USE OF DOPPLER ULTRASONOGRAPHY TO PREDICT THE OUTCOME OF THERAPY FOR RENAL-ARTERY STENOSIS

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ABSTRACT

Background Prospectively identifying patients whose renal function or blood pressure will improve after the correction of renal-artery stenosis has not been possible. We evaluated whether a high level of resistance to flow in the segmental arteries of both kidneys (indicated by resistance-index values of at least 80) can be used prospectively to select appropriate patients for treatment.

Methods We evaluated 5950 patients with hypertension for renal-artery stenosis using color Doppler ultrasonography, and we measured the resistance index as follows: [1−(end-diastolic velocity÷maximal systolic velocity)] ×100. Among 138 patients who had unilateral or bilateral renal-artery stenosis of more than 50 percent of the luminal diameter and who underwent renal angioplasty or surgery, the procedure was technically successful in 131 (95 percent). Creatinine clearance and 24-hour ambulatory blood pressure were measured before renal-artery stenosis was corrected; 3, 6, and 12 months after the procedure; and yearly thereafter. The mean (±SD) duration of follow-up was 32±21 months.

Results Among the 35 patients (27 percent) who had resistance-index values of at least 80 before revascularization, the mean arterial pressure did not decrease by 10 mm Hg or more after revascularization in 34 (97 percent). Renal function declined (defined by a decrease in the creatinine clearance of at least 10 percent) in 28 (80 percent); 16 (46 percent) became dependent on dialysis; and 10 (29 percent) died during follow-up. Among the 96 patients (73 percent) with a resistance-index value of less than 80, the mean arterial pressure decreased by at least 10 percent in all but 6 patients (6 percent) after revascularization; renal function worsened in only 3 (3 percent), all of whom became dependent on dialysis; and 3 (3 percent) died ($P<0.001$ for the comparison with patients with a resistance-index value of at least 80).

Conclusions A renal resistance-index value of at least 80 reliably identifies patients with renal-artery stenosis in whom angioplasty or surgery will not improve renal function, blood pressure, or kidney survival. (N Engl J Med 2001;344:410-7.)

THE use of Doppler ultrasonography in patients with hypertension has led to an increase in the diagnosis of renal-artery stenosis. Patients with stenosis of more than 50 percent of the luminal diameter of a renal artery are usually treated with angioplasty (with or without stenting) or surgery to lower blood pressure or preserve renal function. However, in 20 to 40 percent of patients, treatment does not improve blood pressure or renal function. There is no reliable way to identify these patients prospectively.[1-5] In addition, both angioplasty and surgery are associated with complications, including cholesterol embolism, permanent renal failure, and death.

One possible reason for a poor response to treatment may be structural alterations in smaller renal arteries or arterioles distal to the renal-artery stenosis induced by long-standing hypertension. Such hypertension may cause nephrosclerosis[6-9] or glomerulosclerosis,[10] reducing the intrarenal vascular surface area and increasing vascular resistance in both the affected and the unaffected kidney.[11] Increased vascular resistance may therefore be considered the functional equivalent of structurally altered vasculature.

In a previous study of patients with more than 50 percent stenosis of a renal artery, we found that neither renal function nor blood pressure improved after correction of the stenosis in patients with a resistance-index value of at least 80 in the segmental arteries of both kidneys, as measured by Doppler ultrasonography.[12] The resistance index is calculated with use of the following equation: [1−(end-diastolic velocity÷maximal systolic velocity)]×100. These preliminary retrospective findings prompted us to conduct a prospective study to evaluate whether the resistance index can be used to predict the outcome in patients with renal-artery stenosis that is treated with angioplasty or surgery.

METHODS

Identification of Renal-Artery Stenosis

Between June 1994 and November 1999, we performed color Doppler ultrasonography in 5950 patients who had hypertension and clinical features suggestive of renal-artery stenosis. All the patients had at least one of the following: high blood pressure despite treatment with three or more antihypertensive drugs; a diastolic blood pressure of more than 110 mm Hg; systolic and diastolic murmurs or an isolated systolic abdominal murmur; known coronary, peripheral vascular, or cerebrovascular disease; hypokalemia; retinal hemorrhages, exudates, or papilledema; or unexplained azotemia or a history of azotemia in association with treatment with an angiotensin-converting–enzyme inhibitor. The protocol was approved by the ethics committee of Hannover Medical School, and all patients provided written informed consent.

