Renal Resistive Index and Long-term Outcome in Chronic Nephropathies[1]

Claudia Parolini, MD
Annalisa Noce, MD
Emiliano Staffolani, MD
Gerlando F. Giarrizzo, PhD
Stefano Costanzi, MD
Giorgio Splendiani, MD

Purpose: To assess the clinical validity of renal resistive index (RI) to determine prognosis and guide therapy over a long-term follow-up in patients with chronic nephropathies and to verify the commonly used threshold value of 0.70.

Materials and Methods: Of patients referred to the nephrology center since 1995, 177 were initially enrolled and 86 were followed up for RI and renal function annually for 2–11 years (mean, 5.93 years ± 2.92 [standard deviation]). All patients gave informed consent for the institutional review board–approved study. Correlations were determined between initial RI and age, estimated glomerular filtration rate (eGFR), proteinuria, hematuria, blood pressure, and biopsy scores. The sample was categorized in four groups on the basis of whether initial values of RI and eGFR were normal, and progression to renal failure was compared. With grouping of the sample by using initial RI (≤0.61, 0.62–0.69, and ≥0.70), Kaplan-Meier analysis was used to obtain survival curves.

Results: Initial RI correlated with final eGFR ($R = -0.4$, $P < .001$), systolic blood pressure ($R = 0.39$, $P < .001$), proteinuria ($R = 0.28$, $P = .009$), and age ($R = 0.28$, $P = .007$). In stepwise multiple regression analysis, RI emerged as the only independent risk factor for the progression to renal failure ($P < .001$). Among the four groups of patients with different initial RIs and eGFRs, the group with an initial RI of 0.70 or higher showed a worse outcome, independent of initial eGFR. In the Kaplan-Meier analysis by using initial RI, only the group with a value of 0.70 or higher showed a rapid decline of renal function (>50% decrease in eGFR in 6 years).

Conclusion: An RI of 0.70 or higher is predictive of an unfavorable outcome in patients with chronic nephropathies.

[1] From the Department of Nephrology, Tor Vergata University, Viale Oxford 81, 00133 Rome, Italy (C.P., A.N., E.S., G.F.G., G.S.); and Department of Nephrology, Columbus Hospital, Rome, Italy (S.C.). Received February 21, 2008; revision requested April 10; final revision received January 15, 2009; accepted January 20; final version accepted March 5. **Address correspondence to** C.P. (e-mail: *claudiaparolini.parolini@gmail.com*).

Over the past 2 decades, Doppler waveforms of intrarenal arterial blood flow have been extensively investigated to determine physiologic and pathologic correlations. Among the parameters introduced, the renal resistive index (RI), which is considered a reflection of renal parenchymal resistance (1–8), has been widely used to support diagnostic and therapeutic procedures.

From the initial studies of Rigsby et al (9) on transplanted kidneys and the subsequent work of Rifkin et al (10) and Platt et al (11), as well as of others (12–20), on the behavior of RI in different renal diseases, the mean reference value for normal RI in adults was determined to be 0.60 ± 0.10, with 0.70 as the upper limit of normal. Investigators in several articles (21–25) have indicated threshold values for renal impairment and/or values prognostic of poor renal outcome ranging from 0.60 to 0.79. Such a wide interval contributes to questions about the clinical utility of this measurement. A better-defined threshold value is necessary if RI is to be a useful measurement for prognosis and therapy. Although many studies that were based on correlations among RI, renal function, and renal histopathologic findings have been performed, to our knowledge, none have included a follow-up that exceeded 5 years (mean, 3.0 years ± 1.4 [standard deviation]) (22). The purpose of this study was to assess the clinical validity of renal RI to determine prognosis and guide therapy over a long-term follow-up in patients with chronic nephropathies and to verify the commonly used threshold value of 0.70.

Advances in Knowledge

- Renal function estimated survival curves for three levels of resistive index (RI) show that the high-normal–RI group (RI = 0.62–0.69) has an outcome similar to the normal-RI group (RI = ≤0.61).
- An RI of 0.70 or higher is predictive of unfavorable outcome in chronic nephropathies.
- Unfavorable outcome in patients with an RI of 0.70 or higher is not dependent on initial estimated glomerular filtration rate.

