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ABDOMINAL IMAGING

ORIGINAL ARTICLE

A comparison between the superb microvascular imaging technique and conventional Doppler ultrasound in evaluating chronic allograft damage in renal transplant recipients

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PURPOSE

The present study comparatively evaluates the performance of conventional Doppler ultrasound and superb microvascular imaging (SMI) in delineating the cortical microvessels of the transplanted kidney and compares the chronic allograft damage index (CADI) based on the examination of biopsy specimens with Doppler ultrasound and SMI findings.

METHODS

Sixty-eight renal transplant recipients underwent kidney biopsy with the pre-diagnosis of rejection before undergoing renal Doppler ultrasound examination between January 2020 and October 2020. The distance between the kidney capsule and the vascular structure closest to the kidney capsule was measured at the level of the lower pole in the transplanted kidney using color Doppler ultrasound (CDUS), power Doppler ultrasound (PDUS), and the SMI technique. The kidney size, resistive index at the level of the arcuate artery in the lower pole of the kidney, and renal artery flow rates were also measured.

RESULTS

The mean distance between the kidney capsule and the vessel was 2.44 ± 2.0 mm on CDUS, 1.34 ± 1.2 mm on PDUS, 0.99 ± 1.8 mm using the color SMI (cSMI) technique, and 0.86 ± 1.8 mm using the monochrome SMI (mSMI) technique. The study found that the SMI technique was superior to CDUS and PDUS in delineating the cortical microvasculature of the kidney. Both Doppler ultrasound examinations and the SMI technique proved effective in predicting the CADI (P = 0.006 for CDUS, P = 0.002 for PDUS, P = 0.018 for cSMI, and P = 0.027 for mSMI).

Among conventional Doppler ultrasound examinations and the SMI technique, PDUS had the highest sensitivity, and cSMI had the highest specificity in differentiating high and low CADI values. Both the cSMI and mSMI techniques had similar sensitivity values, whereas only cSMI exhibited high specificity. CDUS had the lowest specificity value (P = 0.003 for CDUS, P = 0.002 for PDUS, P = 0.005 for cSMI, and P = 0.004 for mSMI).

CONCLUSION

The present study is the first in the literature to demonstrate the utility of the distance between the kidney capsule and the vessels in predicting the CADI score and to compare the Doppler ultrasound examinations and SMI technique in doing so.

KEYWORDS

Chronic allograft damage index, Doppler ultrasound, kidney, renal transplant, superb microvascular imaging

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Chronic kidney disease is a significant public health concern because of its increasing incidence, associated high rates of morbidity and mortality, significant impairment in patients' quality of life, high treatment costs, and low level of public awareness. Hemodialysis, peritoneal dialysis, and renal transplantation are used in treating patients with kidney failure. Among these treatment modalities, renal transplantation is considered the ideal treatment method. Renal transplantation confers more prolonged survival and better quality of life compared with peritoneal dialysis and hemodialysis.[1]

The success of a renal transplant depends on the extent to which renal functions have been preserved. Kidney biopsy is the most crucial examination method in exploring renal dysfunction.[2,3] The chronic allograft damage index (CADI) is a scoring system developed in the early 1990s to numerically classify pathological lesions associated with the loss of kidney function in renal transplant recipients. There is a correlation between kidney survival and functions and the CADI, which is calculated using six histopathological lesions (interstitial inflammation, tubular atrophy, interstitial fibrosis, arterial fibrointimal thickening, glomerular mesangial matrix increase, and glomerular sclerosis). The CADI provides beneficial information to the clinician in deciding the treatment and follow-up of the patient, as the CADI is a numeric scoring system reflecting the extent of chronic kidney damage. This scoring system provides a quick overview of the severity of chronic alternations. Previous studies recommend using the CADI as a part of routine clinical assessment when interpreting transplanted kidney biopsies.[4] A strong relationship has been reported between the CADI and graft survival and functions.[5]

