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Contribution of color and power Doppler sonography to the differential diagnosis of acute and chronic rejection, and tacrolimus nephrotoxicity in renal allografts

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Abstract The aim of the present study was to differentiate acute rejection, chronic rejection, and tacrolimus nephrotoxicity with color and power Doppler imaging of renal transplants. One hundred examinations were obtained from 45 patients. Pulsatility and resistive indices were calculated from color Doppler images. The grade of renal vascularization was quantified using computer-assisted pixel analysis in a rectangular region-of-interest. The percentage of vessel-covered renal parenchyma (POV) was calculated using a histogram that discriminated renal vessels from renal parenchyma via power Doppler images. Furthermore, the distance from the most peripherally located vessels to the renal capsule (PVD) was measured. A reduced POV $\leq$ 55 % proved to be the best discriminator when chronic rejection was suspected (sensitivity 79 %, specificity 87 %). Tacrolimus nephrotoxicity showed not only a moderate elevation of the Doppler signal but also an increased PVD $\geq$ 3.9 mm and a normal POV. We conclude that the evaluation of renal vessels by power Doppler images improves diagnostic accuracy for patients with renal allografts.

Key words Doppler sonography · Acute rejection · Chronic rejection · Tacrolimus · Kidney transplantation

Introduction

Major causes of renal transplant dysfunction are acute and chronic rejection, acute tubular necrosis, and cyclosporin A or tacrolimus nephrotoxicity [15]. In the case of acute rejection episodes, several authors recommend sequential analysis of the resistive index (RI) as well as of the pulsatility index (PI) to determine an acute rejection crisis and to monitor the therapy [6, 10, 17].

In the case of chronic rejection, the use of color Doppler imaging (CDI) has been a subject of controversy. RI has shown no difference between allografts with normal function and those with dysfunction [2], but preliminary results have revealed reduced intrarenal flow velocities in segmental and interlobar arteries of renal transplants from patients with chronic rejection [1, 3].

Only a few reports are available concerning the effect of acute cyclosporin A nephrotoxicity. Quarto di Palo et al. reported an increased RI and PI in patients with severe cyclosporin A nephrotoxicity in cortical arteries while no changes were found in the renal artery. These findings were said to probably have been caused by a persistent arteriolar vasoconstriction of the afferent vessels and a reduction in diastolic flow, which is similar to what happens in the case of tacrolimus nephrotoxicity [12, 20]. Merkus et al. [9] found subtle changes in the Doppler spectra in cyclosporin nephrotoxicity, but differentiation between nephrotoxicity and acute rejection was not possible using Doppler spectra alone. To our

knowledge, there are no reports on tacrolimus nephrotoxicity as studied with color Doppler sonography.

The introduction of amplitude-modulated Doppler imaging, or so-called power Doppler imaging (PDI), made it possible for interlobular vessels to be regularly depicted [8] and for blood flow detection in peripherally located vessels to become markedly improved [11]. However, vascular grade was not correlated with creatinine levels or RI [5, 20].

This study was designed to show how the combined use of CDI and PDI makes the differential diagnosis of acute rejection, chronic rejection, and tacrolimus nephrotoxicity possible in patients with renal allografts.

Methods

The present study was carried out in accordance with the ethical standards set down in the 1964 Declaration of Helsinki. All examinations were done as routine follow-up studies on clinical demand of the Department of Nephrology.

Patients

After obtaining informed consent from all participants, a total of 100 consecutive ultrasound examinations were taken of 45 patients (25 male, 20 female) ranging in age from 15 to 77 years (mean 42.3 ± 13.3 years). All examinations were performed between August 1996 and August 1997 by the same investigator (without knowledge of clinical data) using a Sonoline Elegra (Siemens, Erlangen, Germany). The time interval between the ultrasound examination and renal allograft implantation was 1 day to 18.3 years (mean 340 days). Patients with blood pressure up to 140 mm Hg were considered as normotensive, those with blood pressure from 140 to 160 mm Hg as borderline, and those with blood pressure greater than 160 mm Hg as hypertensive.

Patients were divided into four groups on the basis of the clinical and laboratory data or histological results after biopsy. Some patients were considered for more than one group, depending on their status on the day of examination. In group 1, there was no clinical evidence of graft rejection or renal impairment. Creatinine levels were between 0.8 and 1.3 mg/dl. In group 2, acute rejection was histologically confirmed by a biopsy specimen that was obtained within 48 h of sonography. In group 3, chronic rejection was histologically confirmed by at least one biopsy, with signs of arteriolohyalinosis or interstitial fibrosis before or on the day of examination. Finally, in group 4, acute tacrolimus nephrotoxicity with tubulus necrosis was confirmed by a biopsy within 48 h of the examination.