Materials and Methods

Patients and Clinical Evaluation

Among patients referred to our center between 1995 and 2002, 177 patients (mean age, 45.1 years; range, 15–81 years), including 89 female subjects (mean age, 44.6 years; range, 18–79 years) and 88 male subjects (mean age, 45.7 years; range, 15–81 years), were recruited for a study on RI and renal function. Exclusion criteria were clinical or morphologic signs of end-stage renal disease (estimated glomerular filtration rate [eGFR] of <15 mL/min and/or renal length of <8 cm, hyperechoic parenchyma with thickness <1 cm) or technically inadequate pulsed Doppler tracings.

Ultrasonographic (US) examination was performed at the end of the first clinical screening. Patients were examined for RI distribution and correlation with age, sex, and eGFR. All of them gave informed consent for the study, which was approved by the institutional review board of Tor Vergata University, Rome, Italy.

Of the initial group, 86 patients (mean age, 43.4 years; range, 15–81 years), 42 female patients (mean age, 42.8 years; range, 16–79 years) and 44 male patients (mean age, 43.8 years; range, 15–81 years) remained in follow-up for more than 1 year (range, 2–11 years; mean, 5.93 years ± 2.92) and represent our follow-up study group. There were no significant differences between the group with follow-up and the group without follow-up ($n = 91$), except for the diagnosis. Glomerulonephritis was prevalent in the group with follow-up (70.9%, 61 of 86), whereas in the group without follow-up, glomerulonephritis, hypertension with microalbuminuria, and interstitial nephropathies had approximately the same distribution. The variables considered for these two groups, differences, and P values are shown in Table 1. The clinical characteristics of initial and follow-up groups are shown in Table 2.

Twenty-nine patients in the follow-up group had renal function impairment at the beginning of the study (eGFR, 30–60 mL/min in 21 patients and 16–30 mL/min in eight patients). In 26 patients, the RI was 0.70 or higher, and in 17, both parameters were in the abnormal range. Patients were treated with antihypertensive, antiproteinuric, and immunosuppressant agents, according to current therapeutic guidelines (26), independent from the RI evaluation.

In the follow-up group, the parameters considered for correlation with RI were as follows: eGFR (in milliliters per minute per 1.73 m^2), serum cholesterol level (in milligrams per deciliter [millimoles per liter]), hematocrit value (percentage [proportion of 1.0]), proteinuria (milligrams per 24 hours), hematuria, systolic and diastolic blood pressure (millimeters of mercury) and, for 60 patients, the biopsy score.

Renal biopsy was performed only when clinical data were not sufficient for the diagnosis. The score was based on the site of the lesions: score 1, mainly glomerular, or score 2, also involving the tubulointerstitium and vascular compartment.

Renal function was calculated by

Implication for Patient Care

- Performance of renal Doppler US with RI evaluation in patients with nephropathies during the initial clinical screening can help determine prognosis and guide therapy.

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Abbreviations:
eGFR = estimated glomerular filtration rate
RI = resistive index

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using the Modification of Diet in Renal Disease eGFR formula (27). According to the U.S. National Kidney Foundation guidelines for the diagnosis and classification of chronic renal disease, an eGFR of 60 mL/min per 1.73 m or higher is considered to indicate normal or mildly reduced renal function, an eGFR of lower than 60 mL/min is considered to indicate that the patient is at risk for moderate renal dysfunction, and a decrease of 50% or greater of the initial value is indicative of progression to renal failure (28). Renal function was monitored twice a year. Pulsed Doppler examinations were performed once a year. RI variation for each patient during the follow-up period (difference between final and initial RI, or ΔRI) and the mean ΔRI for the entire group were also calculated to determine the variability of the measurement, and whether eGFR variations (difference between final and initial eGFR, or ΔeGFR) were related to ΔRI.

Progression to renal failure for different initial values of RI and eGFR was studied by classifying patients in four groups: group 1, with an eGFR of 60 mL/min or higher and an RI of lower than 0.70 (48 patients); group 2, with an eGFR of 60 mL/min or higher and an RI of 0.70 or higher (nine patients); group 3, with an eGFR of lower than 60 mL/min and an RI of lower than 0.70 (12 patients); and group 4, with an eGFR of lower than 60 mL/min and an RI of 0.70 or higher (17 patients). To examine the clinical importance of the 0.70 RI threshold value and to evaluate possible predictive differences between "normal" (RI, ≤0.61) and "high-normal" (RI, 0.62–0.69) values, Kaplan-Meier analysis was applied to three groups of patients with different initial values of RI: patients with an RI of 0.61 or lower (n = 30), patients with an RI in the range of 0.62–0.69 (n = 30), and patients with an RI of 0.70 or higher (n = 26).

