Fractional Mean Transit Time in Transplanted Kidneys Studied by Technetium-99m-DTPA: Comparison of Clinical and Biopsy Findings

Sonoo Mizuiri, Ikuko Hayashi, Masaaki Takano, Ryuzo Ban, Takehiro Ohara, Yasuhito Sasaki and Akira Hasegawa

Department of Nephrology and Central Radio Nuclear Medicine Laboratory, Toho University, Tokyo; Shimadzu Corporation, Kyoto; and Department of Radiology, Tokyo University, Tokyo, Japan

To determine the usefulness of fractional mean transit time (MTT) in the differential diagnosis of postrenal transplant complications, ^{99m}Tc-DTPA was used to evaluate differences in MTT between the outer zone (cortical nephron) and middle zone (juxtamedullary nephron, calcyces and cortical nephron) of the kidney. It is well known that acute rejection is characterized by delayed cortical transit time, whereas cortical nephron function is well maintained and juxtamedullary function is impaired after renal ischemia. **Methods:** Technetium-99m-DTPA fractional MTT was determined by deconvolution analysis of 89 renograms obtained within 5 days of the date of kidney graft biopsy and evaluation. **Results:** Outer zone MTT was significantly shorter than middle zone MTT in normals (2.7 ± 0.4 versus 3.0 ± 0.6 min, n = 22, $p < 0.001$), acute tubular necrosis (3.4 ± 1.1 versus 3.6 ± 1.4 min, n = 19, $p < 0.01$), chronic rejection (3.9 ± 1.5 versus 5.0 ± 2.3 min, n = 14, $p < 0.001$) and obstruction (4.1 ± 0.6 versus 8.9 ± 3.4 min, n = 13, $p < 0.001$). In contrast, outer zone MTT was significantly longer than middle zone MTT in acute rejection (4.8 ± 3.2 versus 4.2 ± 2.5 min, n = 21, $p < 0.05$). **Conclusion:** Fractional MTT was demonstrated to be useful in differentiating acute rejection and ATN in transplanted kidneys.

Key Words: fractional mean transit time; deconvolution analysis; ^{99m}Tc-DTPA; renal transplantation

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Gruenewald and Britton et al. reported a noninvasive means of measuring intrarenal flow distribution between cortical and juxtamedullary nephrons based on the fact that the long loops of Henle of juxtamedullary nephrons have a longer mean transit time (MTT) than the short loops of Henle of cortical nephrons (*1–5*). We thought that ^{99m}Tc-DTPA MTT might also differ between the outer zone (cortical nephron) and middle zone (juxtamedullary nephron, calyces and cortical nephron) of the kidney. It is well known that acute rejection is characterized by delayed cortical transit time (*6,7*), whereas cortical nephron function is well maintained and juxtamedullary function is impaired after renal ischemia (*8,9*).

This evidence prompted us to determine whether it is possible to differentiate postrenal transplant complications using fractional MTT, that is, outer zone MTT and middle zone MTT, by performing deconvolution analysis of ^{99m}Tc-DTPA renograms and comparing the results with clinical and pathological findings.

MATERIALS AND METHODS

We examined 89 renograms from 69 transplant recipients performed within 5 days of kidney graft biopsy between 1985 and 1992. Where more than one renogram had been performed following biopsy, only the renogram nearest to the date of biopsy was considered for this study. The biopsies were performed using a "Trucut" biopsy needle. The samples were examined by light microscopy, electron microscopy and immunofluorescence studies. All biopsy slides were examined by a pathologist who had no knowledge of the results from renograms. Materials which showed a combination of complications were excluded. The diagnosis was made pathologically, and materials which showed dual pathology were excluded. The diagnosis of obstruction, however, was made by ultrasonography and/or intravenous pyelography.

Renogram studies were performed using a large field of a gamma camera fitted with a low-energy collimator positioned over the patient in the supine position to include the transplanted kidney and abdominal aorta. After rapid intravenous injection of 185 MBq of ^{99m}Tc-DTPA into a medial antecubital vein, 64 × 64 resolution frames were recorded initially at 5-sec intervals for 90 sec, followed by 135 frames at 10-sec intervals to complete the 24-min study. An on-line Scintipac 2400 computer (Shimadzu) was programmed to record and process the data.