The results of the ultrasound examinations were compared with the patient group to which the patient belonged on the date of each examination.

Examination protocol

The kidney transplant was examined parallel to both the longitudinal axis and to the transversal axis. All measurements were taken at breath-hold upon inspiration to avoid motion artifacts.

Conventional color Doppler images (CDI) were acquired subsequently with a gain setting below the occurrence of paravasal color artifacts. The pulse repetition frequency (PRF) was adjusted to between 750 Hz and 1250 Hz with a wall filter frequency of about 125 Hz.

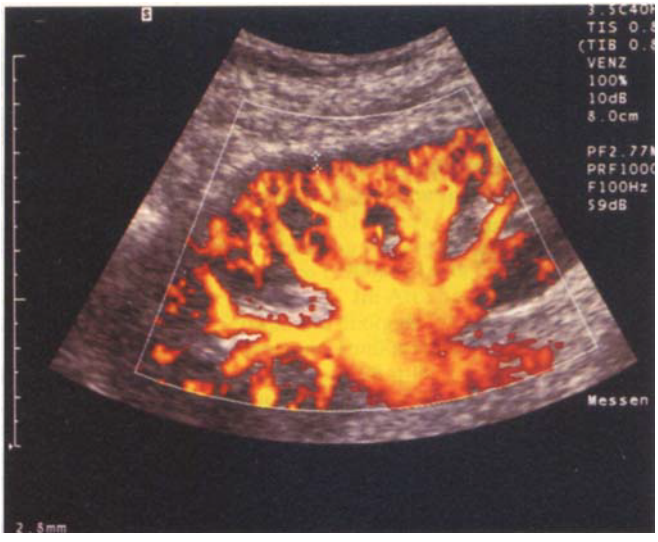


Fig. 1 Power Doppler image of a normal patient showing the peripheral renal vessels extending up to the renal capsule (PVD) at a distance of 2.8 mm

Power Doppler images (PDI) were obtained parallel to the longitudinal axis with a gain setting just below the background noise to avoid motion artifacts. PRF was adjusted to 1000 Hz with a wall filter of 100 Hz. Of three representative midlongitudinal pictures, one breath-hold image was captured that showed a maximum number of renal vessels up to the peripheral cortex, and this was stored on a magnetic optical disc (MOD) for further evaluation. The distance between the most peripheral vessels and the renal capsule was measured in each examination (Fig. 1). This distance is referred to as the peripheral vessel distance (PVD) and is measured in millimeters.

Evaluation of the spectral doppler curves

All measurements were taken with breath-hold in inspiration to avoid motion artifacts. Doppler spectra were obtained of three segmental or interlobar arteries of the most ventrally located part of the kidney transplant. This procedure included one artery from the cranial, middle, and caudal thirds of the kidney. The maximum velocity [v(max)] and the mean velocity [v(mean)] were measured by manually drawn curves that outlined the maximum Doppler shift of one cardiac cycle after angle correction. The angles for the Doppler frequency correction did not exceed 50° and were mostly (> 90%) ≤ 35°. The calculation of the pulsatility index first described by Gosling and King (PI), the resistive index of Pourcelot (RI), and the pulse frequency were calculated with the integrated on-board software of Sonoline Elegra (Siemens, Erlangen) [13].

Semiquantified analysis of the transplant vascularization

The PDI of each examination was stored directly on magnetic optical disks (MOD) and was subsequently stored on the hard disk of a personal computer (Apple Power PC 7500).

