Endothelial Dilatory Function Predicts Individual Susceptibility to Renal Damage in the 5/6 Nephrectomized Rat

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Abstract. In experimental animal models of renal disease the degree of renal damage varies between individuals. This could be caused by variation in the noxious event or by differences in individual susceptibility. Intact endothelial function is assumed to provide a defense mechanism against progressive renal damage. This study hypothesized that interindividual differences in renal endothelial function might be involved in individual susceptibility to renal damage, and it investigated whether endothelial function of small renal arteries before induction of 5/6 nephrectomy (5/6 Nx) in rats was related to development of renal damage after 5/6 Nx. Wistar rats underwent 5/6 Nx, and small renal arteries of the removed right kidney were investigated for endothelium-dependent relaxation to acetylcholine (ACh, 10⁻⁸ to 10⁻⁴ mol/L). The contribution of underlying endothelial dilative mediators, NO, prostaglandins (PG), and endothelium-derived hyperpolarizing factor (EDHF), was assessed using the inhibitors, L-NMMA, indomethacin, and charybdotoxin+apamin, respectively. After 5/6 Nx, proteinuria developed in each rat ranging from 22 to 278 (84 ± 14) mg/24 h at week 5 (n = 23). Interestingly, a significant inverse correlation between individual ACh-relaxation (expressed as area under curve in arbitrary units) and proteinuria 5 wk after 5/6 Nx was found (r = −0.54; P = 0.008; n = 23). An inverse correlation 17 was also found between individual NO contribution as well as PG contribution and proteinuria 5 wk after 5/6 Nx (r = −0.86, P = 0.001, n = 11) and r = −0.74, P = 0.01, n = 11, respectively). In addition, individual ACh-relaxation was positively correlated with GFR measured 6 wk after 5/6 Nx (r = 0.58; P = 0.016; n = 17). This study demonstrates for the first time that individual renal endothelial dilatory function of the healthy rat predicts susceptibility to renal damage after 5/6 Nx, which seems to depend on individual endothelial NO and PG activity.

Development of renal damage is highly variable among individuals, shows racial differences, and may be determined genetically (1–4). In animal models of renal disease, it has been demonstrated that development of renal damage may vary considerably despite similar levels of BP (5,6). In transplantation studies in rats, differential development of renal damage despite similar metabolic and (high) BP environments was ascribed to be intrinsic to the (donor) kidney (7). Even in normotensive environments the susceptibility of the graft to develop renal damage appears to be strain dependent (8). The development of renal damage may also vary considerably among individuals of one rat strain. Accordingly, large interindividual differences in the development of renal functional deterioration after 5/6 nephrectomy (5/6 Nx) in normotensive rats have been found (6,9). It appears that some kidneys may be more susceptible to develop renal damage in response to the same noxe than others. However, the underlying mechanisms of this individual susceptibility are largely unknown. An intact endothelial dilatory function is assumed to provide a powerful defense mechanism against progressive renal damage (10,11), as evidenced by the well-described deleterious effect of NO blockade as well as COX blockade on kidney function (12–15). These studies indicate the importance of endothelium-derived vasodilators, such as NO-derived nitric oxide (NO), COX-derived prostaglandins (PG), and endothelium-derived hyperpolarizing factor (EDHF) in renal integrity. Because renal endothelial dilatory function also displays a large interindividual variability, we hypothesized that interindividual differences in renal endothelial dilatory function might be involved in individual susceptibility to renal damage.

The present study employed the 5/6 Nx rat model of renal damage to address this item. The main objective was to test whether individual renal endothelial dilatory function of the healthy rat predicts the subsequent renal damage induced by 5/6 Nx. Renal damage was assessed as the increase in proteinuria and deterioration in renal function (GFR) after 5/6 Nx. To this end, acetylcholine-induced endothelium-dependent relax-
ation was assessed in isolated small renal arteries at the time of 5/6 Nx in individual rats, and this was related, respectively, to urinary protein levels up to 5 wk and GFR at 6 wk after 5/6 Nx. Furthermore, because endothelial dilatory function involves several different dilator pathways, it appears of significant interest to also explore which underlying endothelial dilative mediators may be involved. The secondary objective therefore, was to assess the contribution of NO, PG, and EDHF in individual rats. To this end, dilatory responses to acetylcholine were additionally studied in presence of pharmacologic inhibitors of the above dilator pathways.