Aortic regions of interest (ROIs) were defined over the abdominal aorta just proximal to the bifurcation of the iliac artery best seen usually between 5 sec and 20 sec after injection). An image of the data obtained at 2 min was reconstructed and displayed, and ROIs were defined from this for the whole kidney and background region (Fig. 1A).

The inner zone was constructed from the 15-min image corresponding to the renal pelvis. It was then removed from the whole

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For correspondence or reprints contact: Sonoo Mizuiri, Dept. of Nephrology, Toho University School of Medicine, 6-11-1 Ohmori-Nishi, Ohta-ku, Tokyo 143, Japan.

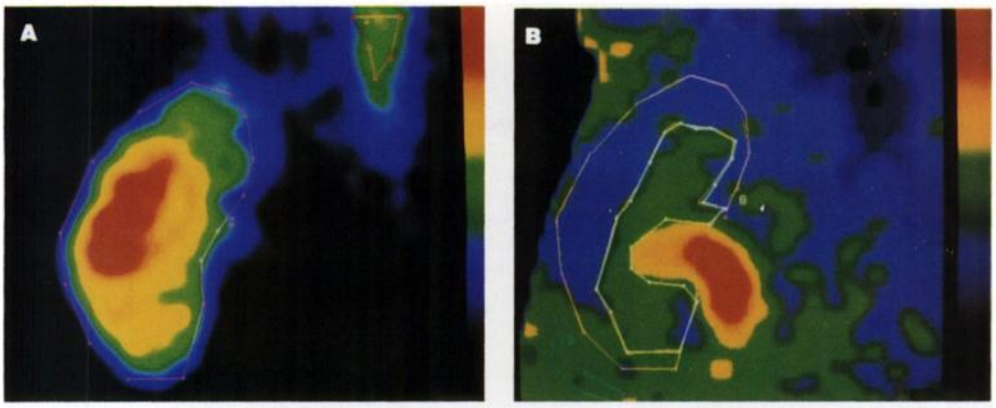

FIGURE 1. (A) A 2-min image in a standard renogram. (B) Mean time image and ROIs.

kidney image. The middle zone was outlined by computer construction of a mean time picture (*10*). In mean time, $\bar{t}$ is calculated for each element of the 64 × 64 matrix and displayed as the intensity variable in the formed image:

$$\bar{t} = \frac{\sum_i t_i \cdot N_i}{\sum_i N_i},$$

where N_i is the number of counts recorded between t_i and t_{i+1}. Due to the later arrival of activity, mean time may be expected to be greater for medullary and calyceal regions in comparison with parenchymal (cortical) regions.

It is then possible to obtain ROIs of the middle zone. The outer region was the substracted middle and inner zones from whole kidney, including mainly the cortical nephrons. Thus, ROIs from the three zones were placed on the graft (Fig. 1B). These zones are not specifically anatomical, but emphasize the dominant component in each zone to aid in subsequent mathematical analysis. The outer zone represents the cortical nephrons, the middle zone mainly contains the medullary and calyceal regions, as well as the cortical component from the over and underlying cortex (Fig. 2).

With the aortic curve representing renal input and the curves from the outer and middle zones delineated separately, deconvolution analysis by the direct matrix algorithm method was performed to determine activity retention in each zone. The early vascular component is then removed from these impulse retention functions by detecting the subsequent plateau level of the retention function followed by back extrapolation from the shoulder of this curve (*1–5*).

According to clinical and pathological diagnosis, post-transplant patients were categorized into five groups: normals (n = 22), acute rejection (n = 21), acute tubular necrosis (ATN) (n = 19), chronic rejection (n = 14) and obstruction (n = 13). MTT and the retention at zero time (H_0) value in the whole graft, outer zone MTT, middle zone MTT and serum creatinine levels during radionuclide evaluation were the parameters.

Values were expressed as mean ± s.d. Statistical significance of differences between groups was determined by Student's unpaired t-test; differences between outer and middle zone MTTs on the same renogram were determined by Student's paired t-test. Correlations between retention at zero time values of the whole graft and serum creatinine values were also obtained.

RESULTS

Clinical and pathological diagnosis obtained concurrent renography and fractional MTT computations are shown in Table 1.

