Serial Resistive Index and Pulsatility Index for Diagnosing Renal Complications in the Early Posttransplant Phase: Improving Diagnostic Efficacy by Considering Maximum Values

Ali Radmehr,[1] Ali Babaei Jandaghi,[1] Amir Pejman Hashemi Taheri,[1] Madjid Shakiba[2]

Abstract

Objectives: **To present new approaches to using duplex Doppler scanning to detect kidney complications in the early posttransplant period.**

Materials and Methods: **We assessed the resistive index and the pulsatility index in 127 renal transplant patients (73 men, mean age, 35.2 ± 14 years) who underwent duplex Doppler scanning on the first, third, and fifth days after transplant. Biopsies were performed in patients suspected of having graft dysfunction owing to clinical and laboratory findings. To differentiate complicated from healthy grafts, a receiver operating characteristic curve analysis was done, and an area under the curve was calculated for each variable.**

Results: **In total, 47 grafts (37%) became complicated (40 rejections). The mean resistive index and mean pulsatility index were statistically significantly higher on the first, third, and fifth days after transplant in patients with complicated grafts than they were in patients with noncomplicated grafts (*P* < .0001). The mean resistive index and mean pulsatility index showed a significant rise from the first to the fifth day in patients with complicated grafts (*P* ≤ .014). The area under the curve of the receiver operating characteristic curve for resistive index and pulsatility index on successive days was statistically significant (*P* < .0001). The resistive index and the pulsatility index area under the curve were statistically significantly lower on the first day than they were on subsequent days. Considering the maximum value of a serially measured resistive index and pulsatility index (which were determined by comparing 3 measurements on the fifth day and selecting the highest one) as a new variable showed a better area under the curve compared with that calculated on the third day (*P* = .05 for resistive index; *P* = .012 for pulsatility index).**

Conclusions: **The resistive index and the pulsatility index are effective means of diagnosing post-transplant renal complications. Including a serial assessment and considering the maximum values could improve the diagnostic efficacy on the fifth day after transplant.**

Key words: *Duplex examination, Renal transplant, Complication, Acute rejection*

Introduction

Kidney transplant is the preferred treatment for patients with end-stage renal disease. These patients are susceptible to complications that could threaten the transplanted kidney, especially in the early days after transplant. The main allograft complications are rejection, pyelocalyceal obstruction, acute tubular necrosis, cyclosporine toxicity, and infection. Acute rejection is the most common cause that demands special attention. It is important to follow and screen these patients properly in the early postoperative period for early onset renal complications and dysfunctions and begin a work-up that will determine the exact nature of the problem and establish the best possible management as soon as possible. It is also important to use a noninvasive

From the [1]Department of Radiology, Shariati Hospital, Tehran University of Medical Sciences. [2]Research Unit, Medical Imaging Center, Imam Khomeini Hospital, Tehran University of Medical Sciences.

Address reprint requests to: *Amir Pejman Hashemi Taheri, MD, Assistant Professor of Radiology, Radiology Department, Shariati Hospital, Tehran University of Medical Sciences, North Kargar St., Tehran, Iran*

Phone: *+98 21 849 02178* ***Fax:*** *+98 21 880 26010* ***E-mail:*** *apejmanht@yahoo.com*

Experimental and Clinical Transplantation (2008) 2: 161-167

technique that can reliably detect and discern the causes of renal transplant dysfunction.

Renal biopsy is the standard means of differentiating these complications, but it is invasive and has inherent risks of morbidity. The usefulness of ultrasonography as a noninvasive technique in assessing these complications is well established, but data discussing the relation between ultrasound findings and allograft function in the early postoperative period are few (1-6). Analysis of the resistive index (RI) has been advocated as a useful technique in diagnosing acute rejection (7-9). However, most studies examining this index have been hampered by being retrospective analyses (10, 11) or lacking histologic verification (9, 12, 13).

The current study sought to determine the diagnostic efficacy of serially measured Doppler measures of the RI and pulsatility index (PI) taken on renal allografts during the early postoperative period.