**Materials and Methods**

**Animals, Surgery, and In Vivo Measurements**

Male Wistar rats (250 to 275 g; n = 23) were obtained from Harlan (Zeist, The Netherlands) and housed under standard conditions at the animal facilities of the University of Groningen. Animals had free access to food (synthetic diet containing 0.3% sodium; Hope Farms, The Netherlands) and drinking water throughout the study. By laparotomy and under anesthesia with isoflurane 3% in N2O/O2 (1:2), rats underwent 5/6 Nx by removing the right kidney and by ligating two or three branches of the renal artery of the left kidney leading to infarction of approximately two thirds of this kidney. The removed right kidney was put into cold Krebs solution, and one small renal (interlobar) artery per kidney was immediately prepared for assessment of vasomotor function. Postoperatively, rats received a subcutaneous injection of 1:10 diluted buprenorphin (Temgesic) for analgetic purposes and were allowed to recover from surgery. Urinary protein excretion (Biuret assay) was determined weekly up to 5 wk thereafter by placing the rats in metabolic cages for 24 h. SBP was also measured weekly in awake animals by means of the tail-cuff method. At 5 wk after 5/6 Nx, rats were instrumented with a jugular and carotid catheter under isoflurane anesthesia. Rats were allowed to recover for 1 wk, and measurement of GFR and effective renal plasma flow (ERPF) was performed according to the continuous infusion method in conscious, freely moving, and spontaneously voiding rats, as described previously (16). Briefly, rats were infused with 125I-iodothalamate and 131I-hippuran, and standard GFR was corrected for inaccurate urine collection by the method described by Donker et al. and Apperloo et al. in humans, and adapted for rat studies by de Vries et al. (16–18). FF was calculated as the quotient of GFR and ERPF. GFR and ERPF could be successfully determined in 17 rats. Dropouts were due to technical failures such as occlusion of catheters. All animal experimentation was conducted in accord with the National Institutes of Health Guidelines for the Care and Use of Laboratory Animals.

**In Vitro Perfusion Setup**

Small renal (interlobar) arteries with an intraluminal diameter of 277 ± 6 μm (n = 23) were transferred to an arteriograph system for pressurized arteries (19) (Living System Instrumentation, Burlington, VT). Artery segments were cannulated at both ends on glass micropipettes and secured, and the lumen of the vessel was filled with Krebs solution through the micropipettes. Intraluminal pressure was set to 70 mmHg and held constant (blind sac) by a pressure servo system (Living System Instrumentation). The vessel chamber was continuously recirculated with warmed (37°C) and oxygenated (5% CO2 in O2) Krebs solution with a pH of 7.4. The vessel chamber was transferred to the stage of an inverted light microscope with a video camera attached to a viewing tube. The video dimension analyzer (Living System Instrumentation) was used to analyze the signal obtained from the video image and to continuously register lumen diameter.

**ACH-Induced Relaxation**

Arteries were allowed to equilibrate for 1 h in regular Krebs solution before being preconstricted with phenylephrine (PE) (3 × 10⁻⁷ to 10⁻⁶ mol/L) by 45 to 50% for subsequent relaxation studies. Preconstricted vessels were studied for endothelium-dependent relaxation by giving cumulative doses of acetylcholine (ACh; 10⁻⁸ mol/L to 10⁻⁶ mol/L) to the recirculating bath. In each individual rat (n = 23), a full concentration-response curve to ACh was obtained for one small renal artery of the removed right kidney. In preliminary experiments, we established that the endothelial dilatory function, as measured in the current study, may be regarded as representative for the investigated kidney, as we demonstrated that ACh-induced relaxation (1) did not differ between renal arteries of different size within the used size range of 230 to 310 μm within one kidney, i.e., ACh-response size (area under curve in arbitrary units) did not depend on (did not show any correlation with) artery diameter (μm) (n = 6 arteries), (2) did not differ between renal arteries of different kidney areas within one kidney, i.e., branches of the superior and inferior segmental artery (n = 4 arteries), and (3) did not differ between (subsequent) vessel preparations (n = 3 arteries).