Main points

- The superb microvascular imaging (SMI) technique seems to be more sensitive than color Doppler ultrasound (CDUS) and power Doppler ultrasound (PDUS) in depicting the kidney cortical microvasculature in the transplanted kidney.
- The distance between the kidney capsule and the vessel measured by CDUS, PDUS, and SMI significantly differed between patients with low and high chronic allograft damage index (CADI) scores.
- CDUS and PDUS examinations and the SMI technique prove effective in predicting the CADI score in transplanted kidneys, and the SMI technique is the most specific in ruling out severe chronic rejection.

Histopathological examination of the transplanted kidney provides beneficial information about the precise diagnosis and treatment.[6] However, biopsy examination also has some known limitations. The examination of a small amount of kidney tissue may fail to detect many renal pathologies. The factors limiting the examination of the biopsy materials include the inability to collect a sufficient amount of kidney tissue, failure to recover cortical tissue, patchy involvement of the kidney in the disease, borderline lesions, therapies received, and the presence of parenchymal scarring.[2]

Some histologic features of chronic allograft nephropathy, such as vascular intimal proliferation and fibrosis, are related to tissue perfusion.[7] Assessing the cortical microvasculature blood flow representing kidney perfusion is challenging due to the small caliber of the vessels with a slow flow. Wang et al.[8] assessed cortical perfusion of renal transplants during acute rejection episodes using power Doppler quantification and found that acute antibody-mediated rejection is associated with significantly decreased cortical perfusion. Schwenger et al.[7] suggest that perfusion intensity assessed by dynamic color Doppler measurements is significantly reduced in allografts with grade 2 and 3 fibrosis compared to allografts without fibrosis.

Imaging techniques have become essential auxiliary diagnostic methods in kidney diseases. Doppler ultrasound is a valuable tool in the diagnosis and follow-up of complications and rejection after renal transplantation. However, color Doppler ultrasound (CDUS) assesses renal perfusion only in large arteries without giving any detailed information regarding the perfusion of preglomerular arterioles. Power Doppler ultrasound (PDUS) is reportedly sensitive to low-velocity and microvascular blood flow. The main drawback of PDUS, though, is its high sensitivity to tissue motion. Superb microvascular imaging (SMI) uses advanced ultrasound algorithms to preserve the subtlest slow-flow components that cannot be depicted using CDUS or PDUS techniques.

A study by Gao et al.[9] compared SMI and other Doppler ultrasound techniques in terms of their sensitivities in demonstrating microvasculature and concluded that SMI performs best in delineating kidney microvasculature. The authors of the present study consider that the superior performance of the SMI technique in demonstrating microvasculature might provide new scientific data that allows insight into the effects of kidney rejection on peripheral vasculature and predicts the degree of rejection.

The studies in the literature have established a strong relationship between the CADI and graft survival and functions.[4,5,10,11-13] However, no radiological method currently exists that predicts the CADI. The present study aims to evaluate the effectiveness of the SMI technique in predicting the type and severity of rejection in renal transplant patients. It also compares the performances of the SMI technique and conventional Doppler ultrasound techniques in predicting the severity of rejection.

Methods

Study design and setting

The present study was designed as a single-center study approved by the hospital's ethics committee (23.10.2019/958). Informed consent forms were signed by all patients in line with the World Medical Association Declaration of Helsinki, revised in 2000 in Edinburgh. The study was financially supported by the Akdeniz University Scientific Research project fund (project no: 5146).

Patient data

The study included patients who were examined by the physicians working at the hospital's transplantation unit and who underwent renal transplant biopsy between January 2020 and October 2020 due to recent-onset proteinuria, persistently elevated serum creatinine levels, and a lack of a decrease to basal levels of serum creatinine despite the therapies.