MTTs of whole grafted kidneys (mean ± s.d.) were 3.0 ± 0.5 min in normals (n = 22), 4.2 ± 2.7 min in acute rejection (n = 21), 4.0 ± 1.3 min in ATN (n = 19), 4.6 ± 1.6 min in chronic rejection (n = 14) and 6.4 ± 1.5 min in obstruction (n = 13). MTTs of whole graft were significantly prolonged in acute rejection ($p < 0.02$), ATN ($p < 0.001$), chronic rejection ($p < 0.01$) and obstruction ($p <$

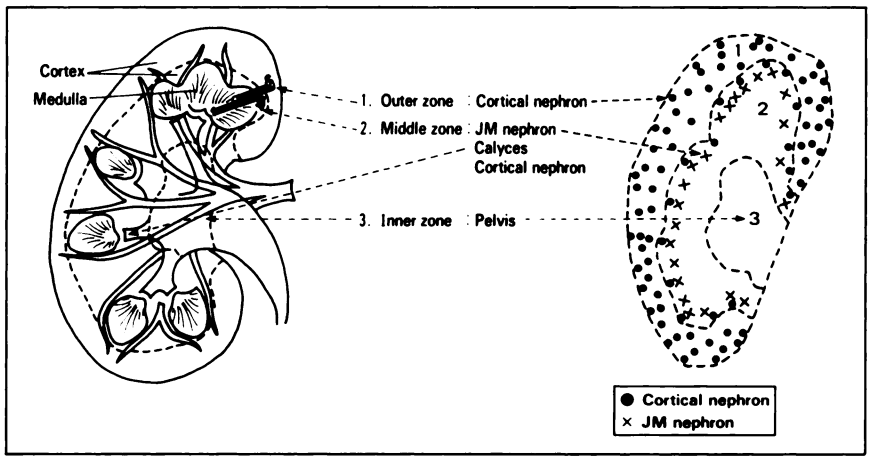

FIGURE 2. Selection of ROIs and anatomy.

TABLE 1
Clinical and Pathological Diagnosis at Time of Renography and Fractional MTT