After determination of full ACh concentration-response curves and a washing and equilibration time of 20 min, 12 of the 23 arteries were used for subsequent investigation of the three underlying endothelial dilative mediators. The other 11 arteries were subsequently investigated for contractile and dilatory properties using PE and sodium nitroprusside (SNP).

**Inhibition of the PG, NO, and EDHF Pathway in ACh-Induced Relaxation**

To determine the contribution of vasoactive PG, NO, and EDHF to endothelium-dependent relaxation, the response to ACh was additionally studied in the presence of various inhibitors added to the bath 20 min before addition of ACh. To this end, indomethacin (10⁻⁶ mol/L) given to the superfusion medium was used to inhibit prostaglandin production. N⁶-monomethyl-L-arginine (l-NMMA, 10⁻⁴ mol/L) given to the superfusion medium in presence of indomethacin was used to inhibit NO production, and a combination of charybdotoxin (chtx, 10⁻⁷ mol/L) and apamin (apa, 5 × 10⁻⁷ mol/L) applied into the lumen of the artery as well as to the superfusion medium in presence of indomethacin and l-NMMA was used to inhibit EDHF (20,21). The exact nature of EDHF has not yet been established, meaning that specific inhibitors are not yet available. Nevertheless, the inhibition of calcium-dependent potassium channels with the combination of charybdotoxin and apamin has consistently been shown to inhibit the l-NMMA-resistant and indomethacin-resistant relaxation and hyperpolarization, which are believed to be mediated by EDHF (21).

It is important to mention that the way in which the endothelial mediators are determined may be critical, as they may not be independent but may interact. In this context NO has been described to attenuate EDHF (release) (22,23), and thus may EDHF be fully active only when NO is inhibited or decreased. Furthermore, NO itself may in part mediate its vasodilatory effect via the opening of potassium channels and hyperpolarization (similar to the mechanism of EDHF) (24). Therefore, if potassium channel blockers are used alone to determine EDHF, not only EDHF-mediated relaxation but also a part of the NO-mediated relaxation may be measured at the same time. It is for this reason that we determined the contribution of EDHF always
in presence of NO inhibition. A total amount of 11 rats/arteries was successfully investigated for contribution of all underlying endothelial dilative mediators.

**SNP-Induced Relaxation and PE-Induced Constriction**

Concentration-response curves to sodium-nitroprusside (SNP, \(10^{-9}\) to \(10^{-3}\) mol/L) were performed to account for dilatory ability of arterial smooth muscle to NO. Concentration-response curves to phenylephrine (PE, \(10^{-8}\) to \(10^{-5}\) mol/L) were performed to control for a potential relation between contractible ability of individual arteries to PE and development of renal damage after 5/6 Nx. Ten rats/arteries were successfully studied for PE and SNP response curves.

**Solutions and Drugs**

Vessel segments were superfused with Krebs solution containing 120.4 mM NaCl, 5.9 mM KCl, 2.5 mM CaCl\(_2\), 1.2 mM MgSO\(_4\), 25.0 mM NaHCO\(_3\), 1.2 mM NaH\(_2\)PO\(_4\), 11.5 mM glucose (Merck, Darmstadt, Germany). Acetylcholine, apamin, charybdotoxin, indomethacin, l-NMMA, phenylephrine, and sodium nitroprusside, were obtained from Sigma-Aldrich Chemie B.V., The Netherlands. They were dissolved in deionized water and diluted with Krebs solution. Stock solution \(10^{-2}\) mol/L) for indomethacin was prepared in 96% ethanol.