Materials and Methods

Patient selection

From March 2004 until March 2007, we evaluated 127 kidney allograft transplant recipients (73 male patients [57.5%], 54 female patients [42.5%]; mean age, 35.2 ± 14 years; age range, 5-65 years) who had received their transplants at the Shariati Hospital of Tehran University of Medical Sciences in Iran. All patients who had undergone an allograft transplant were included. The study protocol was approved by ethics committee of the Tehran University of Medical Sciences and conforms with the ethical guidelines of the 1975 Helsinki Declaration. Ultrasonographic examinations were done in all subjects 3 times during the first week on days 1, 3, and 5 after the transplant for a total of 381 duplex Doppler examinations. All patients were observed at the hospital for at least 2 weeks. Clinical and paraclinical evaluations were done daily, and urinary output was measured carefully. Paraclinical evaluations included routine serum biochemical parameters. Renal biopsies were performed in all grafts suspected of having complications or dysfunction according to clinical (urine output and blood pressure measurements) and laboratory findings (blood urea nitrogen and creatinine levels). All biopsies were reviewed by 2 pathologists who were unaware of the corresponding duplex Doppler and patient's condition. Patients without any abnormal clinical or paraclinical findings were followed up for 2 weeks. Biopsy was the gold standard used to measure dysfunction in all allografts.

Imaging protocol

Doppler scans were obtained using 1 ultrasound system (Hitachi Medical Corporation, Tokyo, Japan) with a 3.5-MHz curved transducer and were done by 1 radiologist. Three spectrums in the upper, middle, and lower part of the kidney on interlobar or arcuate arteries were obtained. Then the mean of these 3 measurements was determined as the RI and PI values. Doppler RI and PI were calculated by the following formulae: RI = (PSV-EDV)/PSV and PI = (PSV-EDV)/TA_{max} (where PSV = peak systolic velocity; EDV = end diastolic velocity and TA_{max} = time-averaged maximum velocity).

Statistical analyses

Statistical analyses were done using SPSS software (Statistical Product and Services Solutions, version 15.0, SPSS Inc, Chicago, IL, USA). The chi square, *t*, repeated measures analysis of variance, and Friedman tests were used for the statistical analyses. The sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, and negative likelihood ratio were calculated by cross-tabulation for nominal variables. Also, for continuous variables, receiver operating characteristic (ROC) curves were plotted with MedCalc software (Mariakerke, Belgium), and the area under the curve (AUC) was calculated. To determine a more-efficient variable to differentiate complicated from noncomplicated grafts, pairwise comparisons of the differing RI and PI values on successive days were done with the MedCalc software comparing the AUCs with each other. A value for P less than .05 was considered statistically significant.

Results

Of 127 patients, 80 had an uneventful recovery, 40 experienced acute rejections, 3 had acute tubular necrosis, 2 had pelvicalyceal obstructions, 2 had cyclosporine toxicity, and 1 had a renal vein thrombosis. One patient had cyclosporine toxicity and acute rejection simultaneously. Diagnosis of renal vein thrombosis and obstructive renal disease were based on ultrasound findings.

The mean kidney size was 113.4 ± 9.9 mm (range, 83-135 mm) on first day, and this rose to 117.2 ± 9.5 mm (range, 86-140 mm) on the fifth day ($P < .0001$). The mean kidney size did not show a statistically significant difference between complicated and noncomplicated allografts recipients on the fifth day (Table 1).

The mean value of RI_1 (first ultrasonography) of the patients with allograft dysfunction (47 patients) was 0.73 ± 0.12, which increased to 0.78 ± 0.1 by the fifth day after surgery (RI_5) ($P = .002$). The results of this measurement on complicated and noncomplicated allografts recipients are shown in Table 2.

Using successive RI and PI values on the first, third, and fifth days, we categorized patients according to presence of any rise in these values into 2 groups: those with increased values and those with stable or decreased values. The percentage of increase in RI in complicated grafts was 59.6% (28/47), while this percentage in the noncomplicated group was 35% (28/80) ($P = .007$). The odds ratio for increases in RI for the complicated grafts was 2.7 (95% confidence interval [CI], 1.3-5.7).

The mean value of PI_1 in the complicated group (47 patients) was 1.57 ± 0.57, which increased to 1.76 ± 0.5 on PI_5 ($P = .01$). The results of this measurement in recipients of complicated and noncomplicated allografts are shown in Table 2.

The percentage increase in PI in complicated grafts was 53.2% (25/47); this percentage was 41.3% (33/80) in the noncomplicated group ($P = .19$). The odds ratio of this increase in PI for complicated grafts was 1.6 (95% CI, 0.8-3.3).