Our technique for color Doppler ultrasonography to evaluate

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renal-artery stenosis enables us to identify a reduction in the diameter of renal arteries of at least 50 percent (i.e., a reduction in area of at least 75 percent) with a sensitivity of 97 percent and a specificity of 98 percent.[13] This method also provides an estimation of the severity of the stenosis that is reproducible (coefficient of variation, 4 percent) and precise. The results are closely correlated with those of intravascular ultrasonography (correlation coefficient, 0.99) (unpublished data).

Treatment of Renal-Artery Stenosis

Among the 5950 patients who underwent color Doppler ultrasonography, 138 patients had stenosis of at least 50 percent of one renal artery (in the case of 91 patients) or both renal arteries (in the case of 47 patients), and these 138 patients subsequently underwent angiography, angioplasty with or without stent placement, or surgery to correct these stenoses. Angiography, angioplasty, and stent placement were performed as described previously.[14] The operative techniques usually consisted of the placement of an aortorenal-vein or synthetic graft or thromboendarterectomy. The 138 patients were classified into two groups according to their segmental-artery resistance-index values: those with values of 80 or more and those with values of less than 80.[12] In a further 16 patients who met the criteria for renal-artery stenosis, angioplasty was not performed but an angiotensin-converting–enzyme inhibitor was given because of occlusion of the renal artery (10 patients), stenosis of intrarenal vessels (3 patients), stenosis in a kidney scheduled to be removed because of a tumor (1 patient), or refusal to undergo angioplasty (2 patients, both of whom had resistance-index values of more than 80).

Base-Line Studies

Before renal-artery stenosis was corrected, blood pressure was measured with a 24-hour ambulatory blood-pressure monitor (model 90217, Spacelab, Redmond, Wash.), creatinine clearance (expressed in milliliters per minute per 1.73 m^2, or milliliters per minute) was determined, and 24-hour urinary protein excretion, serum cholesterol concentration, and serum uric acid concentration were determined by standard laboratory methods. Plasma renin activity was measured with the use of a radioimmunoassay for angiotensin I in which the temperature was 37°C and the pH was 7.4.[15]

Follow-up Studies

After renal-artery stenosis was corrected, the measurements of blood pressure and creatinine clearance and the ultrasonographic procedure were repeated at 3, 6, and 12 months and yearly thereafter. The end points of the study were the blood pressure and renal function at the time of the last follow-up evaluation, renal status, and vital status. An improvement in blood pressure was defined as a decrease in the mean arterial pressure of at least 10 mm Hg with no change or a decrease in the number of antihypertensive drugs. We defined diuretics and nitrates as antihypertensive drugs, even though they may have been given for other reasons. An improvement in renal function was defined as an increase in creatinine clearance of at least 10 percent, and worsening was defined as a decrease of at least 10 percent. The need for dialysis and vital status were ascertained by contact with the patients or their relatives. The mean (±SD) duration of follow-up was 32±21 months.

Renal Ultrasonography

The 5950 patients were scanned in the supine position with an ultrasound machine (Ultramark 9 HDI, Advanced Technology Laboratories, Bothell, Wash.) with the use of either a multifrequency curved-array transducer (2 to 4 MHz) or a multifrequency sector transducer (2 to 3 MHz) with a 2.5-MHz pulsed Doppler frequency and a focal zone at the depth of the renal arteries. Intrarenal Doppler signals were obtained from segmental arteries because a clear signal can always be obtained from these arteries.[16] A clear signal is needed for the measurement of the resistance index to be reliable. We determined the peak systolic velocity (V_{max}, in centimeters per second) and the end-diastolic velocity (V_{min}, in centimeters per second) in order to calculate the dimensionless resistance-index values: resistance index $= [1-(V_{min} \div V_{max})] \times 100$. The resistance-index values were the average of two to three measurements in segmental arteries from the upper, middle, and lower third of each kidney. The course of the main renal artery was determined with color flow imaging. The intraobserver and interobserver coefficients of variation for the measurements of the resistance index were 2.0 percent for the evaluation of 14 patients and 3.2 percent for the evaluation of 420 patients, respectively; the coefficient of variation was 2.8 percent for the evaluation of 264 patients by the same observer on consecutive days.