**Statistical Analyses**

Data are expressed as mean ± SEM. Concentration-response curves to ACh and maximal relaxation (Emax) were expressed in percentage of preconstriction to phenylephrine (PE). The concentration of drugs causing half-maximal responses (EC\(_{50}\) values) were expressed as negative logarithm of the molar concentration (pD\(_2\) values). The area under each individual curve (AUC) was determined and expressed in arbitrary units. The AUC was used to present total (individual) ACh-relaxation and for subsequent analysis of differences in ACh-relaxation with and without indomethacin, l-NMMA, and chtx/apo to estimate the contribution of PG, NO, and EDHF, respectively (25). Statistical differences for Emax, pD\(_2\), AUC values, and whole ACh-response curves were determined by \(t\) test and ANOVA for repeated measures, respectively. Significance was accepted at \(P < 0.05\). The relationship between in vitro and in vivo data were calculated using regression analysis (SPSS).

**Results**

**BP, Proteinuria, and Renal Function**

After 5/6 Nx, proteinuria gradually increased with time reaching a mean value of 84 ± 14 mg/24 h at week 5, individual values ranging from 22 to 278 mg/24 h \((n = 23)\). In contrast, SBP did not increase with time and had a mean value of 138 ± 5 mmHg at week 5 \((n = 23)\). GFR was determined at 6 wk after 5/6 Nx with a mean value of 0.55 ± 0.07 ml/min per 100 g, ranging from 0.17 to 1.13 ml/min per 100 g \((n = 17)\). ERPF showed a mean value of 1.7 ± 0.2 ml/min per 100 g \((n = 17)\), and FF was 0.31 ± 0.02 \((n = 17)\). Control values for GFR, ERPF, and FF were determined concomitantly in a separate group of normal healthy control rats \((1.14 ± 0.04\) ml/min per 100 g, 2.9 ± 0.2 ml/min per 100 g, and 0.41 ± 0.04 ml/min per 100 g, respectively; \(n = 5\) for each).

**Baseline Endothelial Dilatory Function and Development of Proteinuria and Renal Function Loss after 5/6 Nx**

Administration of ACh dilated small renal arteries of individual rats at the time of 5/6 Nx to a variable extent. On average \((n = 23)\), Emax was 73 ± 3% and pD\(_2\) was 6.5 ± 0.1, corresponding with a mean AUC of 179 ± 10. Regression analysis between individual ACh-relaxation (expressed as AUC in arbitrary units) and individual development of proteinuria and GFR after 5/6 Nx was performed. This analysis revealed that ACh-relaxation was inversely related to the individual extent of proteinuria development from baseline to 5 wk after 5/6 Nx \((r = −0.72; P = 0.001; n = 23)\) as well as to individual proteinuria levels measured 5 wk after 5/6 Nx \((r = −0.54; P = 0.008; n = 23)\) (Figure 1A). Furthermore, individual ACh-relaxation was positively related to GFR 6 wk after 5/6 Nx \((r = 0.58; P = 0.016; n = 17)\) (Figure 1B), i.e., rats with more pronounced ACh-relaxation developed less proteinuria and showed higher GFR after 5/6 Nx. The relation between individual ACh-relaxation and ERPF was NS \((r = 0.45; P = 0.08; n = 17)\), whereas individual ACh-relaxation was positively related to individual FF 6 wk after 5/6 Nx \((r = 0.61; P = 0.009; n = 23)\) (Figure 1C). Individual ACh-relaxation was not correlated with individual SBP levels 5 wk after 5/6 Nx.