US Examinations

Doppler examinations were all performed by the same operator (C.P., with 15 years of experience in renal US at the beginning of the study). Different 3.5-MHz transducers were used for examinations for the first 5 years of the study (model SSH-140 A; Toshiba, Nasu, Japan) and for the last

Table 1

Comparison between Patients without Follow-up and Patients with Follow-up

Characteristic	Group without Follow-up (n = 91)	Group with Follow-up (n = 86)	P Value
Sex			.4536
No. of male patients	44	44	
No. of female patients	47	42	
Age (y)*	46.8 ± 17.8	43.4 ± 18.2	.1535
Diagnosis			
No. with glomerulonephritis	29	61	<.0001
No. with hypertension and microalbuminuria	33	16	<.0001
No. with interstitial nephropathies	29	9	<.0001
Serum creatinine level (mg/dL)†	1.59 ± 1.42	1.39 ± 0.87	.1835
RI*	0.65 ± 0.07	0.65 ± 0.07	.9842
eGFR*	82.08 ± 47.22	87.42 ± 52.02	.074

* Data are the mean ± standard deviation.

† To convert to Système International units in micromoles per liter, multiply by 88.4. Data are the mean ± standard deviation.

Table 2

Characteristics of Groups

Clinical Diagnosis	Overall	No. with eGFR ≥ 60*	No. with eGFR < 60*	No. with RI < 0.70†	No. with RI ≥ 0.70†
Initial group					
Glomerulonephritis	89 (50.3)	64 (57.7)	25 (37.9)	69 (54.3)	20 (40.0)
Hypertension and microalbuminuria	49 (27.7)	26 (23.4)	23 (34.8)	33 (26.0)	16 (32.0)
Interstitial nephropathies	39 (22.0)	21 (18.9)	18 (27.3)	25 (19.7)	14 (28.0)
Total	177 (100)	111 (100)	66 (100)	127 (100)	50 (100)
Follow-up group					
Glomerulonenephritis	61 (70.9)	46 (80.7)	15 (51.7)	49 (81.7)	12 (46.2)
Hypertension and microalbuminuria	15 (17.4)	9 (15.8)	6 (20.7)	8 (13.3)	7 (26.9)
Interstitial nephropathies	10 (11.6)	2 (3.5)	8 (27.6)	3 (5.0)	7 (26.9)
Total	86 (100)	57 (100)	29 (100)	60 (100)	26 (100)

Note.—In the initial group (n = 177), there were 88 (49.7%) male patients and 89 (50.3%) female patients, with a mean age of 45.1 years. In the follow-up group (n = 86), there were 44 (51.2%) male patients and 42 (48.8%) female patients, with a mean age of 43.4 years. For both groups, the age range was 15–81 years. Numbers in parentheses are percentages.

* For the initial group, $\chi^2 = 6.483$ ($P = .039$). For the follow-up group, $\chi^2 = 12.123$ ($P = .002$).

† For the initial group, $\chi^2 = 3.060$ ($P = .217$). For the follow-up group, $\chi^2 = 32.902$ ($P < .001$).

6 years of the study (model 3000 HDI; ATL, Bothell, Wash). The US examinations were considered technically adequate when all the following could be obtained: a clear two-dimensional image with definition of the renal parenchyma; a good color image with representation of the intrarenal vascular blood flow; and at least three Doppler time-velocity spectra for each kidney that were representative of all the components of the arterial flow, from the early-systolic to the end-diastolic Doppler shifts. The Doppler measurements were performed on segmental and interlobar arteries, which, particularly in kidneys with disease, give the best Doppler signal both for the quantity of flow and for the correct angle (29). Only waveforms with a clearly represented early systolic peak were used for the determination of the RI. To obtain the best possible definition of the early systolic peak, the sample gate was reduced to the size of the vascular lumen, and the pulse repetition frequency was continuously adapted to the arterial blood flow velocity at the point where the gate was positioned. The RI was measured as usual, with the calculation $(FS_{psys} - FS_{ldia})/FS_{psys}$, where FS_{psys} is the peak systolic frequency shift and FS_{ldia} is the lowest diastolic frequency shift, and was recorded as the mean value of at least three measurements obtained in different parts of the kidney. Morphologic appearance of end-stage renal disease (renal length of <8 cm, hyperechoic parenchyma with thickness of <1 cm) was considered as an exclusion criterion. Other morphologic parameters were not considered in this study.