We categorized these 47 patients into 2 groups: first 40 acute rejections and second, 7 complicated patients other than rejection (ie, acute tubular necrosis, cyclosporine toxicity, renal vein thrombosis, and obstruction of the pelvicalyceal system.) Then we compared the mean RI and PI results. In patients with acute rejection, intraindividual follow-up revealed a significant rise in both RI and PI from the first to the fifth day of examination (mean RI, 0.72 ± 0.12 [first day] compared with 0.77 ± 0.10 [fifth day]; $P = .002$; and mean PI, 1.50 ± 0.56 [first day] compared with 1.72 ± 0.51 [fifth day]; $P = .012$) (Table 3).

Table 1. Mean renal size on different days.

	Complicated	Noncomplicated	All patients	*P* value
1st day	112.2 ± 10.6	115.1± 9.3	113.9 ±9.9	.12
3rd day	115.2 ± 10.4	116.9 ± 8.7	116.3 ± 9.4	.35
5th day	117.3 ± 10.6	117.2 ± 8.9	117.2 ± 9.5	.96
P value	< .002	< .0001	< .0001	

Table 3. Comparison of mean RI and PI values in complicated acute rejection and complicated nonacute rejection groups.

RI_1			
	All complicated patients	0.73 ± 0.12	
	Acute rejection	0.72 ± 0.12	*P* = .025
	Nonacute rejection	0.83 ± 0.12	
RI_1			
	All complicated patients	0.78 ± 0.11	
	Acute rejection	0.77 ± 0.11	*P* =.17
	Nonacute rejection	0.83 ± 0.07	
RI_5			
	All complicated patients	0.78 ± 0.09	
	Acute rejection	0.77 ± 0.10	*P* =.044
	Nonacute rejection	0.84 ± 0.06	
P = .002 (for serially measured RIs on successive days in acute rejection group)			
P = .78 (for serially measured RIs on successive days in nonacute rejection group)			
PI_1			
	All complicated patients	1.57 ± 0.57	
	Acute rejection	1.50 ± 0.56	*P* =.07
	Nonacute rejection	1.92 ± 0.51	
PI_1			
	All complicated patients	1.73 ± 0.54	
	Acute rejection	1.70 ± 0.55	*P* =.26
	Nonacute rejection	1.93 ± 0.49	
PI_5			
	All complicated patients	1.76 ± 0.50	
	Acute rejection	1.72 ± 0.51	*P* =.14
	Nonacute rejection	1.99 ± 0.41	
P = .012 (for serially measured PIs on successive days in acute rejection group)			
P = .89 (for serially measured PIs on successive days in nonacute rejection group)			

Abbreviations: PI, pulsatility index; RI, resistive index.

Table 2. Mean RI and PI on different days.

	RI_1	RI_3	RI_5	*P* value	PI_1	PI_3	PI_5	*P* value
Complicated	0.73 ± 0.12	0.76 ± 0.11	0.78 ± 0.1	.002	1.57 ± 0.57	1.73 ± 0.54	1.76 ± 0.5	.014
Noncomplicated	0.62 ± 0.1	0.61 ± 0.1	0.62 ± 0.1	.078	1.02 ± 0.17	1.03 ± 0.18	1.08 ± 0.2	.001
P value	< .0001	< .0001	< .0001		< .0001	< .0001	< .0001	
All patients	0.66 ± 0.11	0.67 ± 0.12	0.68 ± 0.11	.001	1.22 ± 0.45	1.29 ± 0.49	1.33 ± 0.48	.001

Abbreviations: PI, pulsatility index; RI, resistive index.

The mean RI and PI values were higher in the nonacute rejection group than they were in the acute rejection group; however, they did not differ intraindividually during follow-up (mean RI, 0.83 ± 0.12 [first day] compared with 0.84 ± 0.06 [fifth day]; $P = .78$; and mean PI, 1.92 ± 0.51 [first day] compared with 1.99 ± 0.41 [fifth day]; $P = .89$). Patients with nonacute rejection problems had significantly higher Doppler RIs than did patients with acute rejection (mean RI_1 for nonacute rejection: 0.83 ± 0.12 vs 0.72 ± 0.12 for acute rejection; $P < .05$; mean RI_5 for nonacute rejection: 0.84 ± 0.06 vs 0.77 ± 0.10 for acute rejection; $P < .05$). The difference in PI was not significant (mean PI_1: 1.92 ± 0.51 [nonacute rejection] vs 1.50 ± 0.56 [acute rejection]; $P = .07$; and mean PI_5: 1.99 ± 0.41 [nonacute rejection] vs 1.72 ± 0.51 [acute rejection]; $P = .14$) (Table 3).