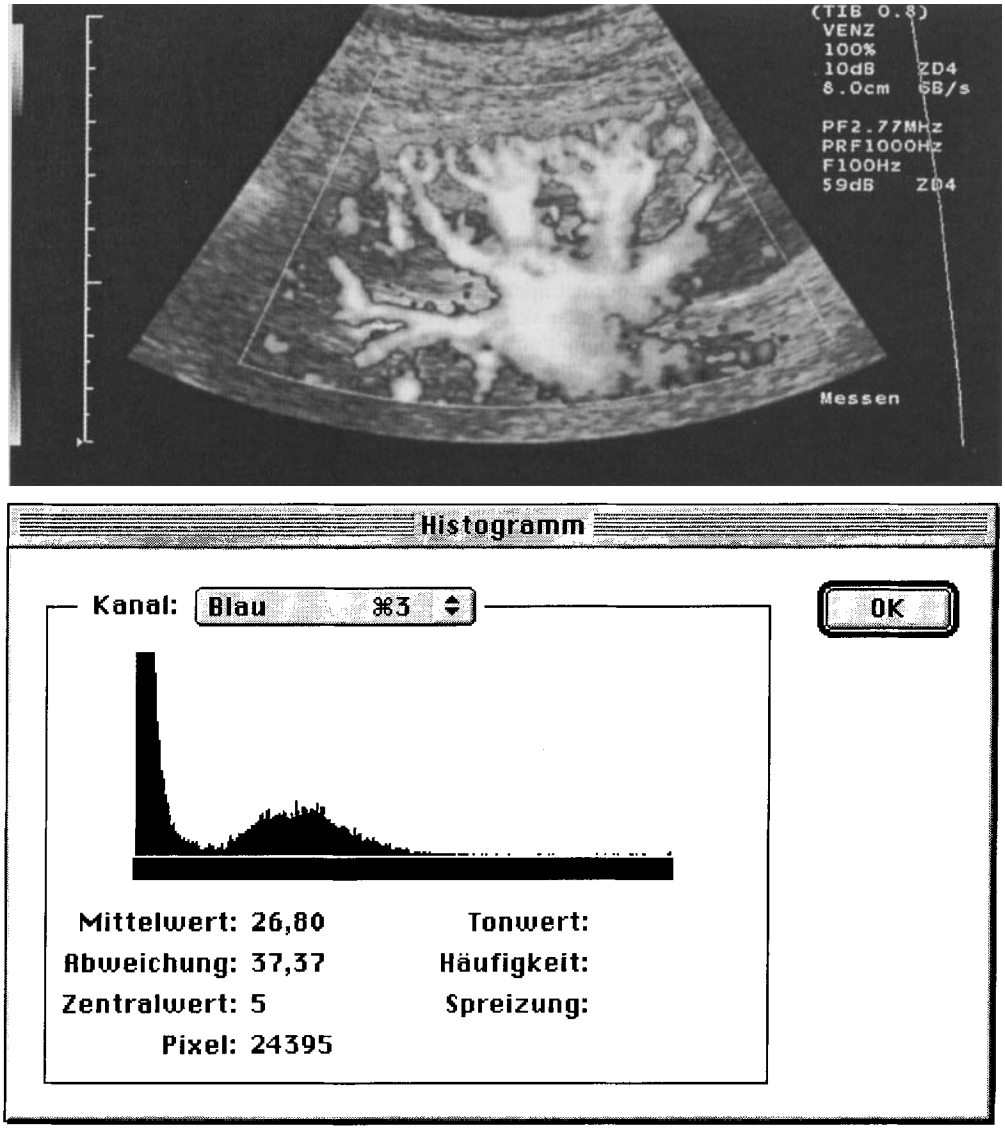


Fig. 2 Rectangular region-of-interest (*ROI*; lighted area *above*) outlining a reference part of the renal parenchyma of the same patient as in Fig. 1. The image was rotated 9° clockwise before placing the ROI. *Below* is the result of the blue-weighted histogram that calculated 70% of pixels with a value below 31 on a 256-step blue scale

Pilot tests of the vessel histograms were performed with the commercially available graphical software Photoshop version 3.05 (Adobe Systems). A region-of-interest (ROI) that outlined only renal vessels showed a histogram with a range of 40–230 on a 256-step grey scale, a range of 125–256 on a 256-step red scale, and a range of 0–30 on a 256-step blue scale. More than 95% of the renal parenchyma showed values from 30 up to 150, independent of the scale. The best distinction between renal vessels and renal parenchyma was achieved using a 256-step blue scale with a cut-off of 30/256, which included more than 95% of the vessel architecture and suppressed more than 95% of the renal parenchyma.

Histograms of the vessels were obtained by a manually drawn rectangular ROI that outlined most of the more ventrally located renal parenchyma. To facilitate a very exact delineation of the ROI, the pictures were rotated clockwise or counterclockwise to ensure that the renal capsule extended nearly parallel to the upper border of each image (Fig. 2), since ROI could only be drawn parallel to the image border. The values up to 30/256 within the ROI were compared to the value from 31 to 256/256 by building a quotient calculated by the software and expressed as a percentage (eq. 1, Fig. 2). These were used as a semiquantified parameter of the vascularization of the renal transplant. This parameter is referred to as the percentage of vascularization (POV).

$$\text{eq. 1: POV} = \frac{\text{number of pixels with a value of less than 30/256}}{\text{total number of pixels within the ROI}}$$

Reproducibility studies

The intra-observer variance of the blood flow velocity measurements and the subsequently calculated Doppler indices were minimized by using the mean result of three measurements obtained from the cranial, middle, and caudal thirds of each kidney transplant.

