Assessment of Individual Renal Function Using ^{99m}Tc -MAG₃ Renography

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Abstract. *Background/Aim:* This study performed ^{99m}Tc -MAG₃ renal scintigraphy on rabbit kidneys and evaluated its ability to identify obstructive or non-obstructive kidneys. *Materials and Methods:* Renal function was assessed during a four-week post-obstruction period by obtaining planar images of ^{99m}Tc -MAG₃ activity following an ear vein injection. The individual renal function was evaluated by renal scintigraphy in conjunction with histopathological and morphological examinations. *Results:* The renal perfusion of ^{99m}Tc -MAG₃ in the right kidney with a ureteral obstruction decreased with time. The width, height, and cortical thickness of the obstructed right kidney were significantly larger than those of the left kidney. A histopathological examination four weeks after the ureteral obstruction revealed a typical pattern of urinary tract obstruction, including multiple tubules, enlargement of the interstitial area, and cytoplasmic vacuoles. *Conclusion:* ^{99m}Tc -MAG₃ renal scintigraphy provides the kidney shape and size and can identify potential obstructive and non-obstructive kidneys in rabbits.

Urinary tract obstruction (UTO) is a condition of urination that can lead to progressive renal dysfunction. It is commonly associated with dysuria, is a frequent cause of kidney damage (1), and can result from a wide range of congenital, intraluminal, parietal, and extrinsic disorders that affect the urinary tract. Renal function should be assessed in both the early stages and during the follow-up of UTO (2).

Hydronephrosis (HN) is a condition in which one or both kidneys grow and swell when urine collects inside the kidneys and can result from several diseases. The conditions

often associated with unilateral HN include acute/chronic unilateral obstructive uropathy, ureter obstruction due to scars, tumors and uroliths, vesicoureteric reflux illness, and kidney stones.

Biochemical and histopathological assays are used to diagnose and characterize renal damage. Blood and urine tests can measure the overall kidney function but not the individual kidney function. The best indicator of the kidney function is believed to be the glomerular filtration rate (GFR). However, the direct measurement of GFR is not feasible because the filtration process occurs simultaneously in millions of glomeruli (3). Renal function is revealed by diagnostic imaging methods, such as magnetic resonance imaging, computed tomography (CT), positron emission tomography (PET), venous pyelography, and renal or abdominal ultrasonography (3). Despite this, these methods cannot evaluate the functional level of individual kidneys. In patients with suspected renal disease, intravenous contrast urography may provide more information on the functionality, but this is a laborious procedure, and the x-ray contrast may be nephrotoxic.

Under normal conditions, animals have sufficient renal function to survive with only one functioning kidney. Unfortunately, this is not always the case for animals with kidney damage. In some cases, the ability to measure the individual renal function is important because such cases may include the prospect of nephrotomy or nephrectomy (4). An assessment of the individual renal function can have a significant impact on the plan to surgically remove kidney stones or the entire kidney damaged by an infection or tumor (5). Non-invasive means of determining renal function in individual kidneys may be advantageous during planning for medical management or surgical intervention of renal diseases.

Renal nuclear medicine imaging techniques offer a combination of information on the morphological aspects of the kidneys, and their functionality (4). ^{99m}Tc -labelled radiopharmaceuticals are highly suitable for kidney disorders, because of their superior imaging qualities, reasonable price, and excellent availability (6). MAG₃ can be labeled with ^{99m}Tc , making it a very suitable tracer for imaging procedures.

Nephrography is often performed to determine the differential renal function of patients undergoing or being

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evaluated for urologic surgery (2). The principle of renal scintigraphy is based on the intravenous administration of radiopharmaceuticals accumulated and excreted by the kidneys. Radiopharmaceuticals can be detected externally with a gamma camera (1). The renogram monitors the arrival and release of radiopharmaceuticals in a dynamic sequence, allowing an estimation of the renal function. Non-invasive means for determining the individual renal function may be advantageous for the medical management or surgical intervention of renal disease (3). Quantitative renal scintigraphy can assess the renal function that may persist after such surgical procedures (7).