To evaluate the efficacy of RI and PI in differentiating complicated from noncomplicated allografts, we used the ROC curve analysis (Figure 1). The AUC of each variable was calculated (Table 4).

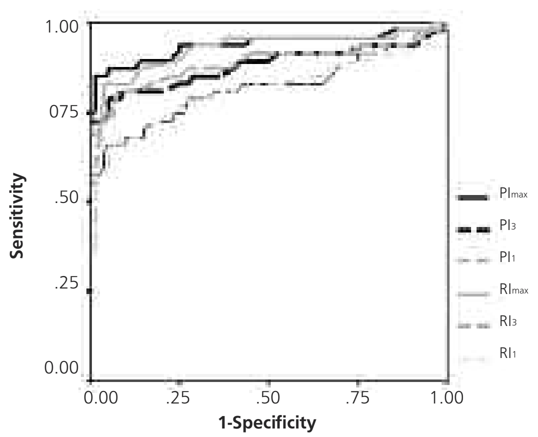

Figure 1. ROC curves of RI and PI values

Table 4. AUC values for RI and PI.

	AUC	95% CI	*P* value
RI_1	0.81	0.74-0.88	< .0001
RI_3	0.89	0.82-0.92	< .0001
RI_5	0.91	0.84-0.95	< .0001
RI_{max}	0.93	0.87-0.97	< .0001
PI_1	0.82	0.74-0.88	< .0001
PI_{max}	0.94	0.81-0.93	< .0001
PI_5	0.90	0.84-0.95	< .0001
PI_3	0.88	0.88-0.97	< .0001

Abbreviations: AUC, area under the curve; CI, confidence interval; PI, pulsatility index; RI, resistive index.

We considered the values on the first, third, and fifth day after transplant for RI and PI and plotted the curve to compute the AUC. Also, we plotted the ROC curve for the maximum amount of RI and PI that were determined on the fifth day (RI_{max}, PI_{max}). For all these variables (ie, RI_{1-5}, RI_{max} and PI_{1-5}, PI_{max}), the AUC was statistically significant (all $P < .0001$) (Table 4). The AUC increased from 0.81 (RI_1) to 0.91 (RI_5), and from 0.82 (PI_1) to 0.90 (PI_5). The highest AUC was shown in RI_{max} (0.93) and PI_{max} (0.94) ($P < .0001$ for both). All pairwise comparisons between successive RIs and also RI_{max} were done; similar analyses were done for successive PIs and PI_{max}. In both RI and PI, the AUCs of the third and fifth days were statistically significantly higher than the AUCs of the first day ($P < .05$ for all); however, differences on the third and fifth days were not statistically significant ($P > .44$ for all). Comparisons of the maximum values determined different results; in both RI and PI, the AUCs of the maximum values on the fifth day were statistically significantly higher than the third day measures (0.93 vs 0.89 for RI [$P = .05$] and 0.94 vs 0.88 for PI [$P = .012$]). All pairwise comparisons between RI and PI values for the same days (for example RI_3 and PI_3) did not show a statistically significant difference ($P > .5$ for all). On the other hand, we could consider RI_{max} and PI_{max} only on the fifth day, because we should select the maximum values among these 3 days. Because there were better ROC curves for RI_{max} and PI_{max} compared with RI_3 and PI_3, respectively (and because there were no statistically significant differences between the RI_{max} and RI_5, RI_5 and RI_3, PI_{max} and PI_5, and PI_5 and PI_3), we chose the cutoff point for RI and PI on the fifth day according to RI_{max} and PI_{max} (instead of RI_5 and PI_5).

Tables 5 and 6 show the efficacy indices of the different cutoff points of RI and PI in detecting renal transplant complications on the first, third, and fifth days after surgery.

Discussion

Conventional ultrasonography can successfully detect anatomic changes in the allograft (eg, hydronephrosis, hematoma, urinoma), but it is less successful in evaluating functional abnormalities, such as acute tubular necrosis, acute rejection, and drug toxicity.

The resistive index is a sensitive index in predicting renal allograft dysfunction. It has been proposed that increased peripheral vascular resistance and decreased end diastolic blood velocity are the causes of the RI rise seen in renal transplant dysfunction.