To evaluate the intra-observer variance of the POV, the POV was measured three consecutive times. Three similar ROI, drawn subsequently on each image, were used to calculate the mean standard deviation of the POV measurements.

The calculated POV of normal patients (group 1), who had follow-up examinations on different days within 1 month, were compared to calculate the mean standard deviation of the POV derived from subsequent follow-up examinations.

Statistical analysis

The results were compared using a multivariate analysis of variance [M(ANOVA)]. Significant differences were further evaluated, group by group, using the Mann-Whitney U-test or an independent t-test if the data followed a normal approximation. The mean maximum velocity and the average mean velocity in segmental or interlobar arteries from each examination were calculated from the three vessels taken from each patient and were used subsequently for statistical evaluation.

Results

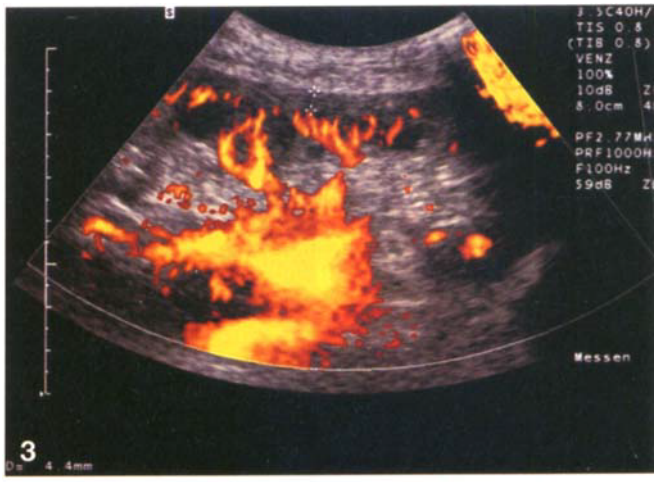
Reproducibility of measurements

The average standard deviation of the PI, RI, maximum velocity, and mean velocity calculated from the three measurements taken at each examination were 0.16, 0.04, 10 cm/s, and 5 cm/s, respectively.

The mean standard deviation of intra-examination-measured POV by ROI analysis of the pixel histogram was 3.4%. Some patients had two or even more follow-up examinations within 1 month that were included in this study. The mean standard deviations of the interexamination-measured PVD and POV obtained from sequential examinations of each patient on different examination days were 0.8 ± 0.4 mm, and $8.0\% \pm 5.6\%$, respectively.

The mean pulse frequency was reduced in the group of patients with chronic transplant rejections. Further evaluation showed a decrease in the pulse frequency, depending on the blood pressure (Fig. 3). The pulse frequencies of normotensive patients were comparable to those observed in the patient group without transplant failure. However, in all other patient groups, high blood pressure was not associated with a decrease in the pulse frequency. Regression analysis showed no correlation between either maximum or mean velocity and pulse frequency ($r = 0.13$; $P = 0.55$).

The values of PI, RI, blood flow velocity, PVD, and POV of the group 1 patients were not statistically different from those of patients with normal blood pressure or hypertension using the Mann-Whitney U-test. Deep or superficial focus localization on power Doppler images did not alter PVD measurement.



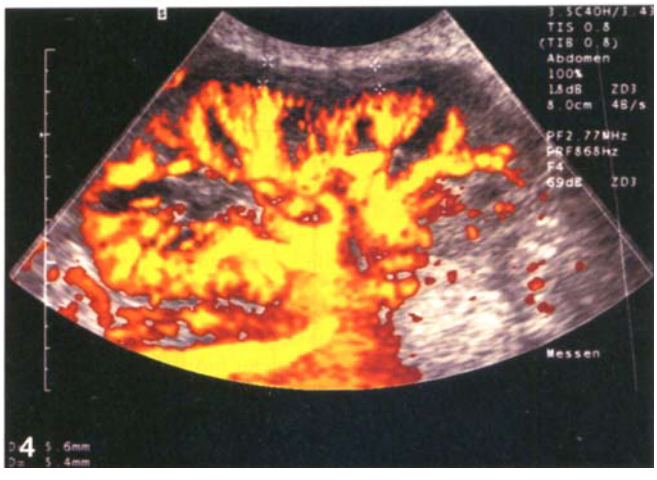


Fig. 3 Power Doppler image of a female patient showing reduced POV (32%). PI and RI were normal: the creatinine level ranged from 1.3 to 1.5 PVD was slightly increased. Biopsy showed minor changes due to chronic transplant rejection. Extrarenal artifacts are due to small bowel movements