Patient no.	Sex	Age at time of Tx	Postoperative days at renogram	Postoperative days at biopsy	S. creatinine at renogram (mg/dl)	Clinical diagnosis	Pathological diagnosisn	MTT (min) Whole graft	MTT (min) Outer zone	MTT (min) Middle zone
1	F	34	66	69	1.2	Normal	Normal	2.50	2.22	2.84
			1870		2.6	Chronic rejection	Chronic rejection	5.54	4.34	6.10
2	M	40	75	80	1.4	Normal	Normal	3.07	2.82	3.03
3	M	43	87	88	1.4	Normal	Normal	2.94	2.86	2.97
4	M	31	73	75	1.4	Normal	Normal	3.02	2.82	3.06
5	F	24	3	0	1.1	Normal	Normal	3.15	2.88	3.04
			7	6	3.9	Acute rejection	Acute rejection	2.19	2.24	2.16
6	M	35	378	373	1.1	Normal	Normal	2.36	2.09	2.41
7	M	36	30	33	1.4	Acute rejection?	Normal	2.68	2.61	2.68
8	M	17	4	0	1.1	Normal	Normal	3.23	3.13	3.25
9	M	22	5	0	1.2	Normal	Normal	3.75	3.67	3.68
10	M	24	45	47	1.5	Acute rejection?	Normal	2.89	2.85	2.94
11	M	40	85	85	1.4	Normal	Normal	3.44	2.94	3.56
12	M	51	4	0	1.4	Normal	Normal	1.93	1.91	1.93
13	M	13	65	69	1.2	Normal	Normal	2.81	2.47	2.76
14	M	38	5	0	1.1	Normal	Normal	3.66	3.05	3.95
15	F	33	4	0	0.9	Normal	Normal	3.08	2.72	2.95
16	F	39	5	0	1.3	Normal	Normal	2.92	2.89	2.99
17	M	26	4	0	1.3	Normal	Normal	2.38	2.35	2.38
18	M	28	5	0	1.5	Normal	Normal	3.69	3.05	3.75
19	M	21	4	0	1.6	Normal	Normal	1.84	1.73	1.81
20	M	27	4	0	1.6	Normal	Normal	3.35	3.34	3.48
21	F	35	4	0	1.1	Normal	Normal	3.15	2.84	3.37
22	M	24	5	0	1.6	Normal	Normal	3.46	2.78	3.72
23	F	45	6	8	3.4	Acute rejection	Acute rejection	5.90	6.22	5.58
			13	15	7.7	Acute rejection	Acute rejection	9.82	9.95	9.86
			1069	1074	2.0	Chronic rejection	Chronic rejection	3.45	3.29	3.64
24	M	38	46	49	1.8	Acute rejection	Acute rejection	2.83	2.89	2.70
25	F	31	32	32	1.5	Acute rejection	Acute rejection	2.17	2.25	2.19
26	F	27	7	9	3.3	Acute rejection	Acute rejection	2.57	2.69	2.30
			39	39	1.9	Acute rejection	Acute rejection	3.12	3.10	3.05
27	F	24	7	7	3.9	Acute rejection	Acute rejection	2.19	2.24	2.16
28	M	25	7	10	11.0	ATN	Acute rejection	5.59	6.39	5.14
			33	38	10.2	Acute rejection	Acute rejection	3.06	3.11	2.98
29	M	23	8		2.6	Acute rejection	Acute rejection	3.92	4.14	3.09
			30		2.3	Acute rejection	Acute rejection	2.31	2.27	2.27
30	M	37	5	0	4.3	ATN	Acute rejection	2.91	2.98	2.59
			7	6	4.3	Acute rejection	Acute rejection	5.64	5.70	5.57
31	M	50	8	8	1.6	ATN	ATN	3.87	3.69	3.95
			99	100	5.7	Acute rejection	Acute rejection	13.28	14.74	10.79
32	M	23	25	28	2.1	Acute rejection	Acute rejection	3.84	3.92	3.57
			1456	1451	2.9	Chronic rejection	Chronic rejection	5.11	4.14	6.04
33	F	24	7	7	1.7	Acute rejection	Acute rejection	1.95	2.01	1.97
34	M	48	7	6	5.4	Acute rejection	Acute rejection	4.13	4.31	4.02
35	M	45	91	91	3.2	Acute rejection	Acute rejection	3.23	3.42	3.13
36	F	27	8	9	4.0	Acute rejection	Acute rejection	4.70	4.83	4.23
37	F	24	7	6	7.1	Acute rejection	Acute rejection	2.79	3.05	2.53
38	M	40	3	0	9.5	ATN	ATN	6.41	6.09	6.77

0.001) compared with normals. MTTs of the whole graft in obstruction were significantly longer than acute rejection ($p < 0.01$), ATN ($p < 0.001$) and chronic rejection ($p < 0.01$). However, MTTs of whole grafts were not significantly different between acute rejection, ATN and chronic rejection. Retention at time zero values of whole grafted kidney (mean ± s.d.) was 1422 ± 667 in normals (n = 22), 631 ± 551 in acute rejection (n = 21), 462 ± 225 in ATN (n = 19), 791 ± 463 in chronic rejection (n = 14) and 1274 ± 577 in obstruction (n = 13). Retention at time zero values were lower in acute rejection ($p < 0.001$), ATN ($p < 0.001$) and chronic rejection ($p < 0.01$) than in normals. The ATN value was significantly ($p < 0.05$) lower than that of chronic rejection. As illustrated in Figure 3,