Statistical Analysis

Statistical software programs (SPSS, version 10.0.5, SPSS, Chicago, and SAS, version 8.0, SAS Institute, Cary, N.C.) were used for all statistical analyses. Unpaired t-tests with Bonferroni's adjustment for multiple tests at different time points or chi-square analysis was used, as appropriate, to assess differences between groups. Odds ratios for the worsening of renal function in association with various risk factors were calculated from two-by-two contingency tables with use of Fisher's exact test. For multivariate analysis, the effects of the resistance index; the degree of renal-artery stenosis; mean ambulatory 24-hour systolic and diastolic blood pressures; pulse pressure; the presence or absence of a nocturnal decrease in blood pressure (a decrease in blood pressure of more than 10 percent as compared with the daytime value); creatinine clearance; age; sex; the size of the kidney with stenosis; peripheral venous renin activity; the presence or absence of atherosclerosis in the heart, legs, or central nervous system; the presence or absence of diabetes mellitus; smoking status; serum uric acid concentrations; the blood-pressure response to treatment with angiotensin-converting–enzyme inhibitors; the number of years since the onset of hypertension; and urinary protein excretion were analyzed in all 131 patients in whom revascularization was successful. In the stepwise forward logistic-regression analysis, variables with a P value of 0.1 or more were removed from the analysis and variables with a P value of 0.05 or less were retained. Unless stated otherwise, all data are expressed as means ±SD.

RESULTS

Among the 138 patients with renal-artery stenosis, the stenosis was corrected in 131. The stenosis was corrected with angioplasty alone in 81 patients, with angioplasty and stent placement in 42 patients, and with surgery in 8 patients (placement of an aortorenal-vein graft in 6, placement of a synthetic graft in 1, and thromboendarterectomy in 1). The changes in 24-hour blood pressure and renal function after technically successful correction were therefore determined in these 131 patients (Table 1). In seven patients angioplasty was unsuccessful; these patients were considered poor candidates for surgery and were therefore excluded from the analysis.

After correction of renal-artery stenosis, the 35 patients with resistance-index values of at least 80 before revascularization had decreases in renal function (Fig. 1) and little improvement in blood pressure despite increased numbers of antihypertensive drugs (Fig. 2), whereas both outcomes improved in the 96 patients with resistance-index values of less than 80. In the latter group, the resistance index had a high sensitivity (96 percent) but a low specificity (53 percent) for predicting an improvement in renal function (Table 2). When the 78 patients who had im-

TABLE 1. BASE-LINE CHARACTERISTICS OF 131 PATIENTS IN WHOM RENAL-ARTERY STENOSIS WAS SUBSEQUENTLY CORRECTED, ACCORDING TO THE RESISTANCE-INDEX VALUE.*