Fig. 4 Power Doppler image of a female patient showing an increased PVD of 5.5 mm combined with a normal POV and a moderate increase in PI and RI. Biopsy showed tacrolimus nephrotoxicity and no signs of transplant rejection

Clinical evaluation

Patient distribution according to clinical and laboratory data

Forty-five examinations were done on 25 patients (42.5 ± 14.0 years) who showed no clinical signs of rejection and had normal creatinine levels. The mean time interval between graft implantation and examination was 105 days. These patients made up group 1.

Eighteen examinations done on ten patients revealed acute rejection. These patients formed group 2. Histolo-

Table 1 Summary of the parameters calculated from CDI and PDI for each patient group separately. Statistically significant differences compared to group 1 (normal transplant function) using multivariate analysis of variance were highlighted

Patient group	PI	RI	Vmax (cm/s)	Vmean (cm/s)	PVD (mm)	POV (%)	Pulse frequency (1/s)
Normal	1.45 ± 0.32	0.73 ± 0.07	39 ± 14	19 ± 6	2.9 ± 1.0	70.8 ± 15.5	81 ± 16
Acute rejection	1.80 ± 0.28	0.79 ± 0.04	36 ± 10	16 ± 5	3.0 ± 1.7	66.3 ± 8.6	86 ± 12
Chronic rejection	1.56 ± 0.42	0.75 ± 0.08	25 ± 12	12 ± 6	5.2 ± 3.8	39.3 ± 20.1	65 ± 12
Tacrolimus nephrotoxicity	1.68 ± 0.25	0.79 ± 0.05	38 ± 16	18 ± 9	5.0 ± 1.6	68 ± 18	75 ± 23
M(ANOVA) P =	0.043	0.008	0.037	0.025	< 0.001	0.004	0.009

gy showed Banff grade I in five patients (13 examinations) and Banff grade II in another five patients (5 examinations). Creatinine levels ranged from 1.3 to 2.9 mg/dl. The mean time interval between graft implantation and examination was 48 days.

Twenty-six examinations on 16 patients (42.3 ± 14.4 years) revealed chronic rejection (group 3). Creatinine levels ranged from 1.3 to 5.8 mg/dl. The mean time interval between graft implantation and examination was 2.8 years.

Eleven examinations done on eight patients (46.3 ± 8.6 years) showed signs of tacrolimus nephrotoxicity (group 4). Creatinine levels ranged from 1.4 to 3.3 mg/dl, and the mean time interval between graft implantation and examination was 50 days.

Kidney transplant morphology

Only 2 of the 45 patients had slightly enlarged pylon; they were not excluded from the study evaluation.

Acute rejection

The pulsatility index (PI) as well as the resistive index (RI) measured in segmental or interlobar arteries of the kidney transplant were significantly elevated in the patient group with acute rejection (Tables 1, 2). Statistical group-by-group analysis showed a significant difference in both PI and RI compared to both the patient group with chronic rejection (1.50 ± 0.32) and the group without clinical evidence of transplant rejection (P = 0.002 and P = 0.001, respectively; Mann-Whitney U-test).

PVD and POV did not differ compared to patient group 1 (normal transplants). However, 1/18 examinations (Banff grade II) showed increased PVD (4.2 mm), combined with a marked increase in PI (2.2) and RI (0.85). Normal PI and RI and increased PVD (8.5 mm) were observed in a histologically confirmed acute transplant rejection (Banff grade 1) in another patient.

Chronic rejection

Using the personal computer-assisted histogram analysis of the digitally stored images, the patients with chronic rejection had a lower POV than all of the other patient groups (P < 0.001; Mann-Whitney U-test), which did not differ from each other (Table 1, Fig. 3). The PVD was more extensive in the patient group with chronic rejection than in that with normal transplant function or with acute transplant rejection (P < 0.002 and P < 0.007), respectively; Mann-Whitney U-test). However, the PVD showed a high variance with only a slightly increased PVD at the beginning of a chronic rejection with minor histological changes compared to progressive chronic rejection (PVD 4.0 ± 2.3 mm and 8.2 ± 5.4 mm, respectively; P = 0.003; Mann-Whitney U-test). The maximum, as well as the mean, velocity was significantly lower in patients with chronic rejection than in all other patient groups (P < 0.001; Mann-Whitney U-test). In contrast, PI and RI did not differ compared to the group with normally functioning kidney transplants (Table 2).

