Assessment of Renal Flow and Flow Reserve in Humans

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OBJECTIVES
The purpose of this work was to establish the normal range of maximal renal hyperemic response in humans and to identify the ideal renal vasodilatory stimuli.

BACKGROUND
Stenotic renovascular atherosclerosis is increasingly treated by percutaneous transluminal renal intervention but with an unpredictable outcome. This may be due to hemodynamically non-significant stenosis or the presence of irreversible damage to the glomerular circulation.

METHODS
In 28 normotensive patients, quantitative angiographic measurements of the renal artery were obtained, and renal artery pressure and flow velocity were continuously recorded after various hyperemic agents.

RESULTS
In a first group of 11 patients, a significant increase in renal artery average peak velocity (APV) was observed after intrarenal (IR) bolus injection of 600 μg isosorbide dinitrate (41 ± 19%), 30 mg papaverine (50 ± 34%), 50 μg dopamine (94 ± 54%), 0.8 μg·kg⁻¹·min⁻¹ fenoldopam (80 ± 25%), and during IR infusion of 1 μg·kg⁻¹·min⁻¹ fenoldopam (86 ± 28%). A second group of 17 patients received intravenous infusion of dopamine (3, 5, 10, 20, 30, and 40 μg·kg⁻¹·min⁻¹). The 3 and 5 μg·kg⁻¹·min⁻¹ of dopamine modestly reduced renal resistance index (RI) (~13 ± 15% and ~25 ± 20%, respectively). At higher dosages, no further decline in RI was observed. No significant change in vessel diameter was observed before and after the administration of the pharmacological stimuli suggesting that changes in APV corresponded with changes in absolute renal blood flow.

CONCLUSIONS
We propose that the renovascular hyperemic response may help identify appropriate patients.

Renal artery stenosis (RAS) may lead to renal failure and difficult in controlling hypertension (1), with comorbidity reaching approximately 10% to 20% in patients with documented coronary atherosclerosis (2,3). Despite percutaneous renal intervention (PRI) being used increasingly to treat RAS (4–6), decline in renal function after PRI (1), substantial restenosis (7) rates, and the absence of clinical benefit in 30% to 40% of patients have been reported (1). This variable response to revascularization is likely to be due to the presence of irreversible renal injury (8) and/or to the selection of patients with physiologically non-significant renal stenoses. Better patient selection may, therefore, improve outcome.

At the level of the coronary circulation, maximal hyperemia is paramount in assessing the physiologic severity of stenoses detected at angiography. By analogy, we propose that pressure or flow measurements performed under conditions of maximal renal hyperemia might be important to determine the true severity of the renal stenoses and, hence, to identify the patients who will benefit from PRI.

The aim of the present study, therefore, was to establish the range of normal maximal renal hyperemic response in humans and to identify the ideal renal vasodilatory stimuli.

METHODS

Patient selection. A total of 28 patients (20 men, mean age 45 ± 8 years, range 27 to 74 years) participated in the study. All patients were normotensive (systolic <100 mm Hg + age and diastolic <90 mm Hg), had a normal renal function (creatinine clearance >100 mg/ml), and a normal glycemic control. They underwent cardiac catheterization for the following reasons: patent foramen ovale or mild atrium septum defect (n = 6), mild mitral regurgitation or mild aortic regurgitation (n = 4), atypical chest pain (n = 11), limited (one-vessel) coronary artery disease (n = 7). Cardiac
medications were interrupted at least 24 h before the catheterization. In a first group of 11 patients, various pharmacologic hyperemic stimuli (isosorbide dinitrate, papaverine, fenoldopam, dopamine) were given intrarenally (IR). In a second group of 17 patients, dopamine was infused intravenously (IV). The study was approved by the institutional ethical review boards of the Onze-Lieve Vrouw Ziekenhuis, Aalst, Belgium, and of the Catharina Hospital Eindhoven, the Netherlands, and informed consent was obtained from all patients.