The biopsy materials consisted of core biopsy performed at different time points after transplantation. Sixty-eight patients were evaluated by renal Doppler ultrasound before undergoing renal biopsy. No glomeruli were observed in the biopsy specimen of one patient, two glomeruli were observed in two patients, three glomeruli were observed in one patient, and these four patients were excluded from the study, as a pathological examination could not be performed due to insufficient glomeruli in the specimens.

Age, gender, serum creatinine levels, the mean time elapsed since transplantation, and the results of a pathological examination evaluating renal allograft rejection were retrieved from the hospital's database (MIA

MED, 1.0.1.3295). Gray-scale ultrasound, CDSU, PDUS, and SMI examinations were performed using an Aplio i800 ultrasound scanner (Canon Medical Systems USA, Tustin, CA) equipped with a linear array transducer (PLT-1005BT, 10 MHz).

Imaging parameters and technique

All patients underwent gray-scale ultrasound, PDUS, CDUS, and SMI in a supine position in a dimly lit ultrasound room before undergoing a biopsy. The results were recorded for later comparison with histopathological results. Table 1 presents the parameters used in the conventional Doppler ultrasound and SMI.

The longitudinal axis, parenchymal thickness, and echo pattern of the transplanted kidneys were evaluated on gray-scale ultrasound examination. Then, the resistive index (RI) was measured at the level of the arcuate artery in the lower pole of the kidney by switching to CDUS mode. Because biopsies were done, the lower pole for RI measurement was preferred. The renal artery flow rate was measured from the point closest to the anastomosis line, and the Doppler angle was measured parallel to the vessel wall with a transducer angle of fewer than 60 degrees. The distance between the kidney capsule and the vascular structure closest to the kidney capsule (capsule-to-vessel distance) was measured by CDUS, PDUS, and SMI at the lower pole level in the transplanted kidney (Figure 1). A small color box in the cortical area and the pre-settings of the Doppler device recommended for renal examination were used to achieve a high frame rate and resolution. Each CDUS mode was performed once at the same region. A single operator who had five years of experience with kidney sonography performed renal CDUS in all patients.

Statistical analysis

The sample size in the study was calculated using a power of at least 80% for each variable and a 5% type 1 error. The Kolmogorov–Smirnov ($n > 50$) test and the Skewness–Kurtosis test were used to examine whether continuous variables were normally distributed, and parametric tests were applied due to the normal distribution of the measurements.

Descriptive statistics were used to express continuous variables, such as mean, standard deviation, minimum, and maximum; categorical variables were expressed as numbers and percentages. The independent-samples t-test was used to compare measurements between the CADI groups. A chi-squared test

Table 1. The parameters used in CDUS, PDUS, and SMI techniques

Parameter	Frequency	Pulse repetition frequency	Mechanical index	Color gain
CDUS	10 MHz	9–14	1.5–1.6	39
PDUS	10 MHz	10–15	1.5–1.6	47
SMI	10 MHz	0.8–1.2	1.5–1.6	40

CDUS, color Doppler ultrasound; PDUS, power Doppler ultrasound; SMI, superb microvascular imaging.

