

Supplement A1. Patient demographics.

Demographics and Clinical Features	
Site	71 Site 1, 28 Site 2
Biopsy Type	
Indication Biopsy	N=71
Protocol Biopsy	N=28
Sex(F/M)	35/64
Race	
Black/African American	46
White	20
Asian	8
Other/Unreported	25
Age (years; mean $\pm$ std, range)	50.1 $\pm$ 13.1 (22-82)
Weight (kg; mean $\pm$ std, range)	79.1 $\pm$ 16.9 (44.5-129.0)
BMI (kg/m ² , mean $\pm$ std, range)	27.4 $\pm$ 4.7 (17.4-38.2)
Allograft Volume (mL, mean $\pm$ std, range)	238 $\pm$ 72 (100-573)
Living Donor	N=43;
Donor Age (years; mean $\pm$ std, range)	44.6 $\pm$ 12.0 (21-68)
Deceased Donor	N=54;
Donor Age (years; mean $\pm$ std, range)	37.25 $\pm$ 12.6 (5-70)*
Kidney Donor Profile Index (KDPI, a measure of likelihood of graft failure after deceased donor kidney transplant; lower is better)	All KDPI < 85
Time since transplant (months; mean $\pm$ std, median, range)	42.9 $\pm$ 61.9, 20.1, (1.3-266)
U-Protein (mg/24hr; mean $\pm$ std, median, range)	140.6 $\pm$ 257.8, 71.4, (1.0-1513), 39 unknown
Calcium Inhibitor status	89 Tacrolimus, 4 Cyclosporine, 6 none
Donor Specific Antibodies status	80 negative, 12 positive, 7 unknown
eGFR (CKD-EPI 2021 mL/min/1.73m²; mean$\pm$std, range)	47.5 $\pm$ 21.3 (8.0-112.0)
eGFR $\leq$ 45 (mL/min/1.73m ² ; mean $\pm$ std, range)	N=46; 29.9 $\pm$ 8.4 (8.0-44.0)
eGFR> 45 (mL/min/1.73m ² ; mean $\pm$ std, range)	N=53; 62.7 $\pm$ 16.9 (45.0-112.0)
Interstitial Fibrosis/ Tubular Atrophy (IFTA)	
IFTA = 0	39
IFTA = 2	22
IFTA = 4	20
IFTA = 6	18
Categories	
eGFR>45 & IFTA=0	25
eGFR>45 & IFTA>0	25
eGFR $\leq$ 45 & IFTA=0	14
eGFR $\leq$ 45 & IFTA>0	35

*one pediatric donor

Supplement A2. Demographic features for the subset of 19 cases used in interobserver comparison.

Demographics and Clinical Features	
Site	14 Site 1, 5 Site 2
Biopsy Type	
Indication Biopsy	N=14
Protocol Biopsy	N=5
Sex(F/M)	8/11
Age (years; mean±std, range)	48.7±12.9 (25-69)
BMI (kg/m ² , mean±std, range)	28.3±4.5 (20.7-38.2)
Living Donor	N=10;
Deceased Donor	N=9; All KDPI < 85
Time since transplant (months; mean±std, median, range)	53.2±62.7, 23.4, (2.0-205)
U-Protein (mg/24hr; mean±std, median, range)	87.7±168.7 (1.0-702), 19.5, 2 unknown
Calcium Inhibitor status	18 Tacrolimus, 0 Cyclosporine, 1 none
Donor Specific Antibodies status	17 negative, 1 positive, 1 unknown
eGFR (CKD-EPI 2021 mL/min/1.73m²; mean±std, range)	40.2±18.0 (14.0-85.0)
eGFR≤ 45 (mL/min/1.73m ² ; mean±std, range)	N=12; 29.4±10.4 (14.0-42.0)
eGFR> 45 (mL/min/1.73m ² ; mean±std, range)	N=7; 58.5±12.7 (45.0-85.0)
Interstitial Fibrosis/ Tubular Atrophy (IFTA)	
IFTA = 0	8
IFTA = 2	4
IFTA = 4	2
IFTA = 6	5
Categories	
eGFR>45 & IFTA=0	4
eGFR>45 & IFTA>0	3
eGFR≤45 & IFTA=0	4
eGFR≤45 & IFTA>0	8

Site 1 patients were recruited from kidney transplant recipients with either acute or chronic allograft injury undergoing percutaneous clinically indicated biopsies, while Site 2 patients recruited kidney transplant recipients undergoing percutaneous clinically indicated biopsies and patients undergoing surveillance biopsy in the setting of donor specific antibody positivity. The decision to perform percutaneous allograft biopsy was based on the clinician's adjudication of each patient's clinical presentation regarding institute specific management or prognostication. Mean age and gender distribution ($\chi^2 = 1.25, p = 0.263$) were not significantly different between the two sites though Site 2 recruited patients with a statistically higher average BMI. As Site 1 and Site 2 recruited different subsets of kidney transplant recipients, in line with expectations Site 2 had a greater number of low IFTA scored patients, and a higher average eGFR due to the surveillance biopsies.