**Involvement of Different Endothelial Mediators**

Combined data on the three underlying endothelial vasodilator pathways together with total ACh relaxation were successfully obtained in 11 individual rats. Curve characteristics in absence and presence of inhibitors are given in Table 1. Figure 2A shows the response to ACh in absence of inhibitors (control condition). Administration of indomethacin \((10^{-5}\) mol/L) to inhibit PG variably resulted in small increases or decreases in ACh relaxation in individual rats. The effect on the group as a whole however was NS (Figure 2A, Table 1). Additional administration of l-NMMA \((10^{-4}\) mol/L) to inhibit NO consistently decreased ACh relaxation, but with a high interindividual variability. Overall, maximal ACh relaxation was significantly decreased (Figure 2A, Table 1), demonstrating the significant contribution of NO in mediating ACh relaxation in this vessel type. Subsequent additional inhibition of EDHF with chtx \((10^{-7}\) mol/L) and apo \((5 \times 10^{-7}\) mol/L) nearly fully abolished the remaining ACh relaxation (Figure 2A, Table 1). This indicates a major importance of EDHF in mediating ACh relaxation in these arteries, which is in line with previous studies (21).

Correlation analysis was performed between individual contribution of different endothelial mediators and the level of proteinuria at 5 wk after 5/6 Nx. This analysis revealed that individual PG contribution was inversely related to proteinuria 5 wk after 5/6 Nx \((r = −0.74; P = 0.01; n = 11)\) (Figure 2B). Interestingly, this relation was based on the fact that in some rats the effect of PG inhibition with indomethacin was constractive (indicating that the net effect of stimulated PG in these arteries was dilatove); in other rats, the effect of PG inhibition was dilative (indicating that the net effect of stimulated PG was constractive). Hence, rats with a predominance of dilative PG
developed less proteinuria compared with rats with a predominance of constrictive PG, whereas the overall effect of PG inhibition on the population as a whole was minimal. Not only PG contribution but also individual NO contribution were inversely related to proteinuria 5 wk after 5/6 Nx ($r = -0.86; P = 0.001; n = 11$; Figure 2C), i.e., rats with more pronounced NO contribution displayed less proteinuria after 5/6 Nx. In contrast, individual EDHF contribution was positively related to development of proteinuria ($r = 0.70; P = 0.02; n = 11$; Figure 2D).

SNP-Induced Relaxation and PE-Induced Contraction
Endothelium-independent relaxation to sodium nitroprusside (SNP) relaxed arteries to $97 \pm 2\%$ (Emax) with a pD$_2$ value of $6.4 \pm 0.2$ and an AUC of $261 \pm 12$ ($n = 10$). Individual values obtained before induction of renal damage were not related to development of proteinuria after 5/6 Nx (data not shown), suggesting that the differences in ACh-relaxation were not due to alterations at the level of smooth muscle response to NO. Similarly, individual values for PE-induced contraction obtained before induction of renal damage were not related to development of proteinuria ($n = 10$).

Discussion
In the current study, we found that renal endothelial dilatory function in the healthy rat predicts renal damage induced by 5/6 Nx. The predictive value was determined by the different dilative mediators of the endothelium (NO, PG, and EDHF) and not by differences in smooth muscle responses.

The 5/6 Nx Model
In the 5/6 Nx model, progressive renal damage and function loss of the initially normal remnant nephrons is described to develop with time (9,26). The initial reduction in neaphron number progressively damages the remaining ones that suffer the consequences of (RAAS-mediated) adaptive increases in glomerular pressure and hyperfiltration leading to progressive proteinuria and decreases in GFR and ERPF, which is in accordance with our present data. Our results show that the development of renal damage in this model of 5/6 Nx is largely variable among individuals as demonstrated previously (6,9). The occurrence of systemic hypertension in this model is described as controversial and seems to depend on the renal ablation procedure, the rat strain used, and sodium intake (26–28). In our study, SBP did not increase over time, indicating that BP may not affect the development of renal damage.