Table 5. Efficacy of different cutoff points of resistive index.

	Cutoff point	TP	FN	TN	FP	Sen (95% CI)	Spec (95% CI)	PPV (95% CI)	NPV (95% CI)	PLR (95% CI)	NLR (95% CI)
RI_1	0.51	46	1	5	75	0.98 0.89-0.99	0.06 0.02-0.14	0.38 0.29-0.47	0.83 0.36-0.99	1 0.9-1.1	2.9 0.35-24.4
RI_3	0.51	46	1	4	76	0.98 0.88-0.99	0.05 0.01-0.12	0.38 0.29-0.47	0.80 0.28-0.99	1 0.9-1.1	2.4 0.3-20.4
RI_{max}	0.55	46	1	11	69	0.98 0.88-0.99	0.14 0.07-0.23	0.40 0.31-0.50	0.92 0.62-0.99	1.1 1-1.3	6.5 0.86-48.5
RI_1	0.62	39	8	43	37	0.83 0.69-0.92	0.54 0.42-0.65	0.51 0.40-0.63	0.84 0.71-0.93	1.8 1.4-2.3	3.2 1.6-6.1
RI_3	0.63	41	6	49	31	0.87 0.74-0.95	0.61 0.50-0.72	0.57 0.45-0.69	0.89 0.78-0.96	2.3 1.7-3	4.8 2.2-10.3
RI_{max}	0.68	44	3	57	23	0.94 0.82-0.99	0.71 0.60-0.81	0.66 0.53-0.77	0.95 0.86-0.99	3.3 2.3-4.6	11.2 3.7-33.7
RI_1	0.7	30	17	76	4	0.64 0.49-0.77	0.95 0.88-0.99	0.88 0.73-0.97	0.82 0.72-0.89	12.8 4.8-34	2.6 1.8-3.9
RI_3	0.7	38	9	74	6	0.81 0.67-0.91	0.93 0.84-0.97	0.86 0.73-0.95	0.89 0.80-0.95	10.8 4.9-23.6	4.8± 2.7-8.17
RI_{max}	0.7	41	6	69	11	0.87 0.74-0.95	0.86 0.77-0.93	0.79 0.65-0.89	0.92 0.83-0.97	6.3 3.6-11.1	6.8 3.2-14.3
RI_1	0.72	28	19	76	4	0.60 0.44-0.74	0.95 0.88-0.99	0.88 0.71-0.96	0.80 0.71-0.88	11.9 4.5-31.9	2.4 1.7-3.3
RI_3	0.73	34	13	78	2	0.72 0.57-0.84	0.98 0.91-0.99	0.94 0.81-0.99	0.86 0.27-0.92	28.9 7.3-115	3.5 2.2-5.6
RI_{max}	0.76	33	14	78	2	0.70 0.55-0.83	0.98 0.91-0.99	0.94 0.81-0.99	0.85 0.76-0.91	28.1 7.1-111.7	3.3 2.1-5.1
RI_1	0.77	17	30	80	0	0.36 0.23-0.51	1.00 0.95-1.00	1.00 0.88-1.00	0.82 0.73-0.89	-	2.8 1.9-4
RI_3	0.77	27	20	80	0	0.57 0.42-0.72	1.00 0.95-1.00	1.00 0.87-1.00	0.80 0.71-0.87	-	2.4 1.7-3.3
RI_{max}	0.78	32	15	80	0	0.68 0.53-0.81	1.00 0.95-1.00	1.00 0.89-1.00	0.84 0.75-0.91	-	3.1 2.1-4.8

Abbreviations: CI, confidence interval; FN, false negative; FP, false positive; NLR, negative likelihood ratio; NPV, negative predictive value; PLR, positive likelihood ratio; PPV, positive predictive value; RI, resistive index; TN, true negative; TP, true positive; Sen, sensitivity; Spec, specificity.

Table 6. Efficacy of different cutoff points of pulsatility index.