Supplement B. Supplementary Tables: Fibrosis Scores

Tabular Data of Spectral Diffusion, IVIM, and ADC values between (a) no fibrosis (IFTA=0) vs. fibrosis (IFTA >0), (b) no fibrosis vs. mild/moderate fibrosis (IFTA=1-4), and (c) no fibrosis vs. severe fibrosis (IFTA=5-6). Features that returned a raw $p < 0.05$ are colored red. Features that passed the Benjamini-Hochberg correction with $fpr = 0.20$ are highlighted yellow.

IFTA 0 vs IFTA > 0				
feature	IFTA=0 (n=39)	IFTA>0 (n=60)	p-value	bh p-value
spectral mean f vascular	0.07± 0.03	0.06± 0.05	0.026	0.062
spectral median f vascular	0.03± 0.04	0.03± 0.05	0.522	0.535
spectral std f vascular	0.09± 0.03	0.08± 0.04	0.031	0.064
spectral mean f tubule	0.09± 0.06	0.07± 0.05	0.012	0.051
spectral median f tubule	0.03± 0.06	0.02± 0.04	0.316	0.383
spectral std f tubule	0.14± 0.05	0.11± 0.06	0.018	0.062
spectral mean f tissue	0.75± 0.07	0.79± 0.09	0.027	0.062
spectral median f tissue	0.77± 0.07	0.82± 0.11	0.045	0.09
spectral std f tissue	0.18± 0.04	0.15± 0.06	0.004	0.051
spectral mean D vascular	89.31± 35.1	68.89± 46.48	0.022	0.062
spectral median D vascular	76.02± 83.41	55.57± 76.41	0.328	0.386
spectral std D vascular	85.05± 8.62	70.11± 26.88	0.011	0.051
spectral mean D tubule	7.58± 4.82	5.41± 4.66	0.010	0.051
spectral median D tubule	2.54± 4.93	2.0± 4.58	0.375	0.416
spectral std D tubule	12.48± 5.65	9.05± 5.09	0.004	0.051
spectral mean D tissue	2.13± 0.3	2.21± 0.32	0.181	0.233
spectral median D tissue	1.97± 0.3	2.05± 0.33	0.270	0.338
spectral std D tissue	0.95± 0.36	0.87± 0.57	0.067	0.116
spectral mean fD vascular	1.52± 0.29	1.67± 0.29	0.013	0.051
spectral mean fD tubule	0.29± 0.77	0.17± 0.43	0.363	0.415
spectral mean fD tissue	4.87± 6.55	4.37± 8.28	0.392	0.424
spectral median fD vascular	1.59± 0.29	1.74± 0.26	0.003	0.051
spectral median fD tubule	0.78± 0.73	0.53± 0.79	0.008	0.051
spectral median fD tissue	6.74± 4.58	5.68± 7.24	0.017	0.062
IVIM mean D	1.6± 0.15	1.65± 0.15	0.070	0.117
IVIM median D	1.61± 0.14	1.65± 0.15	0.150	0.214
IVIM std D	0.25± 0.07	0.21± 0.06	0.009	0.051
IVIM mean D*	35.39± 15.38	33.06± 22.52	0.142	0.211
IVIM median D*	20.96± 9.76	21.13± 18.8	0.156	0.214
IVIM std D*	35.29± 18.25	30.64± 22.16	0.129	0.198
IVIM mean f	0.22± 0.04	0.22± 0.03	0.505	0.532
IVIM median f	0.21± 0.04	0.2± 0.03	0.160	0.214
IVIM std f	0.07± 0.01	0.07± 0.02	0.543	0.543
IVIM mean (1-f)D	1.24± 0.14	1.29± 0.12	0.025	0.062
IVIM median (1-f)D	1.26± 0.14	1.32± 0.12	0.028	0.062
IVIM mean fD*	7.71± 3.37	7.23± 5.42	0.055	0.1
IVIM median fD*	4.35± 1.82	4.38± 4.26	0.011	0.051
mean ADC	1.7± 0.2	1.75± 0.17	0.0668	0.115
median ADC	1.69± 0.19	1.75± 0.17	0.0378	0.081
std ADC	0.3± 0.11	0.26± 0.07	0.1290	0.191

No fibrosis (IFTA=0) vs mild/moderate fibrosis (IFTA=1-4)