**Study protocol.** After the introduction of a 6-F sheath into the femoral artery, a 6-F right coronary guiding catheter was positioned at the ostium of the right or the left renal artery, and 400 μg isosorbide dinitrate was given to avoid changes in diameter of the main renal artery. A 0.014-inch Doppler flow (FloWire, Volcano, Mountain View, California) wire was introduced into the renal artery and positioned under fluoroscopy in order to obtain an optimal and stable flow velocity signal. A high-quality renal angiogram was then performed allowing quantitative angiography (CAAS II, Pie Medical Imaging, Maastricht, the Netherlands). Measurement of the diameter of the renal artery was performed 2 mm distal to the tip of the FloWire as this is the very place where the velocity is measured by the FloWire. This allowed us to calculate absolute renal blood flow and renal resistance. The guide catheter was used as a scaling device. Baseline flow velocity was measured and recorded for at least 2 min to ensure a steady-state baseline flow velocity. Next, the varying pharmacological stimuli, as described in the following text, were administered with renal artery pressure and blood flow velocity being continuously recorded. All pressure and flow measurements were stored digitally for analysis. At the end of the procedure, another renal angiogram was performed for quantitative analysis, and the catheters and sheaths were removed. An example of baseline and hyperemic pressure and flow velocity tracings is shown in Figure 1.

**Pharmacological stimuli. IR ADMINISTRATION.** Eleven patients received successively the following medications at

![Figure 1. Example of simultaneous pressure and velocity pressure tracing before, during, and after intrarenal administration of a bolus of 50 μg·kg⁻¹ of dopamine (DOPA); immediately after administration of the bolus, a marked decrease in renal artery average peak velocity is observed, followed by an almost two-fold increase in flow velocities without changes in blood pressure nor in heart rate.]
the following dosages: 1) IR bolus injection of 600 μg isosorbide dinitrate; 2) IR bolus injection of 30 mg papaverine; 3) IR incremental bolus injections of 10, 15, 20, 25, and 50 μg/kg dopamine; 4) IR bolus of 0.05, 0.1, 0.2, 0.4, and 0.8 μg/kg fenoldopam (each bolus injection was separated by at least 2 min); 5) IR infusion of 0.1, 0.3, and 1 μg/kg/min fenoldopam (each dosage was maintained during at least 2 min). The order of administration was unchanged throughout the study.

IV INFUSION OF DOPAMINE. Seventeen patients received an IV infusion of dopamine at incremental dosages of 3, 5, 10, 20, 30, and 40 μg/kg/min. Dosages of 3 and 5 were maintained during 5 min each; higher dosages were maintained during 2 min each.

We waited for the average peak velocity (APV) to return to baseline for nitrates and papaverine before administration of other vasodilators. For the longer-acting agents, we waited at least 5 min between two different vasodilators, and, for the same vasodilator, we always waited for a steady state of at least 2 min. When it was clear that a given dosage would not elicit a higher vasodilator response, the next dosage was administered.

Data analysis. Renal flow reserve was defined as renal artery APV during pharmacological stimulation divided by renal artery APV at baseline. Changes in renal artery APV are expressed as percent increase as compared to baseline. Renal vascular resistance index (RI) (dimensionless) was calculated as the ratio of mean blood pressure (MBP) to APV.

Statistics. Data are expressed as mean ± SD. Gaussian distributions of data were tested by Kolmogorov-Smirnov test. A paired repeated measures analysis of variance was used to compare APV and RI values obtained after renal and after IV administration of dopamine. For all analysis, a p value of >0.05 was considered non-significant. All analyses were performed using the software package SPSS 11.5 (SPSS Inc., Chicago, Illinois).

A paired t test was used to compare the dimensions of the renal artery before and at the end of the study protocol. An unpaired t test or the Mann-Whitney U test (if the distribution is not normal) was used to compare APV and RI values obtained after renal and after IV administration of dopamine. For all analysis, a p value of >0.05 was considered non-significant. All analyses were performed using the software package SPSS 11.5 (SPSS Inc., Chicago, Illinois).