Tacrolimus nephrotoxicity

The patient group with tacrolimus nephrotoxicity (group 4) showed a tendency to higher PI and RI, but averaged values were lower than those for the patient group with acute rejection (Table 1). Tracrolimus blood levels were 18.2 ± 6.5 ng/ml (9.4 ng/ml–30 ng/ml) compared to 10.9 ± 5.8 in group 1 (normal kidney function) and to 9.1 ± 4.6 ng/ml in group 3 (chronic rejection). However, tacrolimus blood levels were 14.4 ± 4.2 in patients with acute rejection, demonstrating a wide overlap between both patient groups. PVD was more extensive in the patient group with acute tacrolimus nephrotoxicity than it was in the patient group with acute rejection and that with normal transplants (Table 1, Fig. 4). The results reached statistical significance (P = 0.001; Mann-Whitney U-test for group 4 vs groups 1 and 2). After reducing tacrolimus administration, the PVD did not decrease immediately; however, four patients who

Table 2 Clinical value of retrospectively chosen cut-offs to differentiate probable diagnoses *PPV* positive predictive value, *NPV* negative predictive value

Patient group	PI or RI	PVD	POV	Sensitivity	Specificity	PPV	NPV
Normal range	< 1.75	≤ 3.8	≥ 55 %				
Acute rejection	≥ 1.75 or ≥ 0.78	Normal	Normal	78 %	87 %	39 %	94 %
Chronic rejection	< 1.7 or < 0.75	Normal or elevated	Reduced < 55 %	81 %	83 %	84 %	81 %
Tacrolimus nephrotoxicity	Normal or elevated	≥ 3.9 mm	Normal	91 %	71 %	83 %	94 %

Table 3 Conclusions

1. The discriminators for acute rejection are increased PI and/or RI combined with normal blood flow velocity and POV.
2. The discriminators for chronic rejection are a reduced POV of the renal transplant and normal indices. An additive parameter is a reduced blood flow velocity of 30 cm/s or lower.
3. The discriminators for tacrolimus nephrotoxicity are a moderate increase in RI and/or PI, concomitant with a greater PVD on power Doppler images. Normal vascularization, if observed, discriminates tacrolimus nephrotoxicity from chronic rejection.

had undergone sequential analysis showed a decrease in the PVD after different time intervals.

Tacrolimus nephrotoxicity was diagnosed with a sensitivity of 91 % (10/11 examinations were true-positive) when the PVD was 3.9 mm or more. Specificity was 71 % (63/89 were true-negative) because patients with chronic rejections also had an increased PVD. The combination of a longer distance between renal peripheral vessels and the capsule and more than 60 % of renal parenchyma being covered by renal vessels, according to the histogram, increased the specificity to 81 % but resulted in a slight decrease in sensitivity (82 %) when differentiating tacrolimus nephrotoxicity from chronic rejection. To discriminate tacrolimus nephrotoxicity from acute rejection, a cut-off PVD of 3.9 mm had a positive predictive value of 83 % and a negative predictive value of 94 % for patient groups 2 and 4 (Table 2).

Discussion

Color-coded duplex sonography has been established as part of the routine follow-up after kidney transplantation [13]. Frequency-encoded duplex sonography is used not only for diagnosing vascular complications like arterial stenosis at the anastomosis or venous thrombosis [4], but also for nephrological complications.

More recently, amplitude-modulated color Doppler (power Doppler) imaging has been introduced into ultrasound examinations. PDI has been shown to be superior in the depiction of blood vessels with low-flow velocity [16]. Movement artifacts and the loss of information on flow direction are the most commonly reported disadvantages. Moreover, AV fistulae are better depicted with the conventional frequency-encoded color Doppler [18]. Vascularization of the kidney transplant is better visualized by PDI. In this study, the grade of vascularization (POV) and the number of peripheral vessels expressed by the distance to the renal capsule (PVD) were evaluated as a diagnostic approach to differentiate acute rejection, chronic rejection, and tacrolimus nephrotoxicity. The power Doppler mode showed all renal vessels, even when the flow velocity was low. If flow resistance is elevated due to a vascular stenosis or vasoconstriction, the flow velocity is reduced and the PVD should be elevated. The POV could be regarded as a parameter of the number of renal vessels and should be reduced in the case of thrombosis or obstruction of renal arteries, which often accompany chronic rejection. The influence of hematocrit and the correlation with indices obtained from Doppler spectra are controversial issues [16, 18].