feature	IFTA=0 (n=39)	IFTA=1-4 (n=40)	p-value	bh p-value
spectral mean f vascular	0.07± 0.03	0.05± 0.04	0.020	0.075
spectral median f vascular	0.03± 0.04	0.03± 0.04	0.405	0.415
spectral std f vascular	0.09± 0.03	0.07± 0.04	0.031	0.075
spectral mean f tubule	0.09± 0.06	0.07± 0.06	0.038	0.075
spectral median f tubule	0.03± 0.06	0.02± 0.04	0.334	0.382
spectral std f tubule	0.14± 0.05	0.11± 0.07	0.060	0.109
spectral mean f tissue	0.75± 0.07	0.79± 0.1	0.037	0.075
spectral median f tissue	0.77± 0.07	0.82± 0.1	0.036	0.075
spectral std f tissue	0.18± 0.04	0.16± 0.07	0.037	0.075
spectral mean D vascular	89.31± 35.1	68.02± 43.78	0.031	0.075
spectral median D vascular	76.02± 83.41	53.85± 76.17	0.322	0.382
spectral std D vascular	85.05± 8.62	71.61± 27.67	0.094	0.156
spectral mean D tubule	7.58± 4.82	5.73± 5.08	0.030	0.075
spectral median D tubule	2.54± 4.93	2.35± 5.33	0.436	0.436
spectral std D tubule	12.48± 5.65	9.18± 5.2	0.008	0.075
spectral mean D tissue	2.13± 0.3	2.21± 0.28	0.232	0.299
spectral median D tissue	1.97± 0.3	2.04± 0.3	0.243	0.304
spectral std D tissue	0.95± 0.36	0.9± 0.66	0.117	0.167
spectral mean fD vascular	1.52± 0.29	1.67± 0.26	0.013	0.075
spectral mean fD tubule	0.29± 0.77	0.2± 0.49	0.402	0.415
spectral mean fD tissue	4.87± 6.55	3.72± 6.9	0.332	0.382
spectral median fD vascular	1.59± 0.29	1.74± 0.23	0.004	0.075
spectral median fD tubule	0.78± 0.73	0.59± 0.9	0.025	0.075
spectral median fD tissue	6.74± 4.58	5.06± 5.69	0.018	0.075
IVIM mean D	1.6± 0.15	1.65± 0.15	0.097	0.156
IVIM median D	1.61± 0.14	1.65± 0.15	0.170	0.226
IVIM std D	0.25± 0.07	0.21± 0.06	0.007	0.075
IVIM mean D*	35.39± 15.38	30.49± 15.36	0.102	0.156
IVIM median D*	20.96± 9.76	19.14± 9.74	0.152	0.21
IVIM std D*	35.29± 18.25	28.84± 20.07	0.090	0.156
IVIM mean f	0.22± 0.04	0.21± 0.03	0.352	0.386
IVIM median f	0.21± 0.04	0.2± 0.03	0.112	0.166
IVIM std f	0.07± 0.01	0.06± 0.02	0.357	0.386
IVIM mean (1-f)D	1.24± 0.14	1.3± 0.12	0.017	0.075
IVIM median (1-f)D	1.26± 0.14	1.32± 0.12	0.025	0.075
IVIM mean fD*	7.71± 3.37	6.61± 3.93	0.038	0.075
IVIM median fD*	4.35± 1.82	3.91± 2.4	0.010	0.075
mean ADC	1.7± 0.2	1.75± 0.17	0.078	0.133
median ADC	1.69± 0.19	1.76± 0.16	0.033	0.077
std ADC	0.3± 0.11	0.26± 0.08	0.057	0.107

No fibrosis (IFTA=0) vs severe fibrosis (IFTA=5-6)

feature	IFTA=0 (n=39)	IFTA=5-6 (n=20)	p-value	bh p-value
spectral mean f vascular	0.07± 0.03	0.06± 0.06	0.236	0.497
spectral median f vascular	0.03± 0.04	0.04± 0.06	0.943	0.967
spectral std f vascular	0.09± 0.03	0.08± 0.04	0.189	0.445
spectral mean f tubule	0.09± 0.06	0.06± 0.05	0.027	0.188
spectral median f tubule	0.03± 0.06	0.02± 0.04	0.506	0.651
spectral std f tubule	0.14± 0.05	0.11± 0.04	0.028	0.188
spectral mean f tissue	0.75± 0.07	0.79± 0.09	0.128	0.39
spectral median f tissue	0.77± 0.07	0.82± 0.12	0.291	0.518
spectral std f tissue	0.18± 0.04	0.14± 0.03	0.002	0.064
spectral mean D vascular	89.31± 35.1	70.64± 51.4	0.113	0.39
spectral median D vascular	76.02± 83.41	59.01± 76.77	0.570	0.651
spectral std D vascular	85.05± 8.62	67.13± 24.95	0.003	0.064
spectral mean D tubule	7.58± 4.82	4.76± 3.62	0.024	0.188
spectral median D tubule	2.54± 4.93	1.32± 2.33	0.476	0.651
spectral std D tubule	12.48± 5.65	8.81± 4.86	0.036	0.205
spectral mean D tissue	2.13± 0.3	2.22± 0.39	0.298	0.518
spectral median D tissue	1.97± 0.3	2.05± 0.37	0.575	0.651
spectral std D tissue	0.95± 0.36	0.8± 0.28	0.124	0.39
spectral mean fD vascular	1.52± 0.29	1.66± 0.33	0.124	0.39
spectral mean fD tubule	0.29± 0.77	0.11± 0.25	0.506	0.651
spectral mean fD tissue	4.87± 6.55	5.66± 10.39	0.743	0.803
spectral median fD vascular	1.59± 0.29	1.74± 0.32	0.055	0.273
spectral median fD tubule	0.78± 0.73	0.42± 0.45	0.021	0.188
spectral median fD tissue	6.74± 4.58	6.91± 9.51	0.150	0.399
IVIM mean D	1.6± 0.15	1.64± 0.14	0.179	0.445
IVIM median D	1.61± 0.14	1.65± 0.15	0.329	0.548
IVIM std D	0.25± 0.07	0.22± 0.06	0.132	0.39
IVIM mean D*	35.39± 15.38	38.21± 31.78	0.543	0.651
IVIM median D*	20.96± 9.76	25.11± 29.1	0.405	0.623
IVIM std D*	35.29± 18.25	34.24± 25.46	0.532	0.651
IVIM mean f	0.22± 0.04	0.22± 0.03	0.974	0.974
IVIM median f	0.21± 0.04	0.21± 0.04	0.586	0.651
IVIM std f	0.07± 0.01	0.07± 0.02	0.885	0.932
IVIM mean (1-f)D	1.24± 0.14	1.28± 0.12	0.269	0.513
IVIM median (1-f)D	1.26± 0.14	1.31± 0.11	0.212	0.47
IVIM mean fD*	7.71± 3.37	8.47± 7.41	0.370	0.592
IVIM median fD*	4.35± 1.82	5.33± 6.44	0.136	0.39
mean ADC	1.7± 0.2	1.74± 0.18	0.224	0.496
median ADC	1.69± 0.19	1.74± 0.18	0.242	0.496
std ADC	0.3± 0.11	0.28± 0.06	0.773	0.831