RESULTS

Dimensions of the renal artery. There were no significant changes in the diameter of the renal artery before and at the end of the administration of the renal vasodilators (5.51 ± 0.90 mm before vs. 5.49 ± 0.90 mm after, p = NS). Therefore, the changes in renal artery average peak blood flow velocity can be considered proportional to volumetric renal blood flow.

Effect of IR vasodilators. The values of renal artery APV, MBP, HR, and RI at baseline and after each of the IR vasodilators tested are given in Table 1. Figure 2 displays the percent changes in APV and RI induced by the various IR vasodilators tested. All hyperemic stimuli assessed in this study resulted in a significant increase in renal blood flow with respect to baseline measurements (F(3, 56, 53, 64) = 14.20, p < 0.001, η2 = 0.59). Intrarenal bolus administration slightly increased HR (F(3.93, 39.36) = 3.32, p = 0.020, η2 = 0.25) and decreased blood pressure (F(2.91, 29.07) = 5.36, p < 0.001, η2 = 0.36). Accordingly, the increase in APV was paralleled by a significant decrease in RI (F(4, 84, 48.36) = 18.02, p < 0.001, η2 = 0.64). The largest increase in APV was observed for dopamine delivered as an IR bolus of 50 μg·kg⁻¹ (94 ± 55%, range 40% to 214%). In all patients, all IR bolus administrations of dopamine were followed by a biphasic flow response: maximal hyperemia was preceded by a short-lasting decrease in renal blood flow (Fig. 1). The

Table 1. Renal Artery APV, MBP, HR, and RI at Baseline and During the Peak Effect of the Vasodilatory Stimuli as Given IR