Functional and morphologic studies with renal scintigraphic scans play important roles in diagnosing and following up various renal disorders (8). ^{99m}Tc -DMSA renography is considered the standard method for assessing the renal cortex for over 40 years (9). Some physicians have reported ^{99m}Tc -MAG₃ as an alternative to ^{99m}Tc -DMSA in most renal disorders in pediatric patients (1). Up to 90% of ^{99m}Tc -MAG₃ is excreted mainly by tubular secretion, and the rest is excreted from the blood by glomerular filtration. A high percentage of the injected ^{99m}Tc -MAG₃ is bound to the plasma proteins, and is mainly reversible. This study examined the normal or abnormal renal function by performing ^{99m}Tc -MAG₃ scintigraphy using a rabbit model. Here, ^{99m}Tc -MAG₃ was used as a radiopharmaceutical to image the cortical kidney. In addition, histopathological and morphological examinations of the rabbit kidney were performed in parallel to support the renal scintigraphy findings.

Materials and Methods

Experimental animals. Twelve healthy male New Zealand white rabbits (age: 12 weeks, body weight: 3.1-3.2 kg) were divided randomly into two groups of six animals each: saline-injected control and ^{99m}Tc -MAG₃-injected groups. Each rabbit was maintained in a separate cage in an air-conditioned room (temperature $20\pm 2^\circ\text{C}$, humidity 40~60%) with illumination between 08:00 and 20:00 at the Laboratory Animal Research Center (Cheongju, Republic of Korea). The rabbits were anesthetized by intramuscular administration of a cocktail of 35 mg/kg ketamine HCl (Yuhan Pharma Co., Seoul, Republic of Korea) and 5 mg/kg xylazine (Rompun®, Bayer Korea Co., Republic of Korea). For ureter obstruction, each rabbit underwent general anesthesia before the proximal part of the right ureter was ligated with 2-0 silk at two places adjacent to the renal pelvis. All animals received antibiotics intramuscularly (20 mg/kg amoxicillin, Foxoline injection, SamJin Pharma Co., Seoul, Republic of Korea) and analgesics (3 mg/kg tramadol, Tamador injection, DongKwang Pharma Co., Seoul, Republic of Korea) for seven days, respectively. The Animal Care Committee of Chungbuk National University, Republic of Korea, approved all protocols employed in this study (CBNU A-19-23).

^{99m}Tc -MAG₃ renal scintigraphy. Renal scintigraphy was performed before surgical intervention, immediately after surgery, and at one,

two, three, and four weeks post-ureteral ligation. The rabbits were administered atropine (0.05 mg/kg) subcutaneously. Anesthesia was induced with xylazine (1.1 mg/kg) and maintained with ketamine (11 mg/kg). Data were obtained using a dual-head gamma camera with a CT capacity (Infinia Hawkeye, GE Healthcare, Chicago, IL, USA). Scintigraphy was performed after an ear vein injection of 3 mCi ^{99m}Tc -MAG₃ (TechneScan MAG3, Mallinckrodt Diagnostica, the Netherlands) or saline physiological solution. The scintigraphic images were recorded every 2 s for 1 min and then every 1 min for 25 min. The percentage of kidney function was calculated from anterior and posterior images of a ^{99m}Tc -MAG₃ scan and by drawing regions of interest around each kidney and around the background area of each kidney.

Histopathological and morphological assays. All rabbits were euthanized by an intramuscular administration of butorphanol tartrate (0.1 mg/kg, MyungMoon Pharm Co., Seoul, Republic of Korea) and acepromazine maleate (0.8 mg/kg, SF Co., AnSan, Republic of Korea). After each kidney was cut from the rabbits, the width, height, and thickness were measured with calipers. At four weeks after ureter ligation, all rabbits were euthanized and the kidneys were removed followed by overnight fixation in 10% buffered formalin. Subsequently, paraffin tissue sections were stained with hematoxylin and eosin using standard procedures.

Statistical analysis. Statistical analysis was performed using SPSS software (version 19.0.1.1; IBM SPSS Statistics for Windows; IBM Corp., Armonk, NY, USA). Data are presented as the mean $\pm$ standard deviation values. The normality and homogeneity of the data were confirmed before performing an analysis of variance (ANOVA). The differences among experimental groups were assessed by one-way ANOVA followed by Duncan's multiple range tests. The null hypotheses of no significant difference were rejected if the obtained p-values were less than 0.05.