	Cutoff point		TP	FN	TN	FP	Sen (95% CI)	Spec (95% CI)	PPV (95% CI)	NPV (95% CI)	PLR (95% CI)	NLR (95% CI)
PI_1	0.79	46	1	6	74	0.98 0.89-0.99	0.08	0.38 0.03-0.16	0.86 0.30-0.48	1.1 0.42-0.99	3.5 0.9-1.3	0.4-28.4
PI_3	0.78	46	1	3	77	0.98 0.88-0.99	0.04	0.37 0.8-0.11	0.75 0.29-0.47	1.00 0.19-0.99	1.8 0.9-1.1	0.2-16.5
PI_{max}	0.88	46	1	12	68	0.98 0.88-0.99	0.15	0.40 0.08-0.25	0.92 0.31-0.50	1.2 0.64-0.99	7.1 1.00-1.3	0.9-53.5
PI_1	1.1	37	10	55	25	0.78 0.64-0.89	0.69	0.60 0.57-0.79	0.85 0.46-0.72	2.5 0.74-0.92	3.2 1.8-3.6	1.8-5.7
PI_3	1.1	40	7	55	25	0.85 0.72-0.94	0.69	0.62 0.57-0.79	0.89 0.49-0.73	2.7 0.78-0.95	4.6 1.9-3.9	2.3-9.3
PI_{max}	1.21	44	3	55	25	0.94 0.82-0.99	0.69	0.64 0.57-0.79	0.95 0.51-0.75	2.3 0.86-0.99	10.8 2.1-4.2	3.6-32.5
PI_1	1.23	31	15	72	8	0.68 0.53-0.81	0.90	0.80 0.81-0.96	0.83 0.64-0.91	6.8 0.73-0.90	2.8 3.4-13.5	1.8-4.3
PI_3	1.25	38	9	73	7	0.81 0.67-0.91	0.90	0.83 0.81-0.96	0.89 0.69-0.93	8.2 0.81-0.95	4.7 4.2-16	2.6-8.5
PI_{max}	1.39	41	6	75	5	0.87 0.74-0.95	0.94	0.89 0.86-0.98	0.93 0.76-0.96	13.9 0.85-0.97	7.3 5.9-32.8	3.5-15.5
PI_1	1.4	26	21	80	0	0.55 0.40-0.70	1.00	1.00 0.95-1.00	0.79 0.87-1.00	0.70-0.87	2.2	1.6-3.1
PI_3	1.44	34	13	80	0	0.72 0.57-0.84	1.00	1.00 0.95-1.00	0.86 0.90-1.00	0.77-0.92	3.6	2.3-5.7
PI_{max}	1.52	35	12	80	0	0.74 0.60-0.86	1.00	1.00 0.95-1.00	0.87 0.90-1.00	- 0.78-0.93	3.9	2.4-6.4

Abbreviations: CI, confidence interval; FN, false negative; FP, false positive; NLR, negative likelihood ratio; NPV, negative predictive value; PI, pulsatility index; PLR, positive likelihood ratio; PPV, positive predictive value; TN, true negative; TP, true positive; Sen, sensitivity; Spec, specificity.

Choi and associates showed an elevation in RI values in abnormal renal transplant recipients. They could not find a definitive RI value to differentiate normal from abnormal renal transplant. They found sensitivity and specificity equals 88% and 58%, respectively, for the set point of 0.6. They preferred a range of 0.6 to 0.7 for RI to evaluate graft function, rather than a set point as a standard (14). In the current study, considering a cutoff point of 0.62 for the RI on the first day, we showed a sensitivity of 0.83 and specificity of 0.54, which are similar to same variables found by Choi and associates. In our study, using a cutoff point of 0.63 for RI on the third day, we showed a sensitivity of 0.87 and specificity of 0.61, and considering a cutoff point of 0.7 for the RI_{max}, we showed a sensitivity of 0.87 and specificity of 0.86 that is better than the results of the Choi study. This means that considering the results of the RI in later days could improve the specificity of the study.

A review of the data in Tables 5 and 6 shows the diagnostic indices of different cutoff points for both RI and PI on successive days. According to these results, better decision making could be achieved on the first, third, and fifth days. One of the main goals in evaluating posttransplant grafts is screening patients with renal dysfunction as soon as possible and defining the cause of the failure. When the results of a Doppler study are abnormal, the most important question is what caused the abnormality. Unfortunately, the number of nonacute rejection cases in our study was 7, so a statistical analysis differentiating between acute rejection and nonacute rejection was not possible. However, the results of RI and PI showed that complicated patients had higher mean RIs and PIs than did patients with noncomplicated grafts from the first to the fifth day. Among complicated patients, mean RIs and PIs were statistically and/or clinically higher in 7 patients in the nonacute rejection group compared with 40 patients in the acute rejection group. Meanwhile, we found no serial increases in these indices in noncomplicated grafts and complicated nonacute rejection grafts. In fact, patients with complicated nonacute rejections showed relatively fixed, higher values of the mean RI and PI from the first day, while noncomplicated patients showed relatively fixed, lower values of RI and PI from the first day, and the acute rejection patients showed a rising pattern of RI and PI in serial measurements, with the largest rise occurring between the first and the third days. These patterns could be useful in differentiating these 3 groups.