mild/moderate (IFA=1-4) vs severe fibrosis (IFTA=5-6)				
feature	IFTA=1-4 (n=40)	IFTA=5-6 (n=20)	p-value	bh p-value
spectral mean f vascular	0.05± 0.04	0.06± 0.06	0.610	0.981
spectral median f vascular	0.03± 0.04	0.04± 0.06	0.638	0.981
spectral std f vascular	0.07± 0.04	0.08± 0.04	0.784	0.981
spectral mean f tubule	0.07± 0.06	0.06± 0.05	0.900	0.981
spectral median f tubule	0.02± 0.04	0.02± 0.04	0.906	0.981
spectral std f tubule	0.11± 0.07	0.11± 0.04	0.707	0.981
spectral mean f tissue	0.79± 0.1	0.79± 0.09	0.826	0.981
spectral median f tissue	0.82± 0.1	0.82± 0.12	0.638	0.981
spectral std f tissue	0.16± 0.07	0.14± 0.03	0.442	0.981
spectral mean D vascular	68.02± 43.78	70.64± 51.4	0.919	0.981
spectral median D vascular	53.85± 76.17	59.01± 76.77	0.754	0.981
spectral std D vascular	71.61± 27.67	67.13± 24.95	0.297	0.981
spectral mean D tubule	5.73± 5.08	4.76± 3.62	0.683	0.981
spectral median D tubule	2.35± 5.33	1.32± 2.33	0.919	0.981
spectral std D tubule	9.18± 5.2	8.81± 4.86	0.913	0.981
spectral mean D tissue	2.21± 0.28	2.22± 0.39	0.962	0.981
spectral median D tissue	2.04± 0.3	2.05± 0.37	0.838	0.981
spectral std D tissue	0.9± 0.66	0.8± 0.28	0.975	0.981
spectral mean fD vascular	1.67± 0.26	1.66± 0.33	0.471	0.981
spectral mean fD tubule	0.2± 0.49	0.11± 0.25	0.981	0.981
spectral mean fD tissue	3.72± 6.9	5.66± 10.39	0.649	0.981
spectral median fD vascular	1.74± 0.23	1.74± 0.32	0.551	0.981
spectral median fD tubule	0.59± 0.9	0.42± 0.45	0.707	0.981
spectral median fD tissue	5.06± 5.69	6.91± 9.51	0.906	0.981
IVIM mean D	1.65± 0.15	1.64± 0.14	0.838	0.981
IVIM median D	1.65± 0.15	1.65± 0.15	0.950	0.981
IVIM std D	0.21± 0.06	0.22± 0.06	0.355	0.981
IVIM mean D*	30.49± 15.36	38.21± 31.78	0.583	0.981
IVIM median D*	19.14± 9.74	25.11± 29.1	0.778	0.981
IVIM std D*	28.84± 20.07	34.24± 25.46	0.583	0.981
IVIM mean f	0.21± 0.03	0.22± 0.03	0.397	0.981
IVIM median f	0.2± 0.03	0.21± 0.04	0.388	0.981
IVIM std f	0.06± 0.02	0.07± 0.02	0.323	0.981
IVIM mean (1-f)D	1.3± 0.12	1.28± 0.12	0.442	0.981
IVIM median (1-f)D	1.32± 0.12	1.31± 0.11	0.490	0.981
IVIM mean fD*	6.61± 3.93	8.47± 7.41	0.562	0.981
IVIM median fD*	3.91± 2.4	5.33± 6.44	0.452	0.981
mean ADC	1.75± 0.17	1.74± 0.18	0.814	0.981
median ADC	1.76± 0.16	1.74± 0.18	0.572	0.981
std ADC	0.26± 0.08	0.28± 0.06	0.246	0.981

Supplement C. Supplementary Tables: AllograftGroups

Tabular Data of Spectral Diffusion, IVIM, and ADC values between allografts with normal/stable function ($\text{eGFR} \geq 45 \text{ ml/min/1.73m}^2$) and no fibrosis ($\text{IFTA} = 0$) versus (a) normal/stable function and fibrosis ($\text{IFTA} > 0$), (b) impaired function and no fibrosis, and (c) impaired function ($\text{eGFR} < 45 \text{ ml/min/1.73m}^2$) and fibrosis. Features that returned a raw $p < 0.05$ are colored red. Features that passed the Benjamini-Hochberg correction with $\text{fpr} = 0.20$ are highlighted yellow

