A}-receptor blockade was obtained by infusing systemically the peptide antagonist BQ at a rate devoid of any renal hemodynamic action at baseline as previously found by us\textsuperscript{16} and others.\textsuperscript{8} Comparable rates of infusion of BQ, however, were shown to produce systemic...
vasodilation in both CHF and liver cirrhosis patients with presumably activated ET1 system. In addition, BQ prevented renal vasoconstriction in healthy men due to either exogenously infused ET-1 or endogenous ET-1 left unopposed by NO synthase inhibition with low-dose, systemic L-NAME infusion. Thus, amounts of BQ such as those used in the present study should ensure a substantial blockade of ET A receptor. Similar results also have been reported in humans for the oral ET A antagonist ABT-627, which fully prevented vasoconstriction both in the kidney during systemic ET-1 infusion and in the forearm during local infusion of such a peptide, in spite of only minor changes in MAP. Our findings indicate, therefore, that there is only a little contribution, if any, of endogenous ET-1 to the baseline renal vascular tone in normal humans.

However, when ET A blockade was performed after a short-term treatment with the AIIRA TELM, substantial renal vasodilation took place, with rise in RBF and decrease in RVR. GFR remained unchanged and FF fell, in keeping with vasodilation: rise in RBF and decrease in systemic, low-rate infusion of such an L-arginine analog in healthy humans have shown that baseline renal hemodynamics along the entire duration of experiments.

As expected, L-NAME infusion after PL did not produce any renal effect, except for a significant decrease in Na excretion. This is in agreement with early studies in rats showing that Na retention may take place before any renal and systemic hemodynamic variation during systemic low-rate infusion of L-arginine analog nitro-monomethyl-L-arginine (L-NMMA). Because BQ-induced renal vasodilation was prevented by the co-infused, nonvasoconstricting microdose of L-NAME, a preserved intrarenal NO production was required for this renal vasodilatory action of BQ. However, the relative contribution to this interaction of the vasodilator effect of NO left unopposed by ET A blockade and, respectively, of the withdrawal of ET A mediated vasoconstrictor tone, remains uncertain.

Our findings suggest that the balance between endogenous NO and ET A activity plays a major role in the maintenance of renal vascular tone when RAS is blocked, in agreement with Berthold et al who found in dogs that the marked potentiation by ACEI of renal vasodilating actions of ET A blockade was prevented by L-NAME and restored by a NO donor. These authors concluded that tonic, baseline production of NO, and not an increased, bradykinin-mediated NO release due to ACEI, was responsible for such an interaction. In our study, because RAS was blocked at the level of AT1 receptor, any kinin-mediated, ACEI-dependent effect is ruled out. Nevertheless, some degree of stimulation of NO synthesis due to increased availability of endogenous Ang II for activation of AT1 receptors cannot be excluded. In addition, unlike other ET A blockers such as ABT-627, BQ may not displace from ET A receptors significant amounts of ET-1 for the stimulation of NO production at the level of endothelial ET B receptors.

On the other hand, a release of ET-1 with
modest increase in its plasma levels may result from the withdrawal of the NO-dependent inhibition due to L-NAME.\textsuperscript{2,3} However, the rise in plasma ET-1 in acute NO synthesis inhibition in healthy humans may not exceed 20\% of baseline values with a 5\% to 7\% increase in MAP.\textsuperscript{36,37} Such levels are in any case still below the in vivo vasoconstrictor threshold as indicated for renal circulation in human studies of ET-1 infusion.\textsuperscript{6,7,38} Furthermore, plasma ET-1 may not reflect an increase in its tissue concentration due to a preferential release of peptide on the basolateral side of endothelial cells.\textsuperscript{2,3} Thus, although we did not measure plasma ET-1, a participation of a relatively enhanced production of ET-1 in the kidney is unlikely because of the very low dose of L-NAME and slight decrease, rather than increase, in MAP. Taken together, these findings indicate therefore that, because neither NO nor ET-1 were significantly stimulated in our human experimental model, NO and ET\textsubscript{A} receptors interact at (or very close to) their baseline level of activity in controlling renal hemodynamics under AT1 blockade.

To summarize, the present data show that the contribution of the intrarenal balance between baseline NO production and ET\textsubscript{A} receptor activity to the maintenance of baseline renal hemodynamics is markedly accentuated when RAS is blocked. Berthold et al in their previous dog studies\textsuperscript{4,5} have shown that combined blockade of both ET-1 and RAS causes pronounced renal vasodilation, which is fully prevented by L-NAME, whereas blockade of either system alone exerts only minor or no effects on RBF. These findings demonstrate not only that blockade of each system potentiates vasodilation following blockade of the other, but also that such a vasodilation is mediated by the intrarenal NO activity left unopposed by the simultaneous blockade of both vasoconstrictor systems. Thus, these animal data and our own human findings seem to indicate collectively that tonic activity of intrarenal NO not only participates in setting the baseline level of RBF\textsuperscript{3} but also is of major importance in determining the renal vasoconstrictor response to both Ang II and ET-1.

A substantial renal hemodynamic role of ET\textsubscript{A} receptor activity in humans undergoing RAS blockade also is relevant for our understanding of interactions among RAS, ET-1, and NO and their potential impact on drug treatment of renal and cardiovascular human diseases. For instance, recent trials with ET-1 blockers in CHF, seem to indicate that ET-1 receptor antagonism may not only ameliorate symptoms and hemodynamics but also may substantially improve prognosis.\textsuperscript{23,39} In most of such clinical studies, ET-1 blockade has produced hemodynamic improvement when superimposed to a standard ACEI treatment.\textsuperscript{23,39} Such results could parallel, at least in part, our finding of an enhanced, NO-dependent, renal vasodilation with ET\textsubscript{A} blockade in healthy humans pretreated with an AIIRA. In this view, our data may offer further support to the concept of a potential usefulness of ET\textsubscript{A} antagonism in association with RAS blockade in the management of CHF\textsuperscript{23} and of other clinical conditions such as hypertension\textsuperscript{21} or renal disease.\textsuperscript{20,22}

Caution should be taken, however, in extending our results of acute studies of ET\textsubscript{A} blockade and NO synthesis inhibition in young healthy individuals with both RAS and ET-1 presumably not activated to chronic conditions, such as CHF, with marked activation of all vasoconstricting and Naretaining systems.

In conclusion, the present study in healthy humans demonstrates that renal vasoconstrictor activity of endogenous ET-1 via ET\textsubscript{A} receptor, which exerts only marginal effects in the control of renal function under baseline conditions of intact RAS, assumes a major vasoconstrictor role and contributes substantially to renal hemodynamics when intrarenal RAS is blocked at the level of AT\textsubscript{1} receptors. Because ET\textsubscript{A}-dependent vasoconstriction takes place in equilibrium with the intrarenally produced NO, our findings indicate an increasing role of ET-1/NO balance in humans undergoing RAS blockade. The clinical relevance of these observation in healthy humans pertains to CHF and, perhaps, to other human cardiovascular and renal diseases in which a disrupted ET-1/NO balance in the kidney could contribute to renal dysfunction even in the presence of an effective blockade of intrarenal RAS. These issues, which may further support the rationale of an association of ET\textsubscript{A} antagonistic drugs with standard treatment with ACEI or AIIRA, deserve further investigations.

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