TABLE 1
Continued

Patient no.	Sex	Age at time of Tx	Postoperative days at renogram	Postoperative days at biopsy	S. creatinine at renogram (mg/dl)	Clinical diagnosis	Pathological diagnosis	MTT (min) Whole graft	Outer zone	Middle zone
39	M	15	270	266	2.2	Chronic rejection	Chronic rejection	5.90	5.83	6.05
		*17	3	0	8.1	ATN	ATN	4.25	4.31	4.34
			12	7	11.8	ATN	ATN	5.90	5.83	6.05
40	M	54	3	0	6.7	ATN	ATN	3.13	2.98	3.09
41	M	36	7	9	6.3	ATN	ATN	2.31	2.59	2.23
			39	42	3.1	ATN	ATN	3.56	3.35	3.45
42	M	28	5	0	2.6	ATN	ATN	2.15	2.07	2.24
43	M	23	10	8	2.6	Acute rejection?	ATN	5.11	4.72	5.44
44	M	21	6	7	5.6	Acute rejection?	ATN	3.20	3.03	3.42
45	M	18	26	28	2.2	ATN	ATN	2.92	2.99	3.05
46	M	30	1	0	13.8	ATN	ATN	6.79	6.41	8.54
			6	6	15.5	ATN?	ATN	3.43	3.30	3.74
47	M	37	5	0	8.3	ATN	ATN	5.03	4.89	5.01
48	M	29	5	0	10.0	ATN	ATN	2.40	2.36	2.41
49	M	17	15	15	8.1	ATN	ATN	5.90	5.83	6.05
50	M	48	5	0	6.3	ATN	ATN	4.00	3.45	3.47
			20	20	2.6	ATN + Acute rejection?	ATN	2.92	2.81	2.83
51	M	24	21	0	4.5	ATN	ATN	3.42	3.45	3.47
52	M	27	1607	1612	5.1	Recurrence of FGS	Chronic rejection	6.17	5.79	6.96
53	M	23	1095	1095	2.3	Chronic rejection	Chronic rejection	3.33	3.29	3.30
54	M	11	1095	1090	2.0	Chronic rejection	Chronic rejection	3.97	3.32	4.36
			1730	1725	2.8	Chronic rejection	Chronic rejection	4.28	3.83	4.57
55	F	12	1825	1828	4.7	Chronic rejection	Chronic rejection	9.30	8.06	10.85
56	F	29	910	805	3.5	Chronic rejection	Chronic rejection	5.50	3.64	6.73
			1326	1327	6.3	Chronic rejection	Chronic rejection	4.71	4.04	5.24
57	F	36	812	813	3.0	Chronic rejection	Chronic rejection	5.54	4.34	6.10
58	M	20	925	923	5.7	Chronic rejection	Chronic rejection	2.47	2.35	2.71
59	M	36	485	486	3.1	Chronic rejection	Chronic rejection	3.56	3.35	3.45
60	M	12	60		0.7	Obstruction		4.02	2.86	3.99
61	M	7	7		0.5	Obstruction		5.84	4.01	7.95
62	F	9	5		0.7	Obstruction		4.67	2.96	5.26
			12		0.7	Obstruction		5.45	4.89	6.25
63	F	24	21		1.0	Obstruction		8.30	4.90	12.18
			86		1.0	Obstruction		7.23	4.33	10.29
64	F	40	43		2.8	Obstruction		6.87	3.98	8.27
65	M	16	337		1.3	Obstruction		6.59	3.51	8.84
66	F	13	15		0.7	Obstruction		8.96	4.99	14.31
			18		0.7	Obstruction		9.01	5.00	13.99
67	M	57	357		1.6	Obstruction		6.25	3.76	7.59
68	M	57	344		1.1	Obstruction		5.45	3.69	5.14
69	M	50	33		1.5	Obstruction		5.25	4.36	5.37

* Second transplantation. Tx = renal transplantation, FGS = focal segmental glomerular sclerosis.

differentiation between acute rejection and ATN was impossible after combining the MTT of whole grafted kidneys and retention at time zero values. Differentiation between acute rejection and chronic rejection was also difficult by this method.

The mean ± s.d. of serum creatinine values was 1.3 ± 0.2 mg/dl in normals (n = 20), 4.4 ± 2.7 mg/dl in acute rejection (n = 21), 6.8 ± 3.9 mg/dl in ATN, 3.4 ± 1.4 mg/dl in chronic rejection (n = 14) and 1.1 ± 0.6 mg/dl for obstruction (n = 13). Correlation between retention at time zero values of whole kidney and serum creatinine values was significant (n = 89, r = −0.530, $p < 0.001$) (Fig. 4).

Fractional MTTs in 89 renograms studied by ^{99m}Tc-DTPA imaging transplanted recipients are shown in Table 2. The middle zone MTT was significantly longer than the outer zone MTT in normals ($p < 0.02$), ATN ($p < 0.01$), chronic rejection ($p < 0.001$) and obstruction ($p < 0.001$). However, the outer zone MTT was significantly longer than the middle zone MTT in acute rejection (4.4 ± 2.9 min versus 3.9 ± 2.3 min, n = 21, $p < 0.02$). With fractional