Figure 1

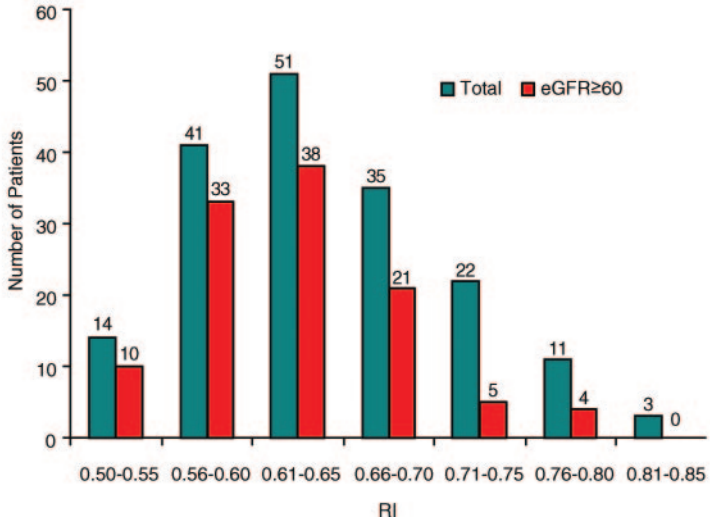

Figure 1: RI distribution in initial group ($n = 177$).

Figure 2

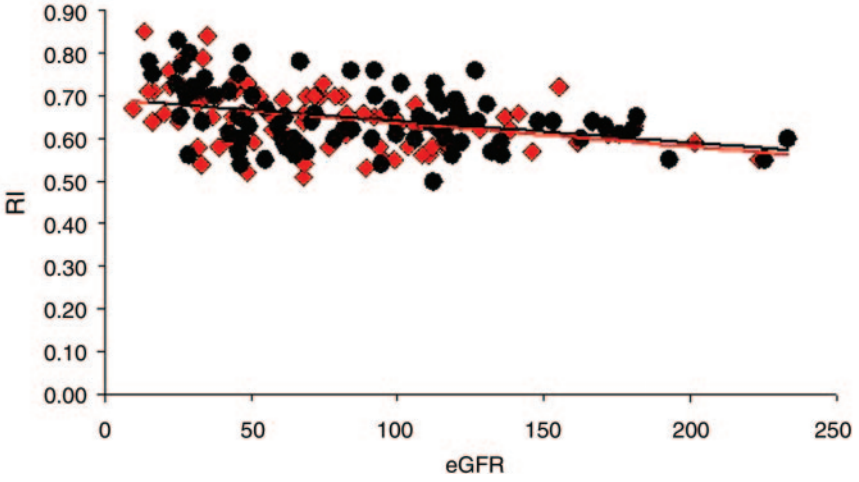

Figure 2: Linear regression between RI and glomerular filtration rate. Red diamonds = initial group, ● = follow-up group.

Statistical Analysis

Statistical analysis was performed by using a statistical package (SPSS, version 5.0 for Windows; SPSS, Chicago, Ill). A difference with a P value of less than .05 was considered significant. Differences between variables were assessed with statistical tests that were based on the underlying distribution of the variables by using two-way analysis of variance, followed by correction for multiple comparisons (Bonferroni test) and the χ^2 test. To study the linear relationship between RI and the other variables, nonparametric correlation (Spearman ρ) and the χ^2 test were used. Stepwise multiple regression analysis was used to identify independent risk factors for the progression to renal failure. Kaplan-Meier analysis was used to compare overall survival rates among groups. The end point of the survival analysis was defined as *(a)* a 50% or greater reduction of eGFR, *(b)* end-stage renal disease with replacement therapy, or *(c)* death, whichever came first. Survival data were right censored. Patients were followed up from the date of enrollment (first visit) to the date of the end point or to the last observation if they did not experience the end point.