**Normal/stable function
& No fibrosis vs.
normal/stable function &
Fibrosis**

Feature	Normal/stable function		p-value	bh p-value
	Healthy Allograft (n=25)	& Fibrosis (n=25)		
spectral mean f vascular	0.07± 0.03	0.05± 0.04	0.035	0.106
spectral median f vascular	0.03± 0.03	0.02± 0.04	0.388	0.408
spectral std f vascular	0.09± 0.03	0.07± 0.05	0.025	0.091
spectral mean f tubule	0.1± 0.06	0.07± 0.06	0.064	0.128
spectral median f tubule	0.03± 0.05	0.02± 0.04	0.290	0.363
spectral std f tubule	0.14± 0.05	0.12± 0.08	0.218	0.291
spectral mean f tissue	0.73± 0.07	0.8± 0.1	0.047	0.11
spectral median f tissue	0.76± 0.08	0.84± 0.1	0.010	0.055
spectral std f tissue	0.18± 0.04	0.16± 0.08	0.093	0.169
spectral mean D vascular	86.0± 34.6	66.73± 46.62	0.133	0.197
spectral median D vascular	76.24± 82.63	45.84± 71.37	0.290	0.363
spectral std D vascular	84.1± 8.49	69.02± 29.3	0.171	0.236
spectral mean D tubule	6.92± 2.85	5.46± 5.33	0.031	0.102
spectral median D tubule	2.25± 3.35	2.58± 6.22	0.367	0.408
spectral std D tubule	11.8± 3.92	8.69± 5.37	0.018	0.074
spectral mean D tissue	2.18± 0.22	2.2± 0.33	0.946	0.946
spectral median D tissue	1.99± 0.24	2.09± 0.36	0.388	0.408
spectral std D tissue	1.0± 0.28	0.83± 0.31	0.101	0.169
spectral mean fD vascular	1.51± 0.26	1.74± 0.31	0.006	0.048
spectral mean fD tubule	0.2± 0.45	0.2± 0.52	0.327	0.385
spectral mean fD tissue	4.62± 5.98	3.41± 6.83	0.327	0.385
spectral median fD vascular	1.6± 0.24	1.76± 0.31	0.037	0.106
spectral median fD tubule	0.72± 0.53	0.62± 1.0	0.061	0.128
spectral median fD tissue	6.26± 4.14	4.96± 5.93	0.056	0.124
IVIM mean D	1.6± 0.16	1.69± 0.17	0.047	0.11
IVIM median D	1.61± 0.16	1.69± 0.16	0.082	0.157
IVIM std D	0.26± 0.06	0.2± 0.06	0.002	0.025
IVIM mean D*	33.38± 13.26	28.54± 13.64	0.165	0.236
IVIM median D*	19.85± 6.81	17.95± 8.04	0.097	0.169
IVIM std D*	33.89± 17.42	26.14± 16.29	0.128	0.197
IVIM mean f	0.23± 0.04	0.21± 0.04	0.357	0.408
IVIM median f	0.22± 0.04	0.2± 0.03	0.128	0.197
IVIM std f	0.07± 0.01	0.06± 0.03	0.479	0.491
IVIM mean (1-f)D	1.23± 0.15	1.33± 0.14	0.014	0.063
IVIM median (1-f)D	1.25± 0.15	1.35± 0.13	0.013	0.063
IVIM mean fD*	7.43± 2.73	6.23± 3.6	0.043	0.11
IVIM median fD*	4.25± 1.21	3.7± 2.04	0.010	0.055
mean ADC	1.68± 0.18	1.78± 0.18	0.025	0.091
median ADC	1.66± 0.17	1.79± 0.18	0.011	0.081
std ADC	0.33± 0.12	0.25± 0.08	0.017	0.082