Results

Renal uptakes of ^{99m}Tc -MAG₃. Time-radioactivity curve (TRC) analysis revealed radiopharmaceutical uptake in both kidneys after a bolus injection of ^{99m}Tc -MAG₃. The renal uptakes of ^{99m}Tc -MAG₃ decreased rapidly in the right kidney with ureteral obstruction but increased relatively in the contralateral left kidney. An abnormal curve was observed in the uptake of ^{99m}Tc -MAG₃ in the occluded right kidney at a level that decreased gradually from one minute after injection (Figure 1). Renal perfusion of ^{99m}Tc -MAG₃ was reduced significantly in the obstructive kidney, which is indicated by the hypoactivity, and further decreased as the disease progressed (Figure 1). Therefore, the renal uptake of ^{99m}Tc -MAG₃ in the obstructive kidney decreased with time, indicating that it was not excreted from the kidney.

Morphological and histopathological assays. The morphology of the kidneys was compared. The ureter-obstructed right kidney was larger than the normal left kidney. The left kidney maintained a consistent size during the experimental periods, but the obstructed right kidney became progressively larger (Figure 2A). A histopathological

Figure 1. $^{99m}\text{Tc-MAG}_3$ renography of a rabbit model with right ureteral obstruction. (A) Regions of interest are drawn around the right and left kidneys. (B) Time-radioactivity curves for left (top, red line) and right kidneys (bottom, green line).

examination four weeks after the ureteral obstruction showed a typical pattern of unilateral UO, including multiple tubules, enlargement of the interstitial area, and cytoplasmic vacuoles. The renal pelvic space was expanded in the obstructed kidneys, and the components of the renal medulla, particularly the inner medulla and papilla, decreased as the disease progressed. The tubulointerstitial region of the ureter-obstructed right kidney appeared markedly degenerated, but no apparent structural changes were observed in the contralateral kidney (Figure 2B). The right kidney at four weeks post-surgical intervention exhibited HN. Four weeks after ureteral obstruction, the size of the obstructed right kidney increased and, width, height, and cortical thickness were significantly larger than those of the left kidney (Figure 3) ($p < 0.05$).

Discussion

The ureter is a bilateral fibromuscular duct that carries urine from the kidney to the urinary bladder. The movement of urine is due to peristalsis, which is transmitted from one muscle cell to the next. Ureteral obstruction (UO) is a condition of dysuria that can cause progressive renal dysfunction and is a frequent cause of renal damage (1). In particular, UO is a significant cause of renal dysfunction in neonatal and infants (10, 11).

Radionuclide research is important in diagnosing and following up various kidney diseases (4). Non-invasive methods for diagnosing renal function may be advantageous for surgical intervention or medical treatment when suffering from renal diseases. A previous study reported renal scintigraphy using various radionuclides such as $^{99m}\text{Tc-}$

MAG_3 , ^{99m}Tc -labeled diethylenetriaminepentaacetate ($^{99m}\text{Tc-DTPA}$), and ^{99m}Tc -labeled dimercaptosuccinic acid ($^{99m}\text{Tc-DMSA}$) (1, 4). ^{99m}Tc -labeled radiopharmaceuticals are suitable for kidney disorders because of their superior imaging qualities, reasonable price, and excellent availability (6). The imaging provided by each radionuclide reflects the various renal functional parameters (12). Although these radionuclides accurately measure all renal functional parameters, there are some differences due to the different biological properties of radionuclides (13). Radionuclides have different plasma protein and plasma clearance levels, depending on the mechanism of renal excretion combined with the retention of radioactive material in renal cells (14).