Figure 3

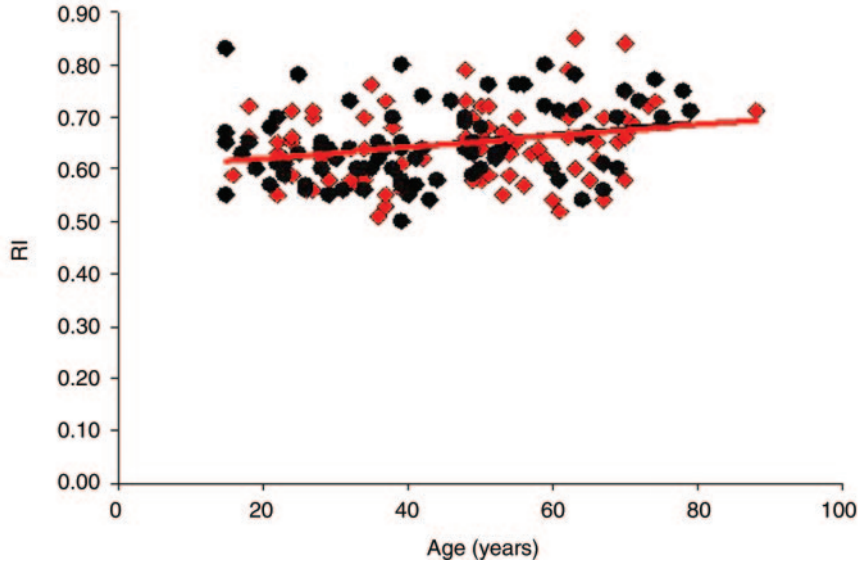

Figure 3: Linear regression between RI and age. Keys are same as for Figure 2.

Results

Initial Group

The distribution of RI values in the total sample and in patients with eGFR of 60 mL/min or higher showed that the most frequent values were between 0.61 and 0.65 (Fig 1). Of 111 patients with an eGFR of 60 mL/min or higher, 102 (91.9%) had RIs between 0.50 and 0.70. Five patients had an RI of 0.80 or higher, and all of them had an eGFR of lower than 40 mL/min (mean, 28.11 ± 7.65). Of patients with impaired renal function, approximately half (31 of 66) had an RI of higher than 0.70. Linear regression analysis showed significant correlations between RI and eGFR ($R = -0.38$, $P < .001$) (Fig 2) and between RI and age ($R^2 = 0.073$) (Fig 3).

Follow-up Group

Linear regression analysis results showed significant correlations between RI and eGFR ($R = -0.37$, $P < .001$) (Fig 2) and between RI and age ($R^2 = 0.081$) (Fig 3). Spearman ρ analysis revealed significant correlations between initial RI and final eGFR ($R = -0.4$, $P < .001$), final systolic blood pressure ($R = 0.39$, $P < .001$), initial eGFR ($R = -0.33$, $P = .002$), final proteinuria ($R = 0.28$, $P = .009$), and age ($R = 0.28$, $P = .007$) (Table 3). The distribution of percentage of patients according to years of follow-up is shown in Figure 4.

No significant relationship was found between RI and biopsy score (Table 4) or histopathologic diagnosis (Table 5). However, our data showed that only 17.2% of lesions limited to the glomeruli were associated with a higher RI.

Stepwise multiple regression analysis showed that only the RI was an independent risk factor for the progression of renal dysfunction ($P < .001$) (Table 6).

Mean ΔRI (difference between final and initial value for each patient for the entire follow-up period) was close to zero (mean, 0.033 ± 0.027; range, 0–0.012). ΔeGFR did not correlate with ΔRI. Patients who had a normal initial eGFR and RI and in whom both parameters remained in the normal range (48 patients) showed a similar RI variation (mean, 0.032 ± 0.027) during a mean follow-up of 5.11 years ± 3.19; 12 of these patients were followed up for 9–11 years. Of 26 patients with an initial RI of 0.70 or higher, only four showed a subsequent decrease below the threshold value, with a maximum ΔRI of −0.05. In these four cases, the decrease did not reflect an improvement in renal function. Two patients in this group with an RI of 0.80 or higher had high serum creatinine levels at the beginning of the study and showed a doubling of this value in 2–4 years.

Classification of 86 patients in four groups on the basis of initial eGFR and RI revealed differences in progression to renal failure (Fig 5). Only 2% of patients with normal initial eGFR and RI (eGFR ≥ 60 mL/min, RI < 0.70) had progression to renal failure, compared with 65% of patients with abnormal initial eGFR and RI (eGFR < 60 mL/min, RI ≥ 0.70). Among the groups with mixed initial values, the group with an RI of 0.70 or higher showed a higher rate of progression to renal failure (56% vs 33% for RI < 0.70), despite better initial renal function (eGFR ≥ 60 mL/min vs eGFR < 60 mL/min).