PI and RI are widely used in the diagnostic work-up of kidney transplants to support the diagnosis and the therapy response of acute transplant rejections [14, 15, 17]. Some authors advocate sequential analysis in order to increase sensitivity [6, 10, 17]. Pelling et al. propose diagnosing an acute rejection with an RI of more than 0.77, and this was supported by our results. We recommend diagnosing an acute rejection with either a PI greater than 1.75 or an RI of 0.78 or higher which, in the present study, showed an acceptable sensitivity (78 %) and specificity (87 %). However, the positive predictive value of only 39 % limited the diagnostic value of the spectral Doppler indices without considering the POV and PVD as additional parameters. Blood flow velocity and vascularization of the renal transplant, as seen in the power Doppler images, were not altered in patients with an acute rejection. The low number of patients with moderate acute rejection (Banff grade II; 5/18 patients) probably explains this observation. However, the few patients with Banff grade II rejection

showed no tendency (except in one case) to a lower POV or an increased PVD.

In contrast, some authors have observed no alteration in the RI or PI in patients with chronic rejection [2, 3], which is supported by our results. Quarto di Palo et al. found a statistically inverse relationship between renal blood flow and transplant age. They reported that the vascular resistance increased with transplant age. Several reports found a reduced blood flow velocity in segmental or interlobar arteries in patients with chronic rejection [1, 3]. In clinically normal patients, the mean maximum blood flow velocity decreased from the renal artery to the periphery and reached 43 cm/s in the segmental arteries and 35 cm/s in interlobar arteries. In our study, the mean maximum blood flow velocity was 40 cm/s in the interlobar or segmental arteries in patients without clinical evidence of abnormal allografts. We found a significant reduction in the vascularization of the kidney transplant in patients with chronic rejection. In contrast, patients with acute rejection had no change in blood flow velocities compared to patients with normal kidney allografts. The significantly lower blood flow velocity in chronic parenchyma degeneration might induce the higher distance between the peripheral vessels and the renal capsule. Our results showed that low vascularization, expressed as POV, is a valuable discriminator of chronic parenchyma alteration and acute rejection, especially when PI or RI is low. We found a cut-off of 55 % or lower to have a sensitivity of 81 % and a specificity of 83 %. The PVD and the maximum flow velocity reached a sensitivity of only about 50 % each and might be used as additional parameters.

Physiological effect of tacrolimus is afferent arteriolar vasoconstriction. Tacrolimus nephrotoxicity is considered when nodular arteriolar hyalinosis is found histologically. The morphological changes are similar to those of cyclosporin A nephrotoxicity. According to existing reports, cyclosporin may increase the PI and RI, but results have either not reached statistical significance or have shown a wide overlap, with abnormal results found only in severe cases [3, 8, 19]. To our knowledge, there are no published data about Doppler sonographic alterations in patients with tacrolimus nephrotoxicity. One would expect the signs of tacrolimus nephrotoxicity to be similar to those of cyclosporin A nephrotoxicity. Our PDI showed no alterations in the vascularization of the renal transplant in patients with tacrolimus nephrotoxicity compared to the patient group without clinical evidence of renal abnormality. The indices were slightly increased. In contrast, we found a significantly longer distance between the visualized renal vessels and the renal capsule, which mimics chronic rejection and might indicate arteriolar changes. Cyclosporin A nephrotoxicity reduces renal blood flow and diastolic flow, and this might account for this observation [12]. Because we only had a few patients with acute tacrolimus nephrotoxicity, the results of this study need to be reproduced with larger patient groups. The subtle changes that tacrolimus nephrotoxicity produced on power Doppler images impaired our ability to discriminate it from acute transplant rejection in individual cases since both resulted in increased PI and RI; a few patients with acute transplant rejection also showed an increased PVD. However, in our study, only one patient with Banff grade I acute transplant rejection showed signs that mimic those of chronic rejection (i. e., reduced POV, increased PVD, and normal PI and RI).

Table 1 shows a wide overlap in the results of all parameters, supporting a multimodality approach to make a differential diagnosis in the clinical follow-up of kidney transplant recipients. Subtle sequential analysis of the patients by the same investigator and exhaustive clinical information are important to optimize the evaluation of the examination data. Data to evaluate the interobserver variability of the measurements were not obtained in this study. The complexity of possible parameters that influence the results of Doppler sonography and their indices need further investigation, but the noninvasive procedure and the recent technical impact encourage further investigations. The results suggest adding the information obtained from power Doppler images to the conventional Doppler indices to improve the accuracy of color Doppler imaging in the diagnostic work-up of kidney transplants.