**Normal/stable function
& No fibrosis vs. Impaired
function & No fibrosis**

Feature	Impaired function & Fibrosis		p-value	bh p-value
	Healthy Allograft (n=25)	(n=14)		
spectral mean f vascular	0.07± 0.03	0.07± 0.03	0.639	0.977
spectral median f vascular	0.03± 0.03	0.03± 0.04	0.884	0.977
spectral std f vascular	0.09± 0.03	0.1± 0.04	0.884	0.977
spectral mean f tubule	0.1± 0.06	0.08± 0.06	0.447	0.971
spectral median f tubule	0.03± 0.05	0.03± 0.07	0.747	0.977
spectral std f tubule	0.14± 0.05	0.13± 0.05	0.725	0.977
spectral mean f tissue	0.73± 0.07	0.77± 0.07	0.429	0.971
spectral median f tissue	0.76± 0.08	0.8± 0.06	0.208	0.971
spectral std f tissue	0.18± 0.04	0.18± 0.05	0.792	0.977
spectral mean D vascular	86.0± 34.6	95.22± 35.23	0.447	0.971
spectral median D vascular	76.24± 82.63	75.62± 84.78	0.977	0.977
spectral std D vascular	84.1± 8.49	86.76± 8.58	0.334	0.971
spectral mean D tubule	6.92± 2.85	8.76± 6.94	0.838	0.977
spectral median D tubule	2.25± 3.35	3.07± 6.87	0.682	0.977
spectral std D tubule	11.8± 3.92	13.71± 7.69	0.539	0.971
spectral mean D tissue	2.18± 0.22	2.04± 0.38	0.057	0.971
spectral median D tissue	1.99± 0.24	1.95± 0.38	0.266	0.971
spectral std D tissue	1.0± 0.28	0.85± 0.47	0.043	0.971
spectral mean fD vascular	1.51± 0.26	1.55± 0.33	0.792	0.977
spectral mean fD tubule	0.2± 0.45	0.46± 1.12	0.725	0.977
spectral mean fD tissue	4.62± 5.98	5.32± 7.43	0.953	0.977
spectral median fD vascular	1.6± 0.24	1.57± 0.35	0.619	0.977
spectral median fD tubule	0.72± 0.53	0.88± 0.99	0.838	0.977
spectral median fD tissue	6.26± 4.14	7.61± 5.17	0.558	0.971
IVIM mean D	1.6± 0.16	1.6± 0.12	0.558	0.971
IVIM median D	1.61± 0.16	1.6± 0.11	0.861	0.977
IVIM std D	0.26± 0.06	0.23± 0.07	0.198	0.971
IVIM mean D*	33.38± 13.26	39.0± 18.01	0.412	0.971
IVIM median D*	19.85± 6.81	22.94± 13.28	0.977	0.977
IVIM std D*	33.89± 17.42	37.79± 19.41	0.539	0.971
IVIM mean f	0.23± 0.04	0.21± 0.04	0.254	0.971
IVIM median f	0.22± 0.04	0.2± 0.04	0.230	0.971
IVIM std f	0.07± 0.01	0.07± 0.01	0.520	0.971
IVIM mean (1-f)D	1.23± 0.15	1.26± 0.12	0.349	0.971
IVIM median (1-f)D	1.25± 0.15	1.28± 0.11	0.349	0.971
IVIM mean fD*	7.43± 2.73	8.23± 4.24	0.977	0.977
IVIM median fD*	4.25± 1.21	4.52± 2.57	0.364	0.971
mean ADC	1.68± 0.18	1.73± 0.23	0.464	0.971
median ADC	1.66± 0.17	1.74± 0.22	0.160	0.971
std ADC	0.33± 0.12	0.26± 0.06	0.074	0.971

**Normal/stable function
& No fibrosis vs. Impaired
function & Fibrosis**

Feature	Impaired function		p-value	bh p-value
	Healthy Allograft (n=25)	& Fibrosis (n=35)		
spectral mean f vascular	0.07± 0.03	0.06± 0.05	0.205	0.391
spectral median f vascular	0.03± 0.03	0.04± 0.06	0.899	0.922
spectral std f vascular	0.09± 0.03	0.08± 0.04	0.311	0.498
spectral mean f tubule	0.1± 0.06	0.06± 0.05	0.016	0.166
spectral median f tubule	0.03± 0.05	0.02± 0.05	0.449	0.599
spectral std f tubule	0.14± 0.05	0.1± 0.05	0.023	0.166
spectral mean f tissue	0.73± 0.07	0.78± 0.09	0.039	0.196
spectral median f tissue	0.76± 0.08	0.81± 0.11	0.136	0.302
spectral std f tissue	0.18± 0.04	0.15± 0.03	0.004	0.13
spectral mean D vascular	86.0± 34.6	70.44± 46.31	0.148	0.311
spectral median D vascular	76.24± 82.63	62.52± 79.09	0.584	0.679
spectral std D vascular	84.1± 8.49	70.9± 24.98	0.056	0.21
spectral mean D tubule	6.92± 2.85	5.38± 4.13	0.058	0.21
spectral median D tubule	2.25± 3.35	1.59± 2.81	0.405	0.559
spectral std D tubule	11.8± 3.92	9.31± 4.87	0.056	0.21
spectral mean D tissue	2.18± 0.22	2.22± 0.31	0.647	0.712
spectral median D tissue	1.99± 0.24	2.02± 0.3	0.934	0.934
spectral std D tissue	1.0± 0.28	0.9± 0.69	0.006	0.13
spectral mean fD vascular	1.51± 0.26	1.62± 0.26	0.124	0.293
spectral mean fD tubule	0.2± 0.45	0.15± 0.35	0.467	0.603
spectral mean fD tissue	4.62± 5.98	5.06± 9.11	0.658	0.712
spectral median fD vascular	1.6± 0.24	1.73± 0.22	0.029	0.166
spectral median fD tubule	0.72± 0.53	0.47± 0.58	0.019	0.166
spectral median fD tissue	6.26± 4.14	6.19± 8.01	0.156	0.313
IVIM mean D	1.6± 0.16	1.62± 0.12	0.264	0.459
IVIM median D	1.61± 0.16	1.62± 0.13	0.564	0.679
IVIM std D	0.26± 0.06	0.22± 0.06	0.025	0.166
IVIM mean D*	33.38± 13.26	36.29± 26.67	0.713	0.751
IVIM median D*	19.85± 6.81	23.41± 23.39	0.495	0.619
IVIM std D*	33.89± 17.42	33.86± 25.05	0.595	0.679
IVIM mean f	0.23± 0.04	0.22± 0.03	0.311	0.498
IVIM median f	0.22± 0.04	0.2± 0.03	0.107	0.267
IVIM std f	0.07± 0.01	0.07± 0.02	0.356	0.528
IVIM mean (1-f)D	1.23± 0.15	1.27± 0.1	0.076	0.233
IVIM median (1-f)D	1.25± 0.15	1.29± 0.11	0.101	0.267
IVIM mean fD*	7.43± 2.73	7.94± 6.32	0.380	0.543
IVIM median fD*	4.25± 1.21	4.87± 5.24	0.089	0.254
mean ADC	1.68± 0.18	1.72± 0.16	0.2640	0.44
median ADC	1.66± 0.17	1.72± 0.16	0.1243	0.293
std ADC	0.33± 0.12	0.27± 0.07	0.1522	0.298