In diagnostic imaging, $^{99m}\text{Tc-MAG}_3$ provides high-quality renal images and is widely recognized as an excellent renal radiopharmaceutical. In patients with markedly impaired renal function, $^{99m}\text{Tc-MAG}_3$ can be used instead of $^{99m}\text{Tc-DTPA}$ to assess renal function due to the faster clearance and higher extraction rate (15). Because $^{99m}\text{Tc-MAG}_3$ is excreted by renal tubular excretion, the renal image is more prominent than a $^{99m}\text{Tc-DTPA}$ renal examination, which is useful for a follow-up examination before the diagnosis and treatment of patients with UTO (1). The important feature of $^{99m}\text{Tc-MAG}_3$ is that it can be cleared from the blood by the renal tubules and excreted to the collecting system (16). This allows an assessment of renal perfusion, tubular function, tubular secretion to the collecting system, and subsequent drainage. Images recorded after an injection of $^{99m}\text{Tc-MAG}_3$ reflect the tracer concentration in the renal tubules, and high-resolution images provide an accurate assessment of the renal cortex integrity (16).

CT, ultrasound, and x-rays show the size and shape of the kidney, but not its function. $^{99m}\text{Tc-MAG}_3$ scintigraphy can

Figure 2. Images of the kidney in a rabbit model of right ureteral obstruction at 4 weeks. (A) Macrophoto shows hydronephrosis in the right kidney. Microphoto shows cell bodies in renal tubules (B, white arrow head, $\times 100$) and glomerular condensation and pyknosis (C, black arrow, $\times 200$). H&E stain.

Figure 3. Comparison of width, height, and cortical thickness of kidneys in rabbits four weeks post-ureter obstruction. $n=6$, $*p<0.05$.

also observe renal blockages, obstructions, or damage (11). $^{99m}\text{Tc-MAG}_3$ remains in the intravascular space and has a high target-to-background ratio and good image quality, particularly when renal function is low or immature (1). Renal scintigraphy with $^{99m}\text{Tc-MAG}_3$ has been used widely to assess post-operative complications in renal transplant recipients (17). Furthermore, this is preferred for neonate patients with renal dysfunction because of the more efficient extraction. In the present study, $^{99m}\text{Tc-MAG}_3$ renal scintigraphy evaluated

renal size and shape by the renal uptake. In addition, renal uptakes of the $^{99m}\text{Tc-MAG}_3$ were compared in rabbits with ureteral obstructive or non-obstructive kidneys.

Histopathological findings are used to diagnose and characterize renal disorders. A morphological assessment of the kidney is an objective method for determining the structure and function of the kidney. The histopathological examination showed that the ureter-obstructed kidney had a minimal degree of interstitial inflammation with mild

dilation of the collecting tubules, flattening, and atrophy (18). These results suggest that the renal functioning of the rabbits with an obstructed ureter was impaired. This study is consistent with previous reports (4).

Although blood and urine exams cannot measure the individual renal function, scintigraphy provides important information regarding the visualization of the collecting system of the kidney. Renal scintigraphy avoids unnecessary additional radiation to children and saves time. This study was consistent with the report that ^{99m}Tc -MAG₃ may evaluate the renal cortex quickly (18).

In renal scintigraphy, the TRC showed radiopharmaceutical radioactivity uptake after ^{99m}Tc -MAG₃ administration. The TRC was determined in each kidney, and renal perfusion was assessed by the renal uptakes of ^{99m}Tc -MAG₃. The renal uptakes of ^{99m}Tc -MAG₃ increased gradually in the non-obstructive kidney but decreased gradually in the obstructive kidney. Therefore, ^{99m}Tc -MAG₃ renography can provide a differential diagnosis between obstructive and non-obstructive kidneys. Given these characteristics, renal scintigraphy is a useful tool for evaluating post-operative complications in renal transplant patients (19). The long residence time of ^{99m}Tc -DMSA in the renal cortex leads to high radiation doses to the neonatal and infant patients (18). This discomfort is one of the major limitations in diagnostic methods. Outpatients are often inconvenient because they need to visit the hospital twice to administer ^{99m}Tc -DMSA and the scan. The low energy and relatively short half-life of ^{99m}Tc -MAG₃ are advantages for keeping the radiation burden low for the patient and practitioner. Therefore, ^{99m}Tc -MAG₃ is good for evaluating renal function in neonatal and infants in a short time. The TRC of ^{99m}Tc -MAG₃ enables a quantitative evaluation of multiple features of renal function, and the renography provides information on the kidney morphology. The TRC increases linearly as ^{99m}Tc -MAG₃ flows into renal tissue, while the descending phase assesses the tubular function (20). The slope of the ascending phase after the renal uptake of ^{99m}Tc -MAG₃ was increased in non-obstructive kidneys. Similar results were demonstrated in rat or dog models (11). The blood flow in post-arterial circulation was increased in the non-obstructive kidney.