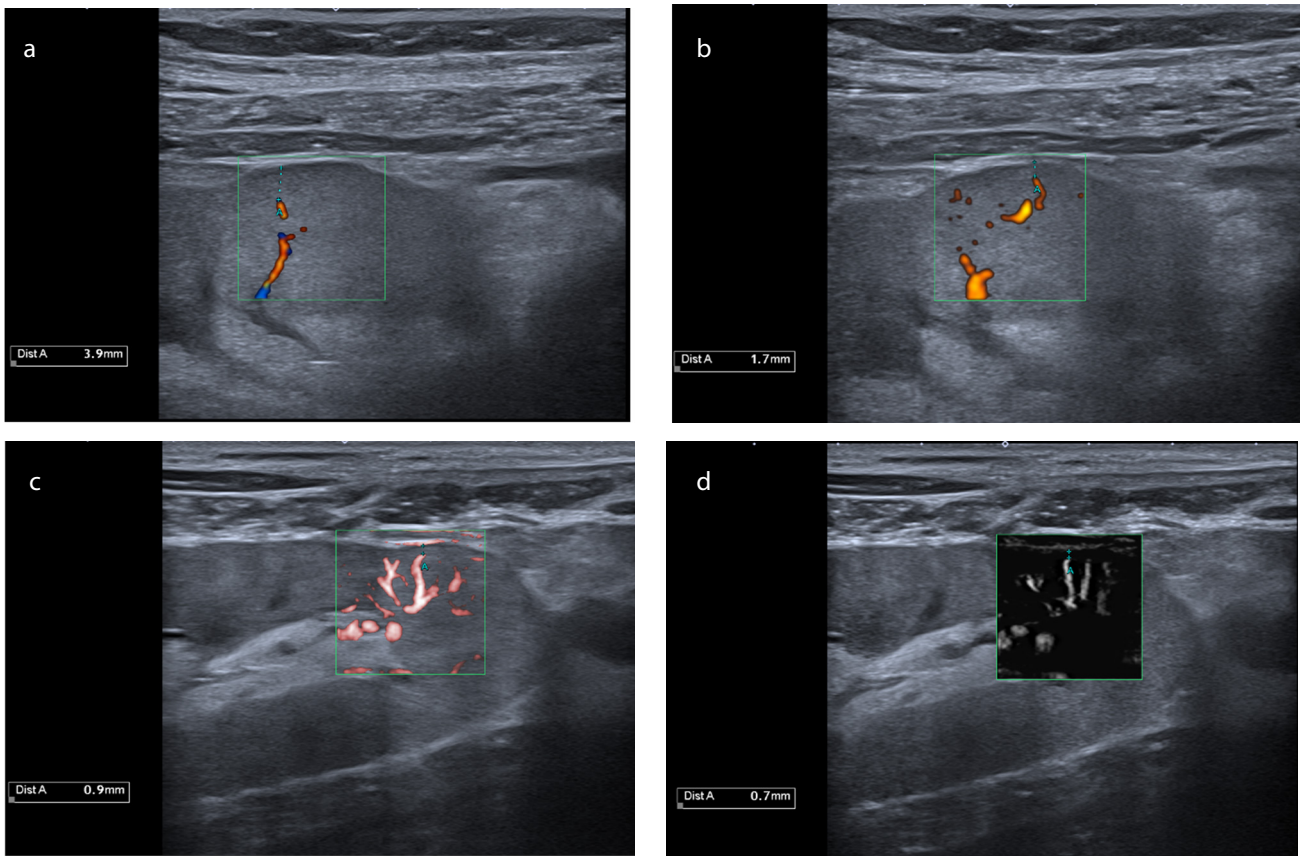

Figure 1. In a thirty-year-old male patient who underwent kidney transplantation five years ago, the distance between the kidney capsule and the vessel was measured as 3.9 mm on **(a)** color Doppler ultrasound, 1.7 mm on **(b)** power Doppler ultrasound, 0.9 mm on **(c)** color superb microvascular imaging examination, and 0.7 mm on **(d)** monochrome superb microvascular imaging examination. The chronic allograft damage index (CADI) score was calculated as 6. The patient was in the high CADI group. The capsule-vessel distances measured by the Doppler examinations were above the cut-off values and correlated with the pathology result. The resistive index was calculated as 0.58, and serum creatinine was 4.54 mg/dL.

was used to examine the relationship between the categorical variables. In receiver operating characteristic (ROC) curve analysis, the area under the curve (AUC), sensitivity, specificity, and cut-off values were calculated to determine the performance of the CADI in predicting the distance between the kidney capsule and the vessel measured by Doppler ultrasound examination.

The Statistical Package for the Social Sciences version 24 software package was used in the statistical analysis. A *P* value of less than 0.050 was considered statistically significant in all statistical analyses.