Supplement D. Supplementary Tables: Interobserver Repeatability

Tabular Data of interclass correlation coefficient and corresponding F-stat and 95% CI for all parameters. The coefficient of variability is also provided. There is a low ICC for median fD tubule (ICC=0.03), due to low agreement of median f tubule ICC (0.04), as many f tubules are zero.

Interobserver Repeatability

Feature	ICC value	F-stat	95% CI	CoV% value
spectral mean f vascular	0.75	7.1	[0.46 0.9]	25.914
spectral median f vascular	0.78	8.29	[0.52 0.91]	62.053
spectral std f vascular	0.44	2.57	[-0. 0.74]	22.751
spectral mean f tubule	0.35	2.1	[-0.11 0.69]	40.850
spectral median f tubule	0.04	1.09	[-0.41 0.48]	75.356
spectral std f tubule	0.55	3.42	[0.14 0.8]	30.253
spectral mean f tissue	0.47	2.78	[0.03 0.76]	5.148
spectral median f tissue	0.35	2.06	[-0.12 0.68]	4.457
spectral std f tissue	0.54	3.38	[0.13 0.8]	16.285
spectral mean D vascular	0.64	4.53	[0.27 0.84]	18.854
spectral median D vascular	0.38	2.22	[-0.08 0.7]	56.568
spectral std D vascular	0.11	1.24	[-0.35 0.53]	7.396
spectral mean D tubule	0.58	3.81	[0.19 0.82]	23.631
spectral median D tubule	0.4	2.34	[-0.05 0.72]	65.052
spectral std D tubule	0.76	7.3	[0.48 0.9]	18.990
spectral mean D tissue	0.21	1.55	[-0.25 0.6]	7.001
spectral median D tissue	0.45	2.65	[0.01 0.75]	5.724
spectral std D tissue	0.3	1.87	[-0.16 0.66]	15.868
spectral mean fD vascular	0.42	2.46	[-0.03 0.73]	9.325
spectral mean fD tubule	0.25	1.68	[-0.21 0.63]	50.211
spectral mean fD tissue	0.71	5.95	[0.39 0.88]	65.881
spectral median fD vascular	0.4	2.32	[-0.06 0.72]	10.330
spectral median fD tubule	0.03	1.06	[-0.42 0.47]	79.441
spectral median fD tissue	0.79	8.64	[0.54 0.91]	34.441
IVIM mean D	0.76	7.39	[0.48 0.9]	2.237
IVIM median D	0.67	5.12	[0.33 0.86]	2.421
IVIM std D	0.89	16.89	[0.73 0.96]	6.088
IVIM mean D*	0.81	9.48	[0.57 0.92]	11.101
IVIM median D*	0.55	3.43	[0.14 0.8]	10.649
IVIM std D*	0.92	23.97	[0.8 0.97]	15.268
IVIM mean f	0.66	4.82	[0.3 0.85]	5.694
IVIM median f	0.63	4.38	[0.26 0.84]	5.517
IVIM std f	0.32	1.92	[-0.15 0.67]	14.865
IVIM mean (1-f)D	0.78	8.2	[0.52 0.91]	3.114
IVIM median (1-f)D	0.71	6.01	[0.4 0.88]	3.140
IVIM mean fD*	0.73	6.52	[0.43 0.89]	13.477
IVIM median fD*	0.56	3.58	[0.16 0.81]	11.270
mean ADC	0.84	11.3	[0.63 0.93]	2.868
median ADC	0.79	8.74	[0.54 0.92]	3.069
std ADC	0.62	4.26	[0.24 0.83]	11.220