References

1. Akiyama T, Ikegami M, Hara Y, Nagano T, Negita M, Ishii T, Nishioka T, Kurita T (1996) Hemodynamic study of renal transplant chronic rejection using power Doppler sonography. Transplant Proc 28: 1458–1460
2. Breitenseher M, Helbich T, Kainberger F, Hübsch P, Trattnig S, Traindl O, Mostbeck G (1994) Color Doppler sonography of renal allografts: is the resistive index a diagnostic tool in the long-term follow-up? Ultraschall Med 15: 24–28
3. Deane C (1992) Doppler and color Doppler ultrasonography in renal transplants: chronic rejection. J Clin Ultrasound 20: 539–544
4. Grenier N, Douws C, Morel D, Ferriére JM, Le Guillou M, Potaux L, Broussin J (1991) Detection of vascular complications in renal allografts with color Doppler flow imaging. Radiology 178: 217–223
5. Hilborn MD, Bude RO, Murphy KJ, Platt JF, Rubin JM (1997) Renal transplant evaluation with power Doppler sonography. Br J Radiol 70: 39–42

6. Hollenbeck M, Hetzel GR, Hilbert N, Meusel F, Willers R, Grabensee B (1995) Efficacy of antirejection treatment after renal transplantation as assessed by Doppler sonography. Dtsch Med Wochenschr 120: 277–282
7. Hoyer PF, Melter M, Offner G, Brodehl J (1993) Significance of duplex and color encoded Doppler sonographic monitoring in children with renal transplants. Transplant Proc 25: 2571
8. Martinoli CM, Crespi G, Bertolotto M, Rollandi GA, Rosenberg I, Pretolesi F, Derchi LE (1996) Interlobular vasculature in renal transplants: a power Doppler US study with MR correlation. Radiology 200: 111–117
9. Merkus JW, Asten WN van, Hoitsma AJ, Hof MA van't, Koene RA, Skotnicki SH (1996) Doppler spectrum analysis in the differential diagnosis of renal transplant dysfunction. Clin Transplant 10: 420–428
10. Pelling M, Dubbins PA (1992) Doppler and color Doppler imaging in acute transplant failure. J Clin Ultrasound 20: 507–516
11. Preidler KW, Szolar DM, Uggowitzer M, Stiskal M, Horina J (1995) Technical note: Comparison of colour Doppler energy sonography with conventional colour Doppler sonography in detection of flow signal in peripheral renal transplant vessels. Br J Radiol 68: 1103–1105
12. Quarto Di Palo F, Rivolta R, Elli A, Castagnone D, Palazzi P, Abelli P, Zafiropulu S, Zanussi C (1993) Effect of cyclosporin A on renal cortical resistances measured by color Doppler flowmetry on renal grafts. Nephron 65: 240–244
13. Quarto di Palo F, Rivolta R, Elli A, Castagnone D (1995) The well-functioning renal graft evaluated by color Doppler flowmetry. Nephron 70: 314–318
14. Quarto di Palo F, Rivolta R, Elli A, Castagnone D (1996) Relevance of resistive index ultrasonographic measurement in renal transplantation. Nephron 73: 195–200
15. Rana DS, Bhalla AK, Gupta A, Kapoor KK, Jauhari H, Kanna PK (1992) Color Doppler studies of the transplant renal artery in patients with allograft rejection – correlation with graft biopsy. Transplant Proc 24: 1886
16. Rubin JM, Bude RO, Carson PL, Bree RL, Adler RS (1994) Power Doppler US: potentially useful alternative to mean frequency-based color Doppler US. Radiology 190: 853–856
17. Ruder H, Nagler B, Gheith S, Rupprecht T, Waldherr R, Deeg KH (1993) Sequential color and pulsed Doppler sonography for monitoring antirejection therapy in pediatric patients. Transplant Proc 25: 2572–2573
18. Turetschek K, Nasel C, Wunderbaldinger P, Diem K, Hittmair K, Mostbeck GH (1996) Power Doppler versus color Doppler imaging in renal allograft evaluation. J Ultrasound Med 15: 517–522
19. Waltzer WC, Shabtai M, Anaise D (1989) Usefulness and limitation of Doppler ultrasonography in the evaluation of post operative renal allografts. Transplant Proc 21: 1901–1902
20. Woodle ES, Cronin D, Newell KA, Millis JM, Bruce DS, Piper JB, Haas M, Josephson MA, Thistlethwaite JR (1996) Tacrolimus therapy for refractory acute renal allograft rejection. Transplantation 62: 906–910