CHARACTERISTIC	RESISTANCE INDEX VALUE ≥80 (N=35)	RESISTANCE INDEX VALUE <80 (N=96)	P VALUE†
Female sex — no. (%)	14 (40)	45 (47)	0.55
Age — yr	67±9	55±14	<0.001
History of severe atherosclerosis —no. (%)	29 (83)	52 (54)	0.001
Coronary artery disease — no. (%)	25 (71)	38 (40)	0.002
Peripheral-artery disease — no. (%)	21 (60)	31 (32)	0.005
Cerebrovascular disease — no. (%)	11 (31)	26 (27)	0.66
Diabetes mellitus — no. (%)	16 (46)	17 (18)	0.005
Current smoker — no. (%)	21 (60)	66 (69)	0.41
No. of packs of cigarettes smoked — $\times 10^{-3}$‡	19.9±9.9	10.3±7.0	0.001
24-Hr ambulatory blood pressure — mm Hg			
Systolic	164±21	150±22	0.002
Diastolic	83±16	89±12	0.05
Pulse pressure — mm Hg	80±19	61±16	<0.001
Nocturnal fall in blood pressure — no. (%)	14 (40)	70 (73)	0.001
Recent worsening of hypertension or new onset of hypertension — no. (%)	18 (51)	61 (64)	0.23
Good control of blood pressure with an ACE inhibitor — no. (%)§	7 (41)	19 (32)	0.56
No. of antihypertensive drugs taken	3.3±1.7	3.2±1.7	0.74
Creatinine clearance — ml/min	33±26	68±41	<0.001
Urinary protein excretion — g/day	1.3±1.3	0.6±1.8	0.06
Serum uric acid — mg/dl	7.8±2.3	6.3±1.6	<0.001
Serum cholesterol — mg/dl	240±66	228±43	0.23
Plasma renin activity — ng/ml/hr	7.8±4.1	4.3±3.0	<0.001
Size of the kidney with the stenotic renal artery — cm	10.8±1.3	11.0±1.3	0.42
Difference in size between kidneys — mm	15±14	13±12	0.42
Degree of stenosis — %	71±13	69±13	0.44

*Plus–minus values are means ±SD. To convert the values for serum uric acid to micromoles per liter, multiply by 59.5. To convert the values for serum cholesterol to millimoles per liter, multiply by 0.026. Blood for the determination of plasma renin activity was drawn from a peripheral vein after 15 minutes of rest with the patient in the supine position.

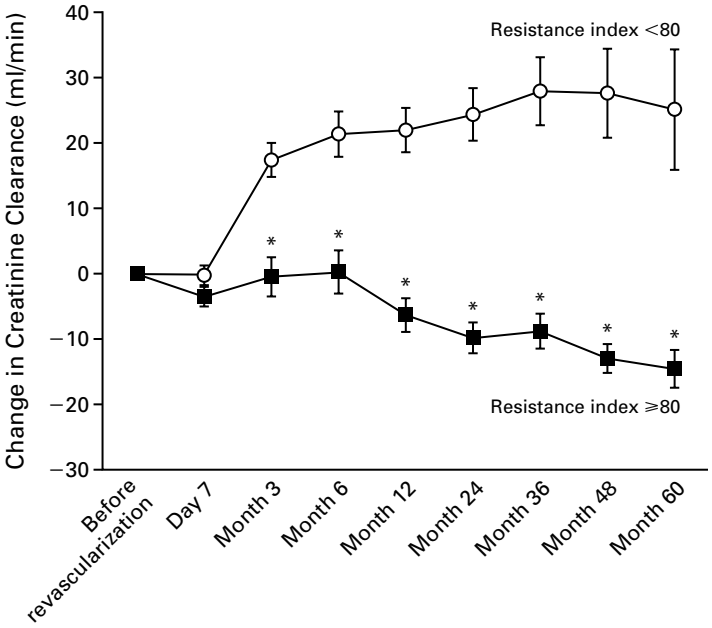
†P values were calculated with use of an unpaired t-test or the chi-square test.

‡This calculation included current and former smokers.

§A total of 18 patients with a resistance-index value of at least 80 and 36 patients with a resistance-index value of less than 80 were not taking an angiotensin-converting–enzyme (ACE) inhibitor at base line.

paired renal function before revascularization (defined as a creatinine clearance that was less than 75 percent of the age-adjusted normal value[17]) or the 45 patients with a creatinine clearance of less than 40 ml per minute at base line were considered, the overall accuracy of the resistance index was improved. In the patients with resistance-index values of less than 80 before revascularization there was no significant difference in the degree of improvement in blood pressure or renal function among the methods used to correct the renal-artery stenosis, whereas in patients with resistance-index values of at least 80, renal function deteriorated less after stent placement than after angioplasty alone (data not shown). The rate of restenosis or spontaneous stenosis was similar among patients who received a stent and those treated by angioplasty alone; this rate averaged about 10 percent per year.