<table>
<thead>
<tr>
<th>Drug Type</th>
<th>APV, cm·s⁻¹</th>
<th>MBP, mm Hg</th>
<th>HR, beats/min</th>
<th>RI, cm³·min⁻¹·mg⁻¹ Hg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>33 ± 5</td>
<td>101 ± 16</td>
<td>67 ± 10</td>
<td>3.10 ± 0.67</td>
</tr>
<tr>
<td>Isosorbide dinitrate IR (bolus) 600 μg</td>
<td>49 ± 14*</td>
<td>100 ± 15</td>
<td>70 ± 12</td>
<td>2.14 ± 0.61*</td>
</tr>
<tr>
<td>Papaverine IR (bolus) 30 mg</td>
<td>50 ± 16*</td>
<td>85 ± 20*</td>
<td>77 ± 12*</td>
<td>1.88 ± 0.72*</td>
</tr>
<tr>
<td>Dopamine IR (bolus) 5 μg·kg⁻¹</td>
<td>52 ± 16*</td>
<td>88 ± 19*</td>
<td>76 ± 14*</td>
<td>1.88 ± 0.72*</td>
</tr>
<tr>
<td>Dopamine IR (bolus) 10 μg·kg⁻¹</td>
<td>54 ± 15*</td>
<td>86 ± 13*</td>
<td>72 ± 10*</td>
<td>1.67 ± 0.51*</td>
</tr>
<tr>
<td>Dopamine IR (bolus) 15 μg·kg⁻¹</td>
<td>57 ± 26*</td>
<td>85 ± 18*</td>
<td>70 ± 11*</td>
<td>1.85 ± 1.17*</td>
</tr>
<tr>
<td>Dopamine IR (bolus) 20 μg·kg⁻¹</td>
<td>61 ± 18*</td>
<td>88 ± 13*</td>
<td>75 ± 10*</td>
<td>1.57 ± 0.55*</td>
</tr>
<tr>
<td>Dopamine IR (bolus) 30 μg·kg⁻¹</td>
<td>62 ± 22*</td>
<td>89 ± 14*</td>
<td>76 ± 18*</td>
<td>1.62 ± 0.70*</td>
</tr>
<tr>
<td>Fenoldopam IR (bolus) 50 μg·kg⁻¹</td>
<td>65 ± 20*</td>
<td>86 ± 11*</td>
<td>77 ± 17</td>
<td>1.44 ± 0.49*</td>
</tr>
<tr>
<td>Fenoldopam IR (bolus) 0.05 μg·kg⁻¹</td>
<td>53 ± 15*</td>
<td>93 ± 17</td>
<td>70 ± 11</td>
<td>1.94 ± 0.83*</td>
</tr>
<tr>
<td>Fenoldopam IR (bolus) 0.1 μg·kg⁻¹</td>
<td>56 ± 13*</td>
<td>90 ± 15</td>
<td>72 ± 12</td>
<td>1.75 ± 0.71*</td>
</tr>
<tr>
<td>Fenoldopam IR (bolus) 0.2 μg·kg⁻¹</td>
<td>57 ± 14*</td>
<td>91 ± 14</td>
<td>71 ± 11</td>
<td>1.74 ± 0.71*</td>
</tr>
<tr>
<td>Fenoldopam IR (bolus) 0.4 μg·kg⁻¹</td>
<td>58 ± 13*</td>
<td>89 ± 16*</td>
<td>73 ± 12</td>
<td>1.59 ± 0.49*</td>
</tr>
<tr>
<td>Fenoldopam IR (bolus) 0.8 μg·kg⁻¹</td>
<td>60 ± 13*</td>
<td>85 ± 15</td>
<td>73 ± 11</td>
<td>1.47 ± 0.35</td>
</tr>
<tr>
<td>Fenoldopam IR (infusion) 0.1 μg·min⁻¹·kg⁻¹</td>
<td>55 ± 13*</td>
<td>88 ± 16*</td>
<td>72 ± 10</td>
<td>1.80 ± 0.63*</td>
</tr>
<tr>
<td>Fenoldopam IR (infusion) 0.3 μg·min⁻¹·kg⁻¹</td>
<td>63 ± 15*</td>
<td>87 ± 14*</td>
<td>74 ± 9</td>
<td>1.45 ± 0.34*</td>
</tr>
<tr>
<td>Fenoldopam IR (infusion) 1 μg·min⁻¹·kg⁻¹</td>
<td>62 ± 15*</td>
<td>84 ± 14*</td>
<td>77 ± 10</td>
<td>1.39 ± 0.29*</td>
</tr>
</tbody>
</table>

*p < 0.05 vs. baseline. p values were Bonferroni-adjusted (17 treatment groups [including baseline]—136 possible comparisons). RI = MBP/APV.

APV = average peak velocity; HR = heart rate; IR = intrarenally; MBP = mean blood pressure; RI = renal resistance index.
magnitude and duration of this transient decrease in flow was dose-dependent. Dopamine and fenoldopam were similar in regard to the maximal effect on renal artery APV.

**Effect of IV dopamine.** The values of renal artery APV, MBP, HR, and RI at baseline and after each dosage of IV dopamine are given in Table 2. Figure 3 displays the percent changes in APV, MBP, and RI induced by the different dosages of IV dopamine. The main effect of increasing the dosage of dopamine IV was statistically significant on APV (\(F(3.18, 50.91) = 14.08, p < 0.001, \varepsilon^2 = 0.47\)), RI (\(F(3.00, 48.15) = 4.14, p = 0.011, \varepsilon^2 = 0.21\)), HR (\(F(3.34, 53.43) = 25.21, p < 0.001, \varepsilon^2 = 0.61\)), and MBP (\(F(2.46, 39.35) = 12.038, p < 0.001, \varepsilon^2 = 0.44\)).