Supplement E. Spectral Diffusion and Multi-Component Diffusion fD

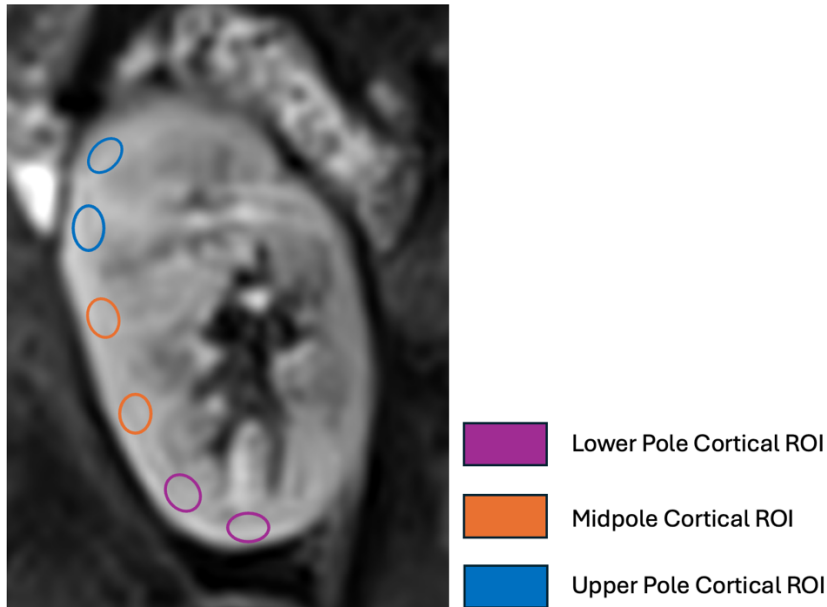
Spectral peaks were sorted into (1) vascular, (2) tubular, and (3) tissue parenchyma components based on diffusion coefficient. A spectrum with peaks in each of the three components listed above would be a tri-exponential, as follows.

$$f_{\text{vasc}}e^{-bD_{\text{vasc}}} + f_{\text{tubule}}e^{-bD_{\text{tubule}}} + f_{\text{tissue}}e^{-bD_{\text{tissue}}}$$

In this work, these three components are ordered from left to right from fastest to slowest diffusion coefficient. The peaks were sorted as follows: the largest peak closest to $1.8 \times 10^{-3} \text{ mm}^2/\text{s}$, a tissue diffusion literature value between two-component and three-component rigid fits[8], was considered the tissue parenchyma peak if below $50 \times 10^{-3} \text{ mm}^2/\text{s}$. Beyond that, peaks were sorted as $0.8 \leq \text{tissue} < 5 \leq \text{tubule} < 50 \leq \text{vascular}$ for diffusion coefficients in units of $10^{-3} \text{ mm}^2/\text{s}$. The boundary of $5 \times 10^{-3} \text{ mm}^2/\text{s}$ for tissue parenchyma is higher than $2 \times 10^{-3} \text{ mm}^2/\text{s}$ to include the boundary of the edge of the tissue peak, even though the peak's maximum is closer to $2 \times 10^{-3} \text{ mm}^2/\text{s}$ (Figure 1). If more than one peak fell within a certain range, the peaks were combined weighted by their respective volume fractions for statistical analysis of diagnostic ability. Peaks with mean $D < 0.8$ were excluded due to $b=800$ being too low to capture very slow diffusion reliably[11].

fD of each peak was treated as a flow proxy. With a Gaussian approximation of each physiologic component[49], fD can estimate the amount of flow of any distinct diffusion component, without capillary network assumptions of conventional IVIM perfusion. Further, as the signal labeling and readout are in the same plane[50, 51], fD as flow is calculated without needing an AIF[52-55]. Therefore, fD may provide information on tissue diffusion, tubular flow, and perfusion without the complexities of selecting an aortic AIF[56] or ASL delay time. Further, non-vascular flow that may not have an AIF, such as diffusion in the renal tubules, can still be imaged with spectral diffusion. Example ROIs drawn on b_0 are shown below.

Figure E1. Example six color-coded cortical ROIs on b_0 of patient with normal/stable function and no fibrosis (47y/M).



Supplement F. Clinical notes

Table F1. Further clinical notes and diagnoses for the 14 patients with allografts that showed impaired function but no fibrosis in this preliminary study.

Patient 1	Active antibody mediated rejection, Chronic active antibody mediated rejection, Chronic active T-cell mediated rejection Grade II, Suspicious or borderline for acute T-cell mediated rejection, Transplant glomerulopathy, moderate glomerulitis, multilayering of interstitial capillary basement membranes, and focally positive (2+) C4d staining of interstitial capillaries, Arteriolar hyalinosis. protein droplets in podocytes positive for albumin and kappa
Patient 2	Active antibody mediated rejection, Acute/active T-cell mediated rejection Grade IB, Acute/active T-cell mediated rejection Grade III, Acute/active vascular rejection Grade III, Recurrent disease, Focal segmental glomerulosclerosis, NOS.
Patient 3	C4d deposition without evidence of rejection, Acute tubular injury, Focal crystals consistent with calcium phosphate, Mild arteriosclerosis. There is no significant tubular or interstitial staining for IgG, IgA, IgM, C3, C1q, Kappa and Lambda light chains, albumin, and fibrinogen.
Patient 4	Acute tubular injury, Thin glomerular basement membranes
Patient 5	Acute tubular injury. There is no significant glomerular, tubular, or interstitial staining for IgG, IgA, IgM, C3, C1q, Kappa and Lambda light chains, albumin, and fibrinogen.
Patient 6	Mild glomerulitis, Mild interstitial lymphoid infiltrates. a scarred region of the glomerulus shows nonspecific smudgy staining for IgM, C3 and C1q
Patient 7	None
Patient 8	1+ C3 seen in vessels, Polyomavirus Nephritis (01 64)
Patient 9	Mild acute tubular injury
Patient 10	negative CD4
Patient 11	None
Patient 12	Mild glomerulitis
Patient 13	None
Patient 14	Mild glomerulitis