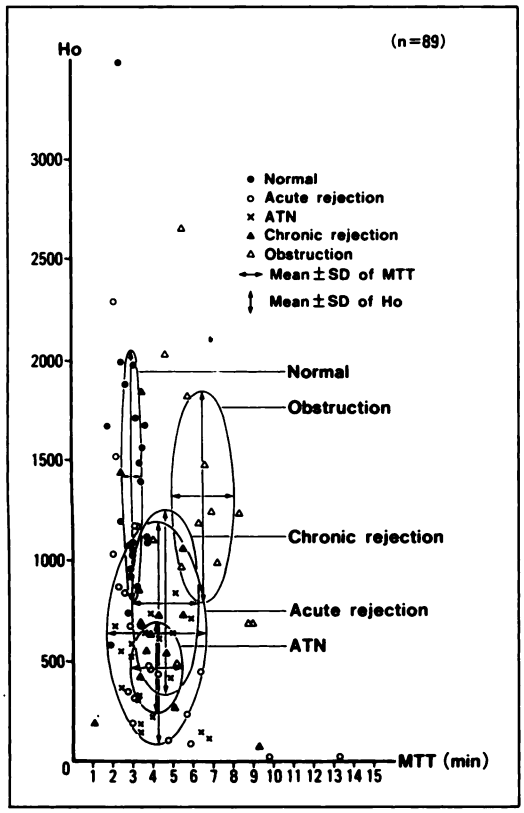

FIGURE 3. Whole graft MTT and H_0 values in 89 renograms from transplant recipients.

MTT, differentiation between acute rejection and ATN was easily made (Fig. 5). Furthermore, acute rejection and chronic rejection could also be differentiated by fractional MTT.

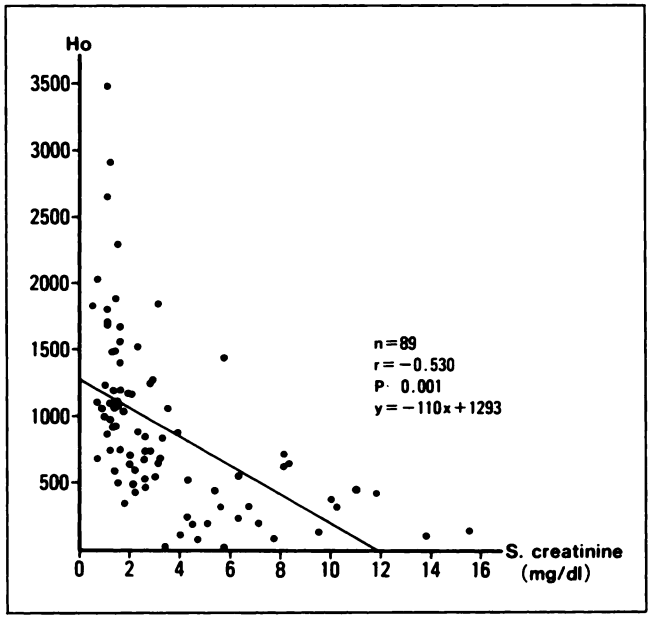

FIGURE 4. Significant correlation is observed between whole graft H_0 values and serum creatinine values.

TABLE 2
Outer Versus Middle Zone MTT in 89 Renograms Studied with ^{99m}Tc-DTPA in Transplanted Recipients

	n	Outer zone MTT (min)	Middle zone MTT (min)
Normals	22	2.7 ± 0.4	3.0 ± 0.6‡
Acute rejection	21	4.8 ± 3.2	4.2 ± 2.5*
Acute tubular necrosis	19	3.4 ± 1.1	3.6 ± 1.4†
Chronic rejection	14	3.9 ± 1.5	5.0 ± 2.3‡
Obstruction	13	4.1 ± 0.6	8.9 ± 3.4‡

The values are means ± s.d.
*$p < 0.05$; †$p < 0.01$; ‡$p < 0.001$ vs. outer zone MTT.