**Table 2.** Renal Artery APV, MBP, HR, and RI at Baseline and at the End of Each Dosage of a Continuous IV of Dopamine

<table>
<thead>
<tr>
<th>Dosage of IV Dopamine</th>
<th>APV, cm/s (^{-1})</th>
<th>MBP, mm Hg</th>
<th>HR, beats/min</th>
<th>RI, cm/s (^{-1})mm Hg (^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>33 ± 11</td>
<td>97 ± 16</td>
<td>64 ± 12</td>
<td>3.25 ± 1.36</td>
</tr>
<tr>
<td>Dopamine IV 3 (\mu g\cdot kg^{-1}\cdot min^{-1})</td>
<td>37 ± 3*</td>
<td>96 ± 15</td>
<td>65 ± 11</td>
<td>2.99 ± 1.52*</td>
</tr>
<tr>
<td>Dopamine IV 5 (\mu g\cdot kg^{-1}\cdot min^{-1})</td>
<td>44 ± 15*†</td>
<td>95 ± 15</td>
<td>66 ± 11</td>
<td>2.56 ± 1.41†</td>
</tr>
<tr>
<td>Dopamine IV 10 (\mu g\cdot kg^{-1}\cdot min^{-1})</td>
<td>46 ± 16*</td>
<td>102 ± 15</td>
<td>67 ± 11</td>
<td>2.59 ± 1.24*</td>
</tr>
<tr>
<td>Dopamine IV 20 (\mu g\cdot kg^{-1}\cdot min^{-1})</td>
<td>48 ± 14*</td>
<td>113 ± 20*</td>
<td>74 ± 13*</td>
<td>2.63 ± 1.02*</td>
</tr>
<tr>
<td>Dopamine IV 30 (\mu g\cdot kg^{-1}\cdot min^{-1})</td>
<td>50 ± 17*</td>
<td>117 ± 17*</td>
<td>88 ± 18*</td>
<td>2.62 ± 1.07*</td>
</tr>
<tr>
<td>Dopamine IV 40 (\mu g\cdot kg^{-1}\cdot min^{-1})</td>
<td>49 ± 10*</td>
<td>121 ± 17*</td>
<td>94 ± 17*</td>
<td>2.60 ± 0.70*</td>
</tr>
</tbody>
</table>

*p < 0.05 vs. baseline; †p < 0.05 vs. previous value. p values were Bonferroni-adjusted (7 treatment groups [including baseline]—21 possible comparisons). RI = MBP:APV.

Abbreviations as in Table 1.
Dosages of 3 and 5 \(\mu g\cdot kg^{-1}\cdot min^{-1}\) ("renal dosages") induced a weak, albeit significant, increase in APV (17 ± 19% and 39 ± 8%, respectively, both \(p < 0.05\) as compared to baseline values). The corresponding values of decrease in RI renal resistance index were \(-13 \pm 15\%\) and \(-25 \pm 20\%,\) respectively (\(p < 0.01\) as compared to baseline values). From 10 to 40 \(\mu g\cdot kg^{-1}\cdot min^{-1},\) a more pronounced increase in APV occurred. These higher dosages of dopamine were paralleled by an increase in blood pressure but no further decrease in RI. The largest increase in APV obtained with IV dopamine (66 ± 59%) was smaller than with IR dopamine (94 ± 55%, \(p = 0.023\) [unpaired \(t\) test]). The maximal decrease in renal RI that was observed with 5 \(\mu g\cdot kg^{-1}\cdot min^{-1}\) (\(-25 \pm 20\%\)) of IV dopamine remained significantly smaller than the largest decrease obtained with IR dopamine (\(-52 \pm 14\%\), \(p < 0.001\) [unpaired \(t\) test]).