On univariate analysis a number of factors present before revascularization were associated with an increased likelihood of a decline in renal function (Fig. 3 and Table 3). However, a resistance-index value of at least 80 had the strongest association. On multivariate analysis (Table 3), only a resistance-index value of at least 80 ($P<0.001$), not smoking ($P=0.01$), a creatinine clearance of less than 40 ml per minute ($P=0.01$), and male sex ($P=0.05$) remained independently associated with a higher risk of a decline



No. with Follow-up Data									
Resistance index <80	96	96	95	83	73	59	43	34	21
Resistance index ≥80	35	35	33	31	26	21	16	8	5

Figure 1. Mean (±SE) Changes in Creatinine Clearance after the Correction of Renal-Artery Stenosis, According to the Resistance-Index Value before Revascularization.

Asterisks indicate a significant difference ($P<0.05$) between the two groups with use of an unpaired t-test with Bonferroni's adjustment.

in renal function after revascularization. Resistance-index values of less than 80 ($P<0.001$) and smoking ($P=0.02$) were associated with the likelihood of an improvement in renal function. Similar findings were obtained in the univariate analysis with respect to the prediction of an improvement in blood pressure: other than a resistance-index value of less than 80, the best predictor was a urinary protein excretion of less than 1 g per day (odds ratio, 4.5; 95 percent confidence interval, 1.7 to 12). On multivariate analysis, only a resistance-index value of less than 80 was significantly associated with the likelihood of an improvement in blood pressure.

Of the 96 patients with a resistance-index value of less than 80 before revascularization who underwent correction of renal-artery stenosis, 3 (3 percent) died during follow-up and 3 (3 percent) required dialysis (all 3 of whom had an initial creatinine clearance of less than 15 ml per minute). In contrast, among the 35 patients who had a resistance-index value of at least 80 before revascularization, 10 (29 percent) died during follow-up and 16 (46 percent) became dependent on dialysis ($P<0.001$ for the comparison with the patients with a resistance-index value of less than 80). In a multivariate analysis, an initial resistance-index value of at least 80 (risk ratio, 19; 95 percent confidence interval, 6 to 58) and a creatinine clearance of less than 40 ml per minute (risk ratio, 8; 95 percent confidence interval, 3 to 21) were independent predictors of the risk of renal failure or death. The mean rate of renal failure at two years among patients with a resistance-index value of at least 80 before revascularization was 50 percent, as compared with a rate of 5 percent among patients with a resistance-index value of less than 80. The rate of restenosis or spontaneous stenosis was similar in the two resistance-index groups and averaged about 10 percent per year (data not shown).

After the correction of renal-artery stenosis, major complications occurred in 8 patients (6 percent) and minor complications in 10 patients (8 percent). The major complications consisted of aortic dissection after angioplasty (one patient; resistance-index value, 75), myocardial infarction during angioplasty with subsequent death (one patient; resistance-index value, 81), renal-artery or intrarenal-vessel occlusion (three patients; resistance-index values, 75, 80, and 80), false aneurysm requiring operative repair (one patient; re-