A thorough analysis of these four subgroups showed that, among the 29 patients with impaired renal function, those with a higher RI at presentation (17 patients) had an almost twofold pro-

Table 3

Correlation Coefficients between RI and Various Parameters in Follow-up Group

Parameter	*R* Value	*P* Value
Age	0.28	.007
eGFR (mL/min)		
Initial time	−0.33	.002
Final time	−0.40	<.001
ΔeGFR	−0.12	.277
Hematocrit value		
Initial time	−0.24	.024
Final time	−0.22	.038
Hematuria		
Initial time	−0.04	.695
Final time	0.02	.852
Proteinuria		
Initial time	0.21	.05
Final time	0.28	.009
Serum cholesterol level		
Initial time	0.08	.472
Final time	0.01	.941
Systolic blood pressure		
Initial time	0.28	.009
Final time	0.39	<.001
Biopsy score	0.097	.498

Note.—The correlation coefficient was the Spearman ρ.

gression to renal impairment as those with an RI of lower than 0.70 (12 patients) (mean ΔeGFR of −15.81 mL/min ± 13.66 vs −8.55 mL/min ± 16.57 over a mean of 5.48 years ± 2.67). Of the 57 patients with normal renal function, those with an RI of 0.70 or higher at presentation (nine patients) developed end-stage renal disease or had a significant decrease in renal function (mean ΔeGFR of −40.26 mL/min ± 23.06 over a mean of 7.33 years ± 2.24). Clinical details of this subgroup are shown in Table 7.

With classification of the 86 patients in three groups on the basis of the initial RI of 0.61 or lower, 0.62–0.69, and 0.70 or higher, Kaplan-Meier analysis revealed a significantly different outcome between the high-RI group and the other two groups (Fig 6). The high-RI group showed a rapid and continuous decline in the survival curve (>50% reduction at 6 years), whereas the high-normal–RI and normal-RI groups had a slow decrease, with 80% and 73% survival, respectively, at 11 years. Results with the log-rank test were significant ($P < .001$).

Figure 4

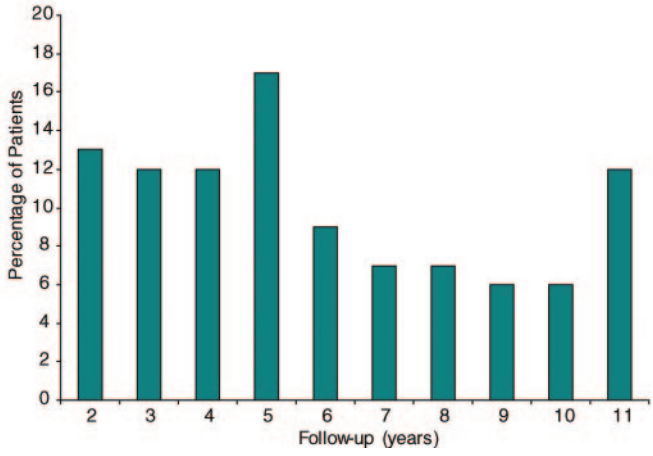

Figure 4: Percentage of patients ($n = 86$ patients) according to years of follow-up (mean, 5.93 years ± 2.92).

Table 4

Relationship between Renal RI and Biopsy Score in 60 Patients

Prevalent Site of Lesions	Score	No. of Patients	No. with RI < 0.70	No. with RI ≥ 0.70
Glomerular	1	29	24 (82.8)	5 (17.2)
Also involving tubulointerstitium and vascular compartment	2	31	21 (67.7)	10 (32.3)

Note.—The association between RI and biopsy score was not significant ($\chi^2 = 1.802$). Numbers in parentheses are percentages.

Table 5

Relationship between Renal RI and Histopathologic Diagnosis in 60 Patients

Diagnosis	No. with RI < 0.70	No. with RI ≥ 0.70
IgA nephropathy ($n = 22$)	20 (90.9)	2 (9.1)
Membranous glomerulonephritis ($n = 15$)	11 (73.3)	4 (26.7)
Focal segmental glomerulosclerosis ($n = 13$)	7 (53.8)	6 (46.2)
Mesangioproliferative glomerulonephritis ($n = 5$)	4 (80.0)	1 (20.0)
Minimal-change glomerulonephritis ($n = 1$)	1 (100)	0
Vasculitis ($n = 2$)	1 (50.0)	1 (50.0)
Secondary amylodosis ($n = 1$)	1 (100)	0
Nephroangiosclerosis ($n = 1$)	0	1 (100)

Note.—The association between RI and biopsy score was not significant ($\chi^2 = 10.494$). Numbers in parentheses are percentages.