Results

Patient characteristics

The mean number of glomeruli was 14.36 (minimum: 7; maximum: 35) in biopsy specimens recovered from 69 patients. The mean kidney size was 113.2 mm. Thirty patients were female (31.25), and 44 were male (68.75%). The mean age was 38.42 years, with a minimum of 8 years and a maximum of 64 years. The highest velocity in the renal artery was 201/43 cm/s, and the lowest was 45/15 cm/s.

The mean time elapsed since renal transplantation was 6.5 years. The time from renal transplantation was less than one year in 15 patients (23.44%), 1–3 years in 10 patients (15.62%), and more than three years in 39 patients (60.94%).

The histopathological CADI score was calculated for a total of 64 patients. Patients with a CADI score of 4 or less were allocated to the low CADI group, and those with a CADI score of greater than 4 were allocated to the high CADI group. The mean CADI score was 1.77 for 23 patients in the low CADI group and 8.49 for 41 patients in the high CADI group. The mean RI was 0.62 (0.4–0.77) and 0.66 (0.54–0.88) in the low and high CADI groups, respectively. The mean creatinine was 1.68 mg/dL in the low CADI group and 2.46 mg/dL in the high CADI group (Table 2).

Table 2. Age, female-to-male ratio, RI, creatinine, and time elapsed since transplantation in the low and high CADI groups

	CADI ≤4 (n = 23)	CADI >4 (n = 41)
CADI score	1.77	8.49
Age (year)	34.29	41.66
Female-to-male ratio	1/3.6	1/3.1
RI	0.62 (0.40–0.77)	0.66 (0.54–0.88)
Creatinine (mg/dL)	1.68	2.46
Time elapsed since transplantation (year)	3.48	7.92

CADI, chronic allograft damage index; RI, resistive index.

Results of color Doppler ultrasound, power Doppler ultrasound, and superb microvascular imaging

The RI was lower than 0.70 in 45 patients and 0.70 or higher in 19 patients. Among 19 patients with a high RI, five had low CADI scores, and 14 had high CADI scores. Among 45 patients with a low RI value, 18 had a low CADI score, and 27 had a high CADI score. The analysis of the relationship between the CADI score and the RI revealed no statistically significant relationship ($P = 0.297$).

The mean capsule-to-vessel distance on CDUS was significantly lower in the low CADI group (1.49 mm vs. 2.33 mm, $P = 0.006$) and was also lower on PDUS in the low CADI group (0.70 mm vs. 1.70 mm, $P = 0.002$) (Table 3).

The mean capsule-to-vessel distance on color SMI (cSMI) was significantly lower in the low CADI group (0.26 mm vs.1.39 mm, $P = 0.018$) (Table 4). Finally, the mean distance between the kidney capsule and the vessel on monochrome SMI (mSMI) significantly dif-

Table 3. Mean, standard deviation, minimum, and maximum values for the kidney capsule-to-vessel distance measured by CDUS, PDUS, cSMI, and mSMI techniques

	Mean ± SD	Min–max (mm)	*P
CDUS			
CADI ≤4 (n = 23)	1.50 ± 1.10	0–4.3	
CADI >4 (n = 41)	2.96 ± 2.33	0.7–13	0.006
Total (n = 64)	2.44 ± 2.09	0–13	
PDUS			
CADI ≤4 (n = 23)	0.70 ± 0.85	0–3.1	
CADI >4 (n = 41)	1.70 ± 1.34	0–5.1	0.002
Total (n = 64)	1.35 ± 1.28	0–5.1	
cSMI			
CADI ≤4 (n = 23)	0.27 ± 0.51	0–1.6	
CADI >4 (n = 41)	1.40 ± 2.19	0–13	0.018
Total (n = 64)	0.99 ± 1.85	0–13	
mSMI			
CADI ≤4 (n = 23)	0.20 ± 0.41	0–1.2	
CADI >4 (n = 41)	1.23 ± 2.16	0–13	0.027
Total (n = 64)	0.86 ± 1.81	0–13	