This experiment investigated the renal uptake of ^{99m}Tc -MAG₃ and compared the histopathological and morphological outcomes in each kidney in a rabbit model with unilateral ureter obstruction. Kidney function is traditionally investigated based on blood analysis or urinalysis. This study provides a minimally invasive, simple, and quantitative renal function test, which does not require blood or urine sampling.

These results suggest that a ^{99m}Tc -MAG₃ renal scan can identify potential obstructive kidneys, a differential diagnosis between obstructive and non-obstructive uropathies, or HN in patients. Nevertheless, further investigation into GFR, effective renal plasma flow, or functional renal mass combined with functional and morphological data will be needed in the future.

Conflicts of Interest

The Authors declare no conflicts of interest in relation to this study.

Authors' Contributions

Lim conceived the original idea and processed the renograms. Choi provided the review and editing support. All Authors have read and agreed to the published version of the manuscript.

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References

- 1 Lee WG, Kim JH, Kim JM, Shim KM, Kang SS, Chae HI and Choi SH: Renal uptakes of ^{99m}Tc -MAG₃, ^{99m}Tc -DTPA, and ^{99m}Tc -DMSA in rabbits with unilateral ureteral obstruction. *In Vivo* 24(2): 137-139, 2010. PMID: 20363984.
- 2 Taylor AT: Radionuclides in nephrourology, Part 2: pitfalls and diagnostic applications. *J Nucl Med* 55(5): 786-798, 2014. PMID: 24591488. DOI: 10.2967/jnumed.113.133454
- 3 Soveri I, Berg UB, Björk J, Elinder CG, Grubb A, Mejare I, Sterner G, Bäck SE and SBU GFR Review Group: Measuring GFR: a systematic review. *Am J Kidney Dis* 64(3): 411-424, 2014. PMID: 24840668. DOI: 10.1053/j.ajkd.2014.04.010
- 4 Jang SJ, Choi BS and Choi SH: Evaluation of renal function in obstructed ureter model using ^{99m}Tc -DMSA. *In Vivo* 34(5): 2431-2435, 2020. PMID: 32871769. DOI: 10.21873/in vivo.12057
- 5 Jackson P, Foroudi F, Pham D, Hofman MS, Hardcastle N, Callahan J, Kron T and Siva S: Short communication: timeline of radiation-induced kidney function loss after stereotactic ablative body radiotherapy of renal cell carcinoma as evaluated by serial (^{99m}Tc)-DMSA SPECT/CT. *Radiat Oncol* 9: 253, 2014. PMID: 25424613. DOI: 10.1186/s13014-014-0253-z
- 6 Vandermeulen E, Ham HR, Dobbeleir AA, De Sadeleer C, Piepsz A, Waelbers T, Vermeire ST, Slegers G and Peremans KY: (^{99m}Tc)-DMSA absolute and relative renal uptake in cats: procedure and normal values. *J Feline Med Surg* 13(6): 387-392, 2011. PMID: 21440474. DOI: 10.1016/j.jfms.2010.12.005
- 7 Meola M, Samoni S, Petrucci I and Ronco C: Clinical scenarios in acute kidney injury: post-renal acute kidney injury. *Contrib Nephrol* 188: 64-68, 2016. PMID: 27170168. DOI: 10.1159/000445468
- 8 Mendichovszky I, Solar BT, Smeulders N, Easty M and Biassoni L: Nuclear medicine in pediatric nephro-urology: an overview. *Semin Nucl Med* 47(3): 204-228, 2017. PMID: 28417852. DOI: 10.1053/j.semnuclmed.2016.12.002
- 9 Rossleigh MA: Renal cortical scintigraphy and diuresis renography in infants and children. *J Nucl Med* 42(1): 91-95, 2001. PMID: 11197988.
- 10 Collins AJ, Foley R, Herzog C, Chavers