Discussion

The capability of RI to aid prediction of progression of renal dysfunction has been demonstrated previously (21,22,30–32). Physiologically or pharmacologically induced RI variation previously has been studied in healthy and hypertensive patients (3,30,33–35). The researchers in those studies found intraindividual RI variation to be no greater than 0.04, including the sampling variability of repeated RI readings, RI readings at different sites within a particular kidney, and RI readings in the right versus left side. We found similar variation in our patients during up to 11 years of follow-up. This long follow-up, the longest in the literature to our knowledge, demonstrates that RI is a reliable parameter, with individual characteristics, that varies little in stable clinical conditions, in spite of many variables such as changes in therapy, blood pressure, age, and sampling variability.

We found a strong correlation between initial RI and final renal function. When we classified patients in four groups on the basis of normal or abnormal initial renal function and RI, we observed that, at the end of the follow-up period, those with an initial RI of 0.70 or higher had the greatest reduction of renal function, independent of initial eGFR. This finding supports similar findings reported in a 30-month follow-up study in 34 patients with lupus

Table 6

Stepwise Multiple Regression Analysis for Independent Risk Factors for Greater than 50% Decrease in Basic eGFR

Parameter*	Wilks λ	*F* Test	*P* Value
Age	0.960	2.321	.133
Sex	0.959	2.373	.129
RI	0.415	77.494	<.001
eGFR	0.980	1.124	.294
Hematuria	0.981	1.061	.308
Proteinuria	0.960	2.268	.138
Uric acid level	0.943	3.330	.073
Serum cholesterol level	0.962	2.170	.146
Systolic blood pressure	0.937	3.679	.06
Diastolic blood pressure	0.994	0.311	.58

*Parameters were initial values.

Figure 5

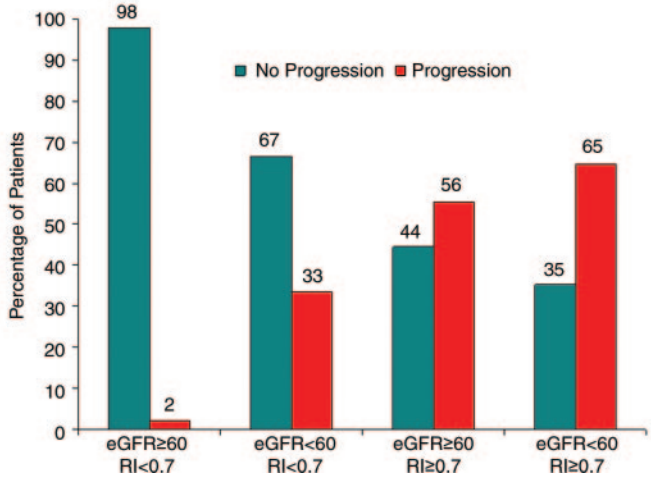

Figure 5: Percentage of patients with and without progression of renal impairment ($\chi^2 = 33.169$, $P <$ .001).

Table 7

Characteristics of Subgroup with eGFR of 60 mL/min or Higher and RI of 0.70 or Higher

Characteristic	Mean	SD	Range
Age (y)	51.7	19.22	22–72
Follow-up (y)	7.33	2.24	3–11
eGFR, initial (mL/min)	97.32	20.02	66.29–126.16
ΔeGFR (mL/min)	−40.26	23.06	−72.9 to −11.51
ΔRI	0.023	0.018	0–0.05

Note.—This analysis included nine patients, with seven male and two female patients. Four patients received a diagnosis of membranous glomerulonephritis; two, of focal segmental glomerulosclerosis; two, of hypertension and microalbuminuria; and one, of vasculitis. SD = standard deviation.