**DISCUSSION**

The present study provides, for the first time, a direct documentation of the renovascular response to various hyperemic agents in man by continuous and simultaneous assessment of flow velocity and pressure in the renal artery. The data indicate that, in patients with normal renal function and angiographically normal renal arteries, renal flow reserve averages approximately 2, varying from 1.4 to 2.1. The most potent, easiest, and cheapest means for achieving maximal renal hyperemia is an IR bolus of dopamine of 30 to 50 \(\mu g\cdot kg^{-1}\). Although we did not investigate the effect of higher bolus doses, no significant difference was observed between the 30 and 50 \(\mu g\cdot kg^{-1}\) suggesting a plateau has been reached. It is proposed that the renal hyperemic response might be useful in identifying hemodynamically significant RAS. Furthermore, the actual induction of a hyperemic response by the kidney suggests persistence of renal vasoreactivity, which may aid in identifying viable renal parenchyma and help in selecting patients in whom revascularization of a RAS leads to a favorable outcome. In addition, the study confirms that "renal dosages" of 3 to 5 \(\mu g\cdot kg^{-1}\cdot min^{-1}\) of dopamine administered IV induce a significant increase in renal flow and decrease in renovascular resistance. Yet, at higher dosages of IV dopamine, a further increase in renal flow appears mainly driven by an increase in systemic blood pressure.

**Methodologic considerations.** Because the diameter of the renal artery was similar at baseline and at the end of the study, renal artery APV could be considered proportional to changes in volumetric blood flow. However, no attempt was made to calculate volumetric renal blood flow on the basis of the dimensions of the vessel, the APV, and HR. The exact sampling place along the diameter of the vessel as well as the uncertainty about the shape of the parabolic profile of renal blood flow at the place of sampling introduce many approximations that might lead to large and uncontrolled inaccuracies (9). Therefore, it was considered reasonable to limit the evaluation of the renovascular hemodynamics to flow velocities and renovascular resistance index instead of volumetric flow and absolute renovascular resistance.

**Renal hyperemia.** The results observed in the present study are in line with earlier animal experiments. In anesthetized dogs, a biphasic renal flow response after IR infusion of dopamine was observed: a dose-dependent short-lasting decrease in flow was followed by an increase of approximately 30% of renal blood flow for a bolus of approximately 10 \(\mu g\cdot kg^{-1}\) (10). Swain et al. (11) showed that in conscious dogs and baboons that a 45-s occlusion of the renal artery was followed by a "flow repayment" of 85 ± 9% (corresponding to a renal flow reserve of 1.85), which is remarkably similar to what we found in humans after an IR bolus of 50 \(\mu g\cdot kg^{-1}\) of dopamine. In animals, this hyperemic response was almost abolished by IV indomethacin, an inhibitor of prostaglandin synthesis.

Mounier-Vehier et al. (12) recently suggested that papaverine-induced increase in renal blood flow could be useful in evaluating the repercussions of a renal stenosis on the distal vasculature. Similar to our findings, these authors reported a vasodilator reserve of 1.6 in non-stenotic renal arteries after administration of 40 mg papaverine. A similar finding was observed by Beregi et al. (13), with vasodilator reserve of 1.5, after administration of 40 mg of papaverine in hypertensive patients with normal renal arteries. Yet the present data suggest that both dopamine and fenoldopam induce a more potent decrease in renovascular resistance and, consequently, a larger increase in renal flow.

We did not study the effects of adenosine, which is used to induce hyperemia in coronary circulation, as it induces a potent vasoconstrictor effect on the renal circulation.

**Dopamine versus fenoldopam.** Dopamine is an endogenous catecholamine of which the renal effects are mediated by the dopaminergic DA1 and, to a lesser extent, DA2 receptors and adrenergic alpha-1, alpha-2, and beta-1 receptors. These respective effects are dose-dependent. DA1 receptors have a vasodilatory action on the main renal artery, the afferent and the efferent arteriole. Fenoldopam is a slightly more potent agonist on DA1 receptors but does not act as an agonist on DA2 receptors or alpha- and beta-adrenergic receptors (14). The present data did not show any significant difference between dopamine and fenoldopam given as IR boluses. Therefore, it is suggested that dopamine is the ideal renal vasodilator because, in addition to producing maximal hyperemia, it is cheaper and more widely available than fenoldopam.