*Independent-samples t-test. CDUS, color Doppler ultrasound; cSMI, color superb microvascular imaging; max, maximum distance between the kidney capsule and the vessel; Min, minimum distance between the kidney capsule and the vessel; mSMI, monochrome superb microvascular imaging; n, number; PDUS, power Doppler ultrasound; SD, standard deviation.

fered between the low and high CADI groups ($P = 0.027$) (Table 3).

In ROC curve analysis, conventional Doppler examinations and the SMI technique proved effective in predicting the CADI score. The calculated AUC value in ROC curve analysis was 0.722 for CDUS, 0.740 for PDUS, 0.712 for cSMI, and 0.718 for mSMI (Table 4). Although the values were close to each other, the highest AUC value was calculated for PDUS. According to ROC curve analysis, the cut-off value for the capsule-to-vessel distance in differentiating between a low and high CADI score was 1.90 mm (a sensitivity of 63% and a specificity of 65%) in CDUS, 1.15 mm (a sensitivity of 68% and a specificity of 70%) in PDUS, 0.85 mm (a sensitivity of 56% and a specificity of 87%) in cSMI, and 0.65 mm (a sensitivity of 56% and a specificity of 83%) in mSMI (Figure 2). PDUS had the highest sensitivity (68%), and cSMI had the highest specificity (87%). Although cSMI and mSMI yielded similar sensitivity rates (each 56%), the cSMI technique yielded higher specificity. CDUS had the lowest specificity.

Discussion

Renal transplantation is a treatment method used in end-stage renal insufficiency. Successful renal transplantation improves patients' quality of life and decreases mortality. Renal transplantation is more valuable than dialysis due to its low cost.[14] Recognizing complications early after renal transplantation is crucial to prolonging graft survival. Early recognition will prevent the loss of health and eliminate the psychological, social, and economic burden of therapies that may be required after rejection.

Doppler ultrasound examination is used to recognize complications and evaluate the vascularity of the transplanted kidney after transplantation. A hemodynamic index, the RI, reflects the vascular compliance of the recipient. A persistently elevated RI has also been considered to be pathological. The RI represents the microcirculation status and provides information about the glomerular function and pathological conditions.[15] The correlation between the RI and glomerular sclerosis, tubulointerstitial, and vascular alterations has been demonstrated in various studies.[16-18] In a study comparing the RI with the transplanted kidney functions and biopsy results, Ikee et al.[19] followed up with 52 patients for two years, and a significant relationship was reported between the RI and age, creatinine clearance, and histopathological results. The RI has been employed as a useful marker in evaluating renal allograft function and the survival and long-term prognosis of the patients.[20,21] In the present study, patients with chronic kidney damage were divided into two groups according to the CADI score: patients with a CADI score of 4 or less were allocated to the group with mild chronic kidney damage, and patients with a CADI score of greater than 4 were allocated to the group with severe chronic kidney damage. The mean RI in the groups of patients with mild and severe chronic kidney damage was 0.62 (0.40–0.77) and 0.66 (0.54–0.88), respectively. In statistical analysis considering a cut-off value of 0.70 for RI, no significant relationship was found between the RI and the degree of chronic kidney damage ($P > 0.050$).