DISCUSSION

There is continuing controversy over the value of renograms in the differential diagnosis of rejection and ATN. In a comparison with biopsy findings, Notghi et al. reported that differentiation between acute rejection and ATN is possible with or without a rapid peak in counts for ^{99m}Tc-DTPA renograms (*11*). Some clinicians have expressed greater doubt about the value of isotope investigations for the diagnosis of rejection and ATN (*12,13*). Recent extensive reviews (*14–16*) on radionuclide evaluation of renal transplants concluded that it is necessary to study both perfusion and function to differentiate post-transplant complications. Poor renal function is seen as decreased uptake of the agent. This may be coupled with relatively good perfusion as in ATN or with poor perfusion as in acute

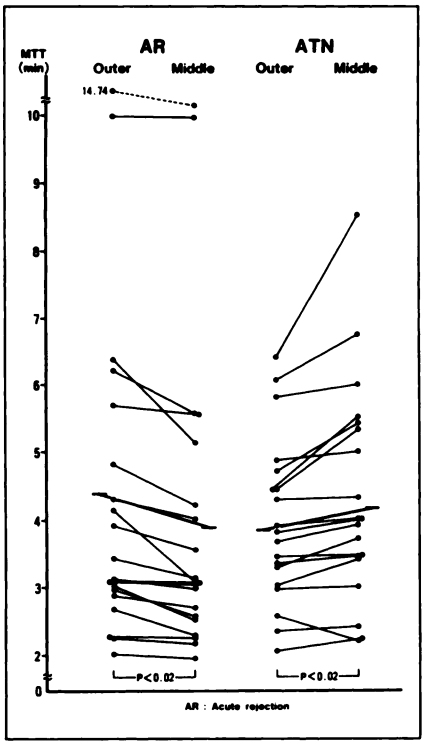

FIGURE 5. Middle zone MTT is longer than outer zone MTT in ATN and in normals. However, outer zone MTT is longer than middle zone MTT in acute rejection. Thick bars show means ± s.d.

rejection. However, it is often difficult to separate these complications qualitatively.

Deconvolution is a mathematical quantitative technique that overcomes tracer input curve effects on renograms. MTT reflects both renal perfusion and parenchymal function (*16,17*). There is agreement that whole kidney MTT is significantly prolonged in obstruction and moderately prolonged in acute rejection and ATN with overlap (*14,17*), findings that are consistent with our results. In contrast, there is disagreement about whole kidney MTT in chronic rejection. There are reports that numerical index changes (including renal transit time) by ^{99m}Tc-DTPA in chronic rejection are indistinguishable from acute rejection (*18*), whereas other reports conclude that MTT in chronic rejection is normal (*17*). Our study shows that MTT is prolonged in chronic rejection. Clinically, it is not difficult to separate acute rejection and chronic rejection because of the rate of onset of rejection.

The images in a standard renogram are a composite figure of a three-dimensional structure at one point, but not a functional image displaying the mean tracer time for each pixel. As shown in Figure 1A, the image in a standard renogram is not always suitable for drawing a middle zone ROI, while the mean time image is a functional image that displays MTT to each pixel. Thus, pixels with a long MTT have high intensity. In practice, this image is useful in delineating the middle zone. Alternatively, factor analysis of renograms may be useful in delineating the middle zone, although we did not try this approach.

Cortical transit time reportedly shows the same characteristics as whole kidney MTT (*14*). However, there is no reported comparison between outer zone (cortical) and middle zone (mainly juxtamedullary) MTT. In comparing fractional MTT between the outer and middle zones, middle zone MTT was found to be longer than outer zone MTT in normals, ATN, chronic rejection and obstruction, as expected. In our study, outer zone MTT, on the other hand, is prolonged when compared with middle zone MTT in acute rejection. The glomerulus and proximal convoluted tubule are more likely to be located in the outer zone as opposed to the middle zone measurement in this study. For delayed cortical transit time (*6,7*), our study demonstrated prolonged outer zone MTT in acute rejection. For ATN, the microsphere technique demonstrated that surface nephron function is well maintained after renal ischemia, which predicts a more pronounced deficiency in medullary than outer cortical blood flow (*8,19*). Prolonged middle zone MTT in ATN in our study may be ascribed to a pronounced deficiency in medullary flow in ATN.

A finding from several reports conflict with our data: namely, intrarenal kinetic changes in renal ischemia are qualitatively and quantitatively similar to those observed in acute rejection (*13*). This discrepancy may be due in part to the inclusion in these reports of cases proven both pathologically and otherwise. We evaluated those findings with concurrent renal biopsy findings and excluded cases indicating dual pathology. We believe that prolonged outer zone MTT in comparison with middle zone MTT is a characteristic feature of acute rejection which is not observed in other postrenal transplant complications. The retention at time zero values of whole kidney correlated significantly with serum creatinine values in our study. Piepsz et al. reported that retention at time zero values correlated with glomerular filtration rate (*17*). In our study, retention at time zero values were lower in acute rejection, ATN and chronic rejection, but were not significantly different in obstruction when compared with normals. It is thought that retention at time zero values is also helpful in estimating renal dysfunction severity.