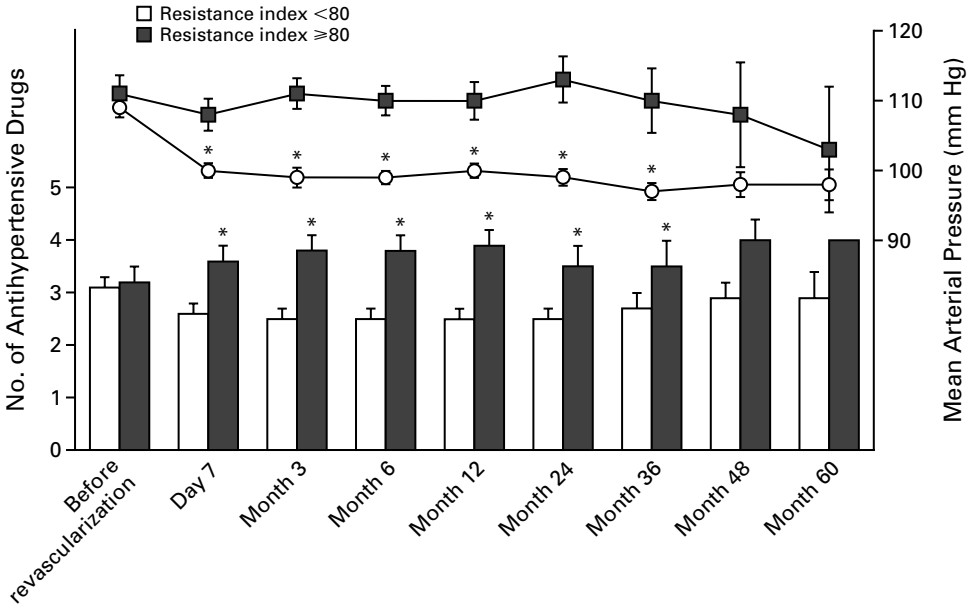


Figure 2. Mean (±SE) Change in Mean Arterial Pressure and the Number of Antihypertensive Drugs Taken after the Correction of Renal-Artery Stenosis, According to the Resistance-Index Values before Revascularization.

In the group of patients with a resistance index of less than 80 before revascularization, mean (±SD) blood pressure was 150±22/89±12 mm Hg initially and 135±14/80±10 mm Hg at the last follow-up visit ($P<0.001$); the respective values in the group of patients with a resistance index of at least 80 before revascularization were 164±21/83±16 mm Hg and 163±19/86±10 mm Hg ($P=0.73$). The antihypertensive drugs included angiotensin-converting–enzyme inhibitors, angiotensin II–receptor blockers, beta-blockers, calcium antagonists, alpha-blockers, direct vasodilators, diuretics, and nitrates. Asterisks indicate a significant difference ($P<0.05$) between the two groups with use of an unpaired t-test with Bonferroni's adjustment.

sistance-index value, 89), and dislocation of the stent into or beyond the aorta (two patients; resistance-index values, 75 and 80). Minor complications consisted of intimal dissections that were corrected with stent placement (nine patients) and a false aneurysm that resolved (one patient).

DISCUSSION

We found that a renal resistance-index value of at least 80 before revascularization was a strong predictor of worsening renal function and a lack of improvement in blood pressure despite the correction of renal-artery stenosis. Conversely, lower resistance-index values were associated with an improvement in both renal function and blood pressure after the correction of renal-artery stenosis. These results contrast with those of a recent study of similar patients, in which angioplasty was not found to be superior to treatment with antihypertensive drugs alone in terms of reducing blood pressure or maintaining renal function.[19] However, in that study no effort was made to identify patients according to their likelihood of a response, blood pressure was measured during an office visit rather than at home over a period of 24 hours, renal function was assessed by measurements of serum creatinine rather than creatinine clearance, and the patients had relatively normal renal function (mean serum creatinine concentration, 1.2 mg per deciliter [106 μmol per liter]) as compared with our patients (mean serum creatinine concentration, 2.1 mg per deciliter [186 μmol per liter]). Finally, far fewer patients were treated by stenting (4 percent, vs. 32 percent in our study).

In patients with renal-artery stenosis who are not treated with angioplasty or surgery, normalization of blood pressure, especially with use of an angiotensin-converting–enzyme inhibitor or a beta-blocker, is not an invariable indicator of the preservation of renal function.[20] On the other hand, angioplasty or surgery is not without risk, as we found. Thus, the development of methods to identify patients who will benefit from the intervention or, perhaps more important, those who would only be harmed by it, should have a high priority.