Renal function is related to the hemodynamic status of the cortical microvasculature.[22,23] It is difficult to evaluate the blood flow in cortical microvessels representing kidney perfusion due to low flow velocity and the small diameter of the vessels.[24] The use of CDUS has been a standard approach for follow-up after renal transplantation and in evaluating possible complications.[25-27] However, CDUS fails to evaluate microvasculature and low flow velocity.[28] Additionally, PDUS is considered sensitive in evaluating the status of microvasculature but is affected by tissue movements.[27] The SMI technique, capable of differentiating tissue movement from low flow velocity due to improved Doppler algorithms and wall filters, was introduced into clinical practice in 2014.[29]

In a study comparing the SMI technique with conventional ultrasound techniques in evaluating the cortical microvasculature of the kidney, Gao et al.[9] reported significant differences in the renal capsule-vessel distances measured by the SMI, PDUS, and CDUS techniques ($P < 0.001$). They found lower capsule-to-vessel distance in SMI than in the other two techniques. The capsule-to-vessel distance was reportedly 1.06 ± 0.43 mm in SMI, 2.11 ± 1.0 mm in PDUS, and 4.5 ± 2.1 in CDUS. Consequently, they suggested that the SMI technique was superior to other Doppler ultrasound techniques in demonstrating the cortical microvasculature of the kidney in healthy individuals.[9] In the present study, 64 renal transplant recipients

Table 4. The diagnostic tests, AUC, and the cut-off values in renal transplant recipients with low and high CADI scores

Doppler technique	AUC	Sensitivity	Specificity	*Cut-off	*P*
CDUS	0.722	0.634	0.652	1.90	0.003
PDUS	0.740	0.683	0.696	1.15	0.002
cSMI	0.712	0.561	0.870	0.80	0.005
mSMI	0.718	0.561	0.826	0.65	0.004

*The cut-off values in millimeters for the distance between the kidney capsule and the vessel measured by Doppler techniques. AUC, area under the curve; CADI, chronic allograft damage index; CDUS, color Doppler ultrasound; cSMI, color superb microvascular imaging; mSMI, monochrome superb microvascular imaging; PDUS, power Doppler ultrasound.

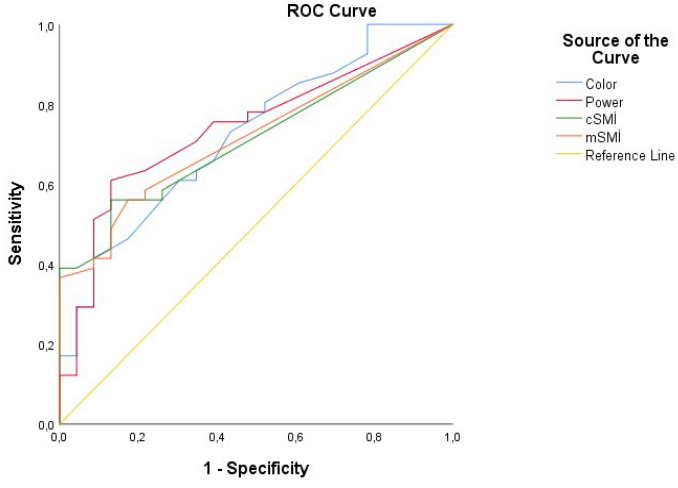

Figure 2. The receiver operating characteristic curve demonstrating the efficacies of Doppler ultrasound examinations in predicting the chronic allograft damage index score. ROC, receiver operating characteristic; cSMI, color superb microvascular imaging; mSMI, monochrome superb microvascular imaging.

underwent CDUS, PDUS, cSMI, and mSMI on the same day as the kidney biopsy procedure. The distance between the kidney capsule and vascular structures could not be observed in four patients using CDUS, 20 patients using PDUS, 34 patients using cSMI, and 36 patients using mSMI. The cSMI technique demonstrated the vascular structures in the subcapsular area, which could not be observed in 30 patients using CDUS and 14 patients using PDUS. The SMI technique also detected all those patients detected by CDUS and PDUS. The mean capsule-to-vessel distance was 2.44 ± 2.0 mm in CDUS, 1.34 ± 1.2 mm in PDUS, 0.99 ± 1.8 mm in cSMI, and 0.86 ± 1.8 mm in mSMI. The distance of the end vessels of the cortex to the kidney capsule represents the sensitivity of color Doppler images in depicting small vessels because vessels closer to the kidney capsule are smaller. In other words, the shorter distance of the cortical end vessel to the kidney capsule indicates the higher sensitivity of SMI in depicting smaller vessels in the cortex near to the kidney capsule. Similar to the studies in the literature, the present study reports the superiority of the SMI technique to CDUS and PDUS in demonstrating the cortical microvasculature of the kidney.