We found that the maximum values for RI and PI determined on the fifth day (RI_{max}, PI_{max}) had the best efficacy for evaluating graft dysfunction. As mentioned earlier, each patient had undergone a Doppler examination on 3 days. On the fifth day, we analyzed the ROC curves, and calculated the AUC for the parameters ($RI_{1,3}$, and $_5$, and RI_{max}, $PI_{1,3}$, and $_5$, and PI_{max}). The highest AUC was related to RI_{max} and PI_{max}. Table 4 shows that the AUCs for RI_{max} and PI_{max} were 0.93 and 0.94, respectively. Regarding the better AUC curve for RI_{max} and PI_{max} compared with RI_3 and PI_3, respectively, it would be better to consider RI_{max} and PI_{max} for decision making on the fifth day. In our study, the cutoff point of 0.77 is a critical value for RI on the first and third days; for RI values beyond 0.77, the specificity and positive predictive value would be 1 (although the sensitivity decreased to 0.36 [first day] and 0.57 [third day]). It means that even if a single RI equals 0.77, the graft is certainly complicated on first and third days. This critical value for RI_{max} is 0.78 that yielded a sensitivity of 0.68. Also, this means better sensitivity for the positive predictive value of 1 compared with the RI on the first and third days. These critical values for the PI were 1.4, 1.44, and 1.52 on the first, third, and fifth days that yielded sensitivities of 0.55, 0.72, and 0.74, respectively. The important point is that at any cutoff point, the sensitivity and specificity of RI_{max} and PI_{max} is the highest. On the other hand, if the results of the RI and PI on these days are inconclusive, we can use the RI_{max} and the PI_{max} for better clinical decision making on the fifth day. It is worth mentioning that it does not mean we should wait until the fifth day to use the maximum value for clinical decision making. When the values of RI and PI are significantly high on the first or third days (eg, RI = 0.77, PI = 1.4, Tables 5 and 6) or the clinical impression according to the other findings points to a complication, the necessary management should take place as soon as possible.

As mentioned in previous studies, a sequential rise in RI and PI levels is important in diagnosing allograft dysfunction. By the way, the RI_{max} and PI_{max} are best for differentiating between complicated and noncomplicated grafts. Naturally, the higher cutoff points of RI and PI are associated with more specificity but lower sensitivity.

Our data show that follow-up examinations and sequential Doppler technique have higher sensitivity and specificity than do single examinations, as mentioned in previous studies (15-18). Hollenbeck and associates showed that a continuous rise in RI and PI was a true positive result in allograft rejection (15). Sharma and associates demonstrated that the sensitivity of a single high RI and PI is lower than the sensitivity of serial increase in the values. Therefore, serial Doppler evaluation of a transplant kidney can be more useful than single measurement in diagnosing acute rejection (19). Stevens and associates demonstrated an elevation of RI and PI values in acute rejection, but high initial levels of these indices in acute tubular necrosis that decreased on follow-up examinations (20). In our study, a rise in RI and PI from the first to the fifth day was seen when acute rejection was the cause of graft dysfunction (Table 3); this is in contrast to patients with nonacute rejection, in whom the values are higher on the first day and do not show a significant rise by the fifth day. According to our data, when these indices are high on the first day but remain stable or even decrease, they mostly are indicative of nonacute rejection causes, especially acute tubular necrosis.

Finally, it is worth mentioning that there were no statistically significant differences between RI and PI indices in evaluating renal transplant dysfunction during the early postoperative period. As shown in Table 4, the AUC for the RI on each day is nearly the same as the corresponding PI. This means that according to our study, it is not necessary to calculate both the RI and the PI at the same time. According to our results, a good study would be set up by enrolling enough patients with only complicated transplanted kidneys to evaluate the diagnostic efficacy of RI and PI to differentiate different causes of renal allograft dysfunction; mainly differentiation of acute rejection (as the most common cause of dysfunctions that necessitate an immediate but different management) from other graft problems. A review of our data suggests that RI and PI could differentiate these 2 main groups from each other but unfortunately, our sample size of nonacute rejection patients was not large enough to permit a statistically good ROC analysis.