Among other noninvasive tests, captopril scintigraphy has been reported to be of value in identifying patients in whom blood pressure is likely to decrease after successful correction of renal-artery stenosis, with a sensitivity of 92 percent (range, 84 to 100 percent) and a specificity of 78 percent (range, 62 to 100 per-

TABLE 2. SENSITIVITY, SPECIFICITY, AND POSITIVE AND NEGATIVE PREDICTIVE VALUE OF THE RENAL RESISTANCE INDEX AS A MEANS OF IDENTIFYING THE RESPONSE OF RENAL FUNCTION AND BLOOD PRESSURE TO SUCCESSFUL REVASCULARIZATION.*

OUTCOME	SENSITIVITY	SPECIFICITY	POSITIVE PREDICTIVE VALUE	NEGATIVE PREDICTIVE VALUE
		percent (no./total no.)		
Improvement in renal function				
Resistance index <80 before revascularization	96 (68/71)	53 (32/60)	71 (68/96)	91 (32/35)
Resistance index <80 and creatinine clearance below normal before revascularization	96 (43/45)	79 (26/33)	86 (43/50)	93 (26/28)
Resistance index <80 and creatinine clearance <40 ml/min before revascularization	95 (18/19)	85 (22/26)	82 (18/22)	96 (22/23)
Decline in renal function				
Resistance index ≥80 before revascularization	90 (28/31)	93 (93/100)	80 (28/35)	97 (93/96)
Resistance index ≥80 and creatinine clearance <40 ml/min before revascularization	86 (19/22)	83 (19/23)	83 (19/23)	86 (19/22)
Improvement in blood pressure				
Resistance index <80 before revascularization	99 (90/91)	85 (34/40)	94 (90/96)	97 (34/35)

*An improvement in renal function was defined as an increase in the creatinine clearance of at least 10 percent, and worsening as a decrease of at least 10 percent. The creatinine clearance was considered to be below normal if it was less than 75 percent of the age-adjusted normal value. The age-adjusted normal value was calculated according to the formula of Keller.[17] An improvement in blood pressure was defined as a decrease in the mean arterial pressure of at least 10 mm Hg with no change or a decrease in the number of antihypertensive drugs.

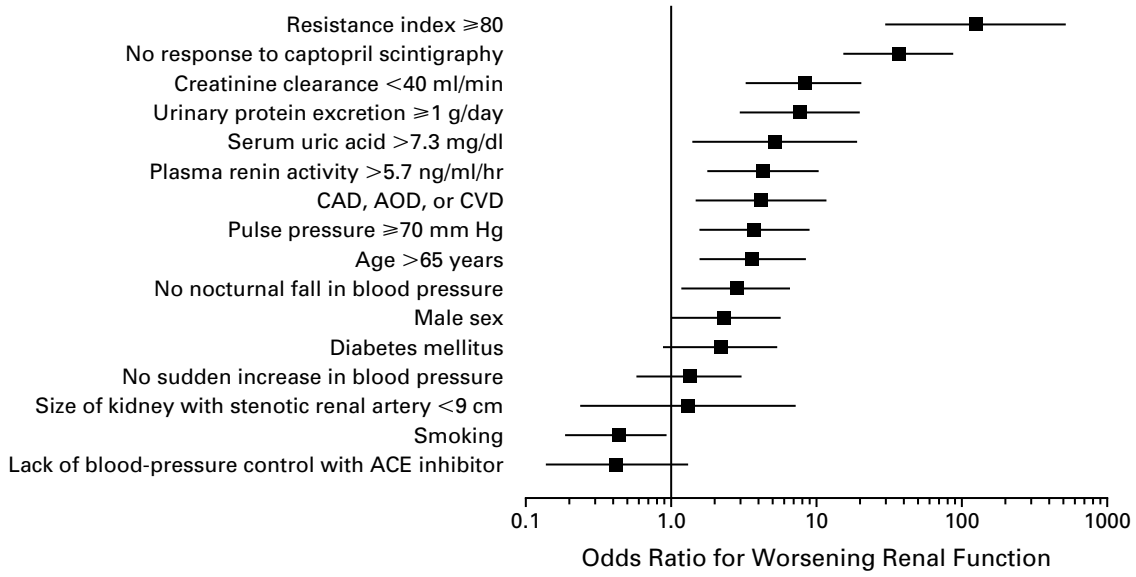


Figure 3. Univariate Odds Ratios for a Worsening of Renal Function after Correction of Renal-Artery Stenosis, with 95 Percent Confidence Intervals, Associated with Various Factors before Revascularization.