We conclude that fractional MTT was useful in differentiating acute rejection and ATN in transplanted kidneys.

REFERENCES

1. Gruenewald SM, Nimmon CC, Nawaz MK, Britton KE. A noninvasive gamma camera technique for the measurement of intrarenal flow distribution in man. *Clin Sci* 1981;61:385–389.
2. Nimmon CC, Lee TY, Britton KE, Gruenewald SM. Practical applications of deconvolution techniques to dynamic studies. In: *Medical radionuclide imaging*. Vienna: International Atomic Energy Agency; 1981:367–387.
3. Nimmon CC, Lee TY, Britton KE, Gruenewald SM, Henry JA, Nawaz MK. Intrarenal distribution of blood flow: development of a gamma camera technique using I-123-OIH and its validation in man. In: Jokes AM, Constable AR, Brown NJG, Tauxe WN, eds. *Radionuclides in nephrology*. London: Academic Press; 1982:55–63.
4. Britton KE. Radioisotopic renal function studies in essential hypertension. *Cardiology* 1985;72:22–29.
5. Britton KE, Nawaz MK, Nimmon CC, et al. Total and intrarenal flow distribution in healthy subjects. Technique, acute effects of ibopamine and indoramin. *Nephron* 1986;43:265–273.
6. Tourville DR, Kim DU, Viscuso R, et al. Anticipation of renal transplant failure by postanastomosis biopsy and immunofluorescence. *Transplant Proc* 1977;9:91–95.
7. Anaise D, Oster ZH, Atkins HL, et al. Cortex perfusion index: a sensitive detector of acute rejection crisis in transplanted kidneys. *J Nucl Med* 1986;27:1697–1701.
8. Mason J, Welsch J, Takabatake T. Disparity between surface and deep nephron function early after renal ischemia. *Kidney Int* 1983;24:27–36.
9. Brazis M, Rosen S, Epstein FH. Acute renal failure. In: Brenner BM, Rector FC, eds. *The kidney*, 4th edition. Philadelphia; Saunders; 1991:1008–1009.
10. Britton KE, Nimmon CC, Whitfield HN, et al. The evaluation of obstructive nephropathy by means of parenchymal functions. In: Hollenberg NK, Lange S, eds. *Radionuclides in nephrology*. New York: George Thiem Verlag Stuttgart; 1980:164–172.
11. Notghi A, Merrick MV, Anderton JL, Yates PA. Value of the gamma camera renogram in the differential diagnosis of acute tubular necrosis and rejection in the early post-transplant period. Comparison with biopsy findings. *Br J Radiol* 1989;63:594–599.
12. Munro I, Fox R, Sharp D. Imaging the transplanted kidney [Editorial]. *Lancet* 1986;i:781–783.
13. Magnusson G, Lewander R, Lundgren CT, Sarby B, Svensson L. The intrarenal kinetics of hippuran in acute rejection of renal allograft. In: *Contrib Nephrol*. Basel: Karger; 1990:123–126.
14. Dubovsky EV, Russell CD. Radionuclide evaluation of renal transplants. *Semin Nucl Med* 1988;13:181–198.
15. Hilson AJW. The renal transplant perfusion index: where are we now? *Eur J Nucl Med* 1991;18:227–228.
16. Dunn EK. Radioisotopic evaluation of renal transplants. *Urol Radiol* 1992; 14:115–126.
17. Piepsz A, Ham HR, Erbschman F, Hall M. A cooperative study on the clinical value of dynamic renal scanning with deconvolution analysis. *Br J Radiol* 1982;55:419–433.
18. Rutland MD. A comprehensive analysis of renal DTPA studies II. Renal transplant evaluation. *Nucl Med Commun* 1985;6:21–30.
19. Norllén BJ, Engberg A, Källskog O, Wolgast M. Intrarenal hemodynamics in transplanted rat kidney. *Kidney Int* 1978;14:1–9.