References

1. Tublin ME, Dodd GD third. Sonography of renal transplantation. Radiol Clin North Am. 1995;33(3):447-459.
2. Hricak H, Toledo-Pereyra LH, Eyler WR, Madrazo BL, Sy GS. Evaluation of acute post-transplant renal failure by ultrasound. Radiology. 1979;133(2):443-447.
3. Frick MP, Feinberg SB, Sibley R, Idstrom ME. Ultrasound in acute renal transplant rejection. Radiology. 1981;138(3):657-660.
4. Kashi SH, Lodge JP, Giles GR, Irving HC. Ultrasonography of renal allografts: collecting system dilatation and its clinical significance. Nephrol Dial Transplant. 1991;6(5):358-362.
5. Silver TM, Campbell D, Wicks JD, Lorber MI, Surace P, Turcotte J. Peritransplant fluid collections. Ultrasound evaluation and clinical significance. Radiology. 1981;138(1):145-151.
6. Isiklar I, Ozuner O, Demirag A, Haberal M. Early postoperative ultrasound of normally functioning transplanted kidneys: abnormal findings and their significance. Transplant Proc. 1999;31(8):3320-3323.
7. Rifkin MD, Needleman L, Pasto ME, et al. Evaluation of renal transplant rejection by duplex Doppler examination: value of the resistive index. AJR Am J Roentgenol. 1987;148(4):759-762.
8. Needleman L, Kurtz AB. Doppler evaluation of the renal transplant. J Clin Ultrasound. 1987;15(9):661-673.
9. Arima M, Takahara S, Ihara H, et al. Predictability of renal allograft prognosis during rejection crisis by ultrasonic Doppler flow technique. Urology. 1982;19(4):389-394.
10. Buckley AR, Cooperberg PL, Reeve CE, Magil AB. The distinction between acute renal transplant rejection and cyclosporine nephrotoxicity: value of duplex sonography. AJR Am J Roentgenol. 1987;149(3):521-525.
11. Taylor KJ, Burns PN. Duplex Doppler scanning in the pelvis and abdomen. Ultrasound Med Biol. 1985;11(4):643-658.
12. Ubhi CS, Irving HC, Norwood HM, Guillou PJ, Giles GR. Monitoring of renal allografts by Doppler ultrasound. Ann R Coll Surg Engl. 1987;69(5):229-232.
13. Rigsby CM, Taylor KJ, Weltin G, et al. Renal allografts in acute rejection: evaluation using duplex sonography. Radiology. 1986;158(2):375-378.
14. Choi CS, Lee S, Kim JS, et al. Usefulness of the resistive index for the evaluation of transplanted kidneys. Transplant Proc. 1998;30(7):3074-3075.
15. Hollenbeck M, Hilbert N, Meusel F, Grabensee B. Increasing sensitivity and specificity of Doppler sonographic detection of renal transplant rejection with serial investigation technique. Clin Investig. 1994;72(8):609-615.
16. Leimenstoll G, Engemann R, Grigat KP, Bartholdy A, Niedermayer W. Duplex ultrasound: monitoring of rejection episodes of renal allografts. Transplant Proc. 1990;22(4):1392-1394.
17. Meyer M, Paushter D, Steinmuller DR. The use of duplex Doppler ultrasonography to evaluate renal allograft dysfunction. Transplantation. 1990;50(6):974-978.
18. Rob PM, Jansen O, Richter V, Erbslöh-Möller B, Marienhoff N, Wiedemann G. Diagnosis of renal transplant failure by real-time and duplex Doppler sonography. Clin Investig. 1993;71(7):531-536.
19. Sharma AK, Rustom R, Evans A, et al. Utility of serial Doppler ultrasound scans for the diagnosis of acute rejection in renal allografts. Transpl Int. 2004;17(3):138-144.
20. Stevens PE, Gwyther SJ, Hanson ME, Woodrow DF, Phillips ME, Boultbee JE. Interpretation of duplex Doppler ultrasound in renal transplants in the early postoperative period. Nephrol Dial Transplant. 1993;8(3):255-258.