The absence of a nocturnal fall in blood pressure was determined from measurements of 24-hour ambulatory blood pressure. The odds ratio for captopril scintigraphy was calculated from published data.[4,18] A "sudden increase in blood pressure" refers to recent worsening of hypertension or recent onset of hypertension. To convert the value for serum uric acid to micromoles per liter, multiply by 59.5. CAD denotes coronary artery disease, AOD arterial occlusive disease of the legs, CVD cerebrovascular disease, and ACE angiotensin-converting enzyme.

TABLE 3. FACTORS ASSOCIATED WITH AN INCREASED RISK OF WORSENING RENAL FUNCTION OR AN INCREASED LIKELIHOOD OF AN IMPROVEMENT IN RENAL FUNCTION OR BLOOD PRESSURE AFTER THE CORRECTION OF RENAL-ARTERY STENOSIS IN 131 PATIENTS.*

FACTOR	UNIVARIATE ODDS RATIO (95% CI)	MULTIVARIATE ODDS RATIO (95% CI)†
Likelihood of worsening renal function		
Resistance index ≥80	124 (30–511)	1392 (50–38,402)
Smoking	0.4 (0.2–1.0)	0.04 (0.00–0.5)
Creatinine clearance <40 ml/min	8.2 (3.3–20)	12.7 (1.7–95)
Male sex	2.3 (1.0–5.6)	8.0 (1.0–61)
Likelihood of improvement in renal function		
Resistance index <80	26 (7.3–92)	146 (20–1059)
Smoking	3.5 (1.6–7.5)	8.0 (1.4–45)
Likelihood of improvement in blood pressure		
Resistance index <80	510 (59–4392)	1132 (86–14,831)

*An improvement in renal function was defined as an increase in the creatinine clearance of at least 10 percent, and worsening as a decrease of at least 10 percent in the 78 patients with impaired renal function (a glomerular filtration rate that was less than 75 percent of the age-adjusted normal rate[17]) before correction of renal-artery stenosis. An improvement in blood pressure was defined as a decrease in the mean arterial pressure of at least 10 mm Hg with no change or a decrease in the number of antihypertensive drugs. CI denotes confidence interval.

†Stepwise logistic-regression analysis was used. Only findings that remained independent predictors after stepwise forward logistic-regression analysis are listed.

cent).[4,5,21-25] However, this approach is less accurate in patients with renal impairment, patients with bilateral renal-artery stenosis, and patients with unilateral renal-artery stenosis.[4] Furthermore, the value of captopril scintigraphy as a means of identifying patients in whom renal function is likely to improve after the correction of renal-artery stenosis has not been assessed prospectively. The ability to identify such patients is particularly important, because preservation of renal function is the main rationale for performing angioplasty or corrective surgery in patients with renal-artery stenosis and reduced renal function.

The use of various risk factors has been proposed to differentiate between patients who are likely to benefit from the correction of renal-artery stenosis and those unlikely to benefit. We found that urinary protein excretion of at least 1 g per day, hyperuricemia, creatinine clearance of less than 40 ml per minute, an age of more than 65 years, pulse pressure of at least 70 mm Hg, the absence of a nocturnal fall in blood pressure, and the presence of coronary artery disease, arterial occlusive disease of the legs, or cerebrovascular disease were useful in identifying patients unlikely to benefit. However, none of these findings had a predictive value approaching that of the renal resistance index in univariate or multivariate analyses. Smoking, a known risk factor for the development of renal-artery stenosis,[26] was not a predictor of worsening of renal function after treatment. We interpret the finding as suggesting that correction of renal-artery stenosis should not be denied patients merely because they smoke.

Renal-artery angioplasty is associated with major complications in about 10 to 15 percent of patients and a death rate of 1 to 5 percent.[27-30] Renal-artery surgery has complication rates of 8 to 11 percent and a death rate of 2 to 8 percent.[30-32] Our results were within these ranges. Intervention should therefore be reserved for patients in whom renal function is likely to improve or at least stabilize or in whom blood pressure is likely to decrease. We conclude that patients with renal resistance-index values of at least 80 should be excluded from these interventions.

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