Figure 6

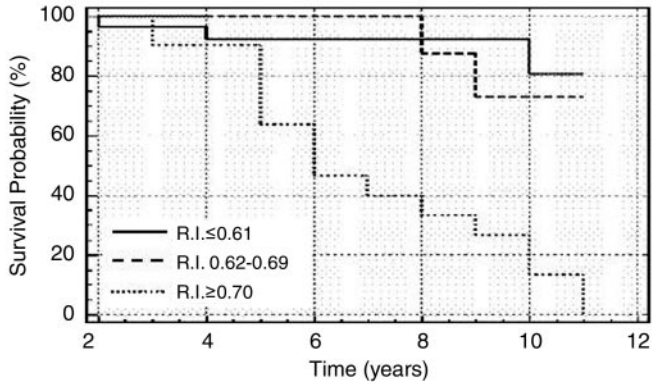

Figure 6: Kaplan-Meier analysis applied to follow-up patients classified in three groups by using initial RI (≤0.61, $n = 30$; 0.62–0.69, $n = 30$; ≥0.70, $n = 26$). Comparison of survival curves (log-rank test, $P <$ .0001). Data were right censored.

nephritis (31), where RI, but not serum creatinine level, was significantly higher in patients with poor outcomes. Our results confirm that, in chronic nephropathies, increased RI could be a marker of vasculointerstitial lesions that may precede the clinical detection of renal dysfunction.

The point we aimed to elucidate with our study was the clinical importance of values of RI that were lower than 0.70, which are within the range considered normal. In at least three studies in the literature, researchers found that an RI higher than 0.60 was predictive of renal damage (23–25). Given that most of the patients in our study with an eGFR of 60 mL/min or higher had RIs in that range, we compared their clinical outcome with that of the other two groups (patients with an RI ≤ 0.61 and patients with an RI ≥ 0.70) The survival curves of the high-normal–RI and normal-RI groups were similar, approaching 75% by 11 years. This contrasts with the high-RI group (RI ≥ 0.70), whose survival probability decreased to 0% by 11 years.

According to the data in this study, only an RI of 0.70 or higher in patients with chronic nephropathies seems to in-

dicate irreversible damage. An RI of 0.80 or higher has been shown to be prognostic for poor renal outcome in patients with renal artery stenosis, as well as in patients with renal disease (22,36). In our sample, patients with an RI of 0.80 or higher had high serum creatinine levels at the beginning and those who were followed up showed a doubling of this value in 2–4 years. The relatively low RIs in our cohort can be explained by the high prevalence of glomerulonephritis with minor symptoms. In fact, since we were assessing patients in whom a good therapeutic response could still be obtained, prior to entry into the study, we excluded patients with signs of advanced nephropathy or end-stage renal disease. Researchers in previous studies (13,24,31,37) reported an increased RI in several pathologic conditions, mainly related to vasculointerstitial lesions, although those in others (15,21,38,39) did not find a specific histopathologic correlation. In our study, we could not demonstrate a significant correlation between histopathologic data and RI. However, the score we used only considered two kinds of lesions, those limited to the glomeruli or those including the vasculotubulointerstitium, and that could have led us to underestimate mild vascular lesions.

Hypertension and age are two other well-known parameters that influence renal resistance. A significant correlation among RI, age, and systolic blood pressure previously has been shown (40,41) and was confirmed by our results. Nevertheless, it is common to find people with renal failure or hypertension or age over 50 years with normal RI. The mechanism that leads to changes in renal impedance that can be measured by using RI is only partially understood. In vitro studies by Bude and Rubin (5) showed that RI is an expression of renovascular resistance only with compliant vessels and becomes progressively independent of renovascular resistance to the degree that compliance is impaired. That could explain the relatively small increase in RI in some patients with end-stage renal disease and in patients with advanced hypertensive vascular lesions. Arteriolosclerosis may reduce vascular compliance to such an extent that Doppler measurements no longer reflect hemodynamic changes. However, the shape of the Doppler waveform reflects this reduction as a decrease of the late systolic peak (29), allowing a correct interpretation of the Doppler data.

The main limitation of this study was the limited number of follow-up cases (86 of 177). Given the differences in the populations with respect to glomerulonephritis, hypertension, and interstitial nephropathy, our results may not be applicable to all patients. In addition, we had a wide range of follow-up (2–11 years), so our results may not reflect results in a larger cohort with longer follow-up. Our small sample size could have limited our ability to detect a significant difference between the high-normal– and normal-RI groups with the survival curves obtained with Kaplan-Meier analysis.

In conclusion, our data on the behavior of RI and its correlations with renal function show that RI does not change significantly even within a long period of observation unless structural changes develop, an RI lower than 0.70 can be found in diseased kidneys but does not presage a rapid progression of disease, an RI higher than 0.70 is a strong predictor of progression to renal failure, equal or better than is eGFR, and RI evaluation can help determine prognosis and guide therapy in patients with chronic nephropathies.

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