Individual Endothelial Dilatory Function Predicts Development of Renal Damage after 5/6 Nx
We found large interindividual variations in endothelium-dependent ACh-induced dilatory function of small renal arteries. Regression analysis revealed that individual ACh-relaxation measured before induction of 5/6 Nx predicted the development of renal damage and renal function loss, measured as proteinuria and GFR, after 5/6 Nx. In contrast, endothelium-independent relaxation to SNP and contractility to PE

![Figure 1](https://example.com/figure1.png)

**Figure 1.** (A) Relation between individual acetylcholine (ACh)-induced relaxation of small renal arteries at the time of 5/6 nephrectomy (5/6 Nx) operation and proteinuria (mg/24 h) 5 wk after 5/6 Nx ($n = 23$). (B) Relation between individual ACh-induced relaxation of small renal arteries at the time of 5/6 Nx operation and GFR (ml/min per 100 g) 6 wk after 5/6 Nx ($n = 17$). (C) Relation between individual ACh-induced relaxation of small renal arteries at the time of 5/6 Nx operation and FF 6 wk after 5/6 Nx ($n = 17$).
were related to neither proteinuria nor GFR, demonstrating that the predictive value may be due to endothelium-dependent mechanisms rather than to differences in smooth muscle properties.

Our results may be in line with the concept that an intact endothelial dilatory function may be a powerful defense mechanism against progressive renal damage (10,11,29–32). In the 5/6 Nx model, strong increases in glomerular pressure and hyperfiltration of the remnant nephrons are believed to largely contribute to the development of renal damage (33,34); in this respect, it may be hypothesized that an intact vasomotor regulation with intact endothelial dilatory ability may protect the kidney from deleterious pressure effects after 5/6 Nx. However, whether endothelial dilatatory function of small renal arteries exerts a direct protective effect on the development of renal damage in this model cannot be determined from the present study. Alternatively, endothelial dilator function, as determined in the present study, may be a reflection of other protective properties of the endothelium. In this respect, it may be interesting to know whether the predictability of renal damage by endothelial dilatory function may also be valid in other models of renal disease or if it may be specific to the hemodynamic component of renal disease progression in this 5/6 Nx model.

Role of Nitric Oxide, Prostaglandins, and EDHF in the Development of Renal Damage

We found that individual NO contribution to ACh-relaxation was inversely related to development of proteinuria, *i.e.*, rats with more pronounced NO contribution developed less proteinuria after 5/6 Nx. That NO may exert renoprotective functions is supported by a large number of studies. NO is not only an important counteractor of constrictive mediators, but it also prevents leukocyte adhesion and mesangial cell hypertrophy/hyperplasia and may inhibit renal renin release. Genetic differences in NOS-activity are believed to account for different rates of occurrence of renal injury (35,36). A direct protective role of NO on renal hemodynamics is supported by the deleterious effects of NOS-inhibition. Independent of systemic BP effects, NOS-inhibition leads to increased intraglomerular pressure, which may partly be due to a greater increase in efferent compared with afferent arteriolar resistance (12,37–42). In accordance with our data, it may be suggested that an intact NO-activity may protect the kidney from maladaptive effects such as increased glomerular resistance and glomerular hyperfiltration after 5/6 Nx. In the current study, we have determined NO contribution in renal (interlobar) arteries, which may not be directly involved in determining glomerular resistance. In this respect, it is important to mention that (larger) renal arteries are believed to be a major source of renal vascular NO production, which, transported by blood flow, may act on downstream arterioles to regulate renal vascular resistance (30).

Apart from NO contribution, also individual PG contribution, measured at the time of 5/6 Nx, was inversely related to development of renal damage after 5/6 Nx, *i.e.*, rats with a predominant influence of dilative PG developed less proteinuria compared with rats with a predominant influence of constrictive PG. Inhibition of PG with indomethacin had only a slight but NS effect on ACh-relaxation in the group on average, as has been described before (21). Our study for the first time shows that the lack of effect of indomethacin in this artery type shows that the lack of effect of indomethacin in this artery type may act on downstream arterioles to regulate renal vascular resistance (30).