A transplanted kidney functions for approximately 10–20 years, and chronic kidney damage remains among the unresolved problems leading to the loss of kidney function. The histopathological alterations precede kidney function loss, and histopathological scoring of the damage in a functional kidney provides beneficial information to clinicians in predicting allograft prognosis.[4]

Nankivell et al.[30] suggest that the distance between the margin of the vascular structures and the kidney capsule can predict chronic allograph nephropathy. The present study is the first to evaluate the use of Doppler examinations and the SMI technique in predicting the CADI score. Patients were divided into two groups: patients with a CADI score of 4 or less and those with a CADI score of greater than 4. The reasons for selecting a CADI score of 4 as the cut-off level were the reports in the literature showing a significantly higher rate of graft loss and significantly higher serum creatinine levels in patients with a CADI score of greater than 4 compared with patients with a CADI score of 4 or less.[5,10,12,13] The capsule-to-vessel distance measured by CDUS, PDUS, and SMI significantly differed between the patients with low and high CADI scores, and it is found that these methods can effectively predict the score. The authors consider that this finding will enable the provision of appropriate therapy to transplant recipients at a high risk of graft dysfunction before graft loss occurs and will inform the clinicians about the necessity of performing a renal biopsy in patients anticipated to have a high CADI score.

There are some limitations in the present study. One of the main limitations was the small sample size. To find a significant difference between the CADI groups, the sample size was calculated using the G power statistical program. According to this; with Power (test power) 0.80, Effect size 0.8, and Type-1 error (α) 0.05 (for 2 groups, CADI≤4 and CADI >4), a total of 42 patients with "minimum 21 observations (patient data)" in each group determined as ". However, to ensure the number of samples and to keep the Power value high, the number of samples was increased and "CADI ≤4 n = 23" and "CADI >4 n = 41" patient data were obtained in our study. The power recalculated based on this new sample size was 91%. The scarcity of patients with a CADI ≤4 was the most important limitation of the sample size. When the contribution of Doppler ultrasound and the SMI technique in predicting the degree of rejection is investigated in a larger study sample, more appropriate cut-off values and optimal sensitivity and specificity values can be achieved. Another limitation of the study was that only one investigator was involved in collecting the study data, making it impossible to evaluate interobserver variability.

The flow data of the vessels are presented in color codes and gray-scale maps in the cSMI technique. In the mSMI technique, flow signals are received from small and large vessels, and a gray-scale flow map is created by removing the background data.[8] In comparing the cSMI and mSMI techniques, a limiting factor for measuring the distance between the kidney capsule and the vessel is the fact that gray-scale data are eliminated in the mSMI technique.

Furthermore, the time elapsed since transplantation was different between the study patients. The authors consider that the effectiveness of the SMI and conventional Doppler ultrasound techniques would be increased in future studies, provided that the study period covers a certain period after transplantation.

In conclusion, the present study is the first in the literature to demonstrate the utility of the capsule-to-vessel distance measured by Doppler ultrasound examinations and the SMI technique in predicting the CADI score, which is closely related to graft survival and function. When compared with CDUS and PDUS, the SMI technique was found to be superior in delineating the cortical microvasculature of the kidney.

The statistical analyses in the present study suggest that both conventional Doppler ultrasound examinations and the SMI technique prove sensitive in predicting the CADI score. The study also finds that the SMI technique is the most specific in ruling out severe chronic rejection. There is, however, a need for further national and international studies involving larger patient groups.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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