**Clinical implications.** Fortuitous diagnosis of RAS has become common (15), resulting in the growth of PRI being performed but with only a minority of patients actually benefiting from the procedure (1). The reasons for poor outcome after renal angioplasty observed in studies could be due to inclusion of patients with angiographically "significant" but hemodynamically non-significant stenosis and performing renal angioplasty on kidneys with significant parenchymal tissue damage. At present, there is no test to accurately select patients who will benefit from renal angio-
plasty. The decision to perform an angioplasty is most often triggered by an angiographic image, whereas the relationship between the angiographic appearance and hemodynamic impact of the stenosis is very poor (16). It is suggested that the renal artery pressure gradient as measured with 0.014-inch pressure-monitoring guide wires, rather than thin catheters, would be better at selecting those patients who are likely to benefit from an angioplasty (17). In addition, and by analogy with what happens in the coronary circulation, it is possible that the hyperemic pressure gradient (rather than the mere resting gradient) or the ratio of hyperemic distal-to-proximal renal pressure (“renal fractional flow reserve”) may provide more useful information on the extent to which the renal blood flow is limited by the presence of the stenosis. However, in order to accurately measure and quantify renal fractional flow reserve, an ideal hyperemic agent is required, and, as was observed in this study, IR bolus of dopamine at 30 to 50 $\mu$g·kg$^{-1}$·min$^{-1}$ appears to be an efficient method.

In contrast to the coronary circulation, a significant transstenotic pressure gradient indicating a hemodynamically important RAS can be masked by constriction of the efferent artery. Therefore, an appropriate hyperemic stimulus to unmask significant stenosis should have a vasodilatory effect on both the afferent and the efferent artery. Unlike adenosine, dopamine appears to be such a stimulus. Further studies are mandatory to establish what magnitude of (hyperemic) gradient or which value of “renal fractional flow reserve” indicates a significant stenosis (i.e., a stenosis leading to renovascular hypertension and ischemic nephropathy). It is speculated that a resting renal artery pressure gradient that increases after IR bolus injection of dopamine indicates that there is both a hemodynamically significant stenosis and a well-functioning parenchymatous blood flow regulation.

Goldberg et al. (18) first introduced the concept of protective effect of low-dose dopamine. It is generally accepted that infusion rates smaller than 5 $\mu$g·kg$^{-1}$·min$^{-1}$ produce stimulation of dopaminergic receptors with an increase in renal blood flow and of glomerular filtration rate without accompanying increase in blood pressure and HR. The present study confirms a decrease in renovascular resistance by 25% with 5 $\mu$g·kg$^{-1}$·min$^{-1}$. From 5 to 10 $\mu$g·kg$^{-1}$·min$^{-1}$, $\beta$-adrenergic effects predominate and $\alpha$-adrenergic effects gradually become important. Infusion rates larger than 10 $\mu$g·kg$^{-1}$·min$^{-1}$ produce mainly $\alpha$- and $\beta$-adrenergic effects with a trend toward vasoconstriction. An increase in renal artery APV of 17% and 39% with infusion rates of 3 and 5 $\mu$g·kg$^{-1}$·min$^{-1}$, respectively, supports the earlier findings of Goldberg et al. (18). Whether this effect is maintained in patients with renal dysfunction and comorbidities is debated, with some current evidence suggesting that low-dose dopamine is ineffective in critically ill patients (19,20).

This study could be summarized as follows: 1) renal flow reserve is approximately 2, and dopamine IR (50 $\mu$g·kg$^{-1}$ as a bolus) is the easiest means to achieve maximal renal hyperemia; the latter could be useful in identifying the hemodynamic severity of renal stenosis; 2) low-dose IV dopamine induces a limited, albeit significant, increase in renal blood flow in normals. The present data provide a reference for normal renal artery flow reserve and a basis for assessing the renovascular status in diseased states such as hypertension, diabetes mellitus, and RAS.

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REFERENCES