Apart from NO and PG, another endothelium-derived factor

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**Table 1. Curve characteristics of acetylcholine (ACh)-induced relaxation and effect of inhibitors**

<table>
<thead>
<tr>
<th></th>
<th>n = 11</th>
<th>Emax</th>
<th>pD2</th>
<th>AUC</th>
</tr>
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<tbody>
<tr>
<td>Control</td>
<td>11</td>
<td>83 ± 3%</td>
<td>6.5 ± 0.1</td>
<td>211 ± 10</td>
</tr>
<tr>
<td>+ indomethacin</td>
<td>11</td>
<td>86 ± 7%</td>
<td>6.2 ± 0.2</td>
<td>191 ± 19</td>
</tr>
<tr>
<td>+ l-NMMA</td>
<td>11</td>
<td>69 ± 8%&lt;sup&gt;d,e&lt;/sup&gt;</td>
<td>5.9 ± 0.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>142 ± 23&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>+ indomethacin + l-NMMA</td>
<td>11</td>
<td>3 ± 1%&lt;sup&gt;d,e,f&lt;/sup&gt;</td>
<td>—</td>
<td>4.7 ± 1.0&lt;sup&gt;d,e,f&lt;/sup&gt;</td>
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<sup>a</sup> Emax is the maximal relaxation to ACh in percentage of precontraction to phenylephrine.

<sup>b</sup> pD2 is the negative logarithm of the molar concentration of ACh causing half maximal responses (EC50).

<sup>c</sup> AUC is the area under the concentration-response curve expressed in arbitrary units.

<sup>d</sup> P < 0.05 versus control.

<sup>e</sup> P < 0.05 versus indomethacin.

<sup>f</sup> P < 0.05 versus indomethacin + l-NMMA.

<sup>g</sup> chtx, charybdotoxin; apa, apamin.

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Figure 2. (A) Concentration-response curves to ACh in small renal arteries (n = 11) at the time of 5/6 Nx operation in absence of any inhibitor (control), in presence of indomethacin (10^{-5} mol/L), in additional presence of N^ω-monomethyl-L-arginine (L-NMMA, 10^{-4} mol/L), and in additional presence of charybdotoxin (chtx, 10^{-7} mol/L) and apamin (apa, 5 \times 10^{-7} mol/L). * P < 0.05 for L-NMMA versus control and indomethacin; †P < 0.05 for chtx+apa versus control, indomethacin, and L-NMMA. (B) Relation between individual contribution of prostaglandins (PG) to ACh-induced relaxation at the time of 5/6 Nx operation and proteinuria (mg/24 h) 5 wk after 5/6 Nx (n = 11). (C) Relation between individual contribution of NO to ACh-induced relaxation at the time of 5/6 Nx operation and proteinuria (mg/24 h) 5 wk after 5/6 Nx (n = 11). (D) Relation between individual contribution of EDHF to ACh-induced relaxation at the time of 5/6 Nx operation and proteinuria (mg/24 h) 5 wk after 5/6 Nx (n = 11).

commits to endothelium-dependent dilation, called EDHF, which mediates its effect via hyperpolarization of underlying smooth muscle cells. The exact nature of EDHF has not yet been elucidated (45), and the role of EDHF in the kidney is largely unknown. Recently, several studies suggested that EDHF may act as a dilative backup system that may be upregulated under conditions when NO is decreased (46–48). In the current study, individual EDHF contribution, in contrast to NO contribution, was positively related to development of proteinuria. This may be best explained by its putative function as a dilative backup mediator, i.e., in rats with low NO activity, EDHF may partly have compensated this NO deficiency. This may also explain why the individual NO activity is even more strongly related than individual total ACh-relaxation, because total ACh-relaxation may have been partly restored by (increased) EDHF.

In this study, we have demonstrated for the first time that the degree of renal damage in this model can be predicted by testing endothelial dilatory function of small renal arteries before induction of renal damage. It provides a method to identify those individuals out of a group of normal rats with high individual risk to develop renal damage by a relatively easy measurement, i.e., the determination of renal ACh-induced relaxation. Furthermore, our study provides direction on underlying mechanisms of individual susceptibility to renal damage, namely individual NO activity and the individual balance between constrictive and dilative PG. Further research in animals, and especially in patients, may not only be crucial to explore exact underlying mechanisms of individual susceptibility to renal damage but may also provide new directions for the development of individual risk assessment and for therapeutic risk management in the clinical setting, such as in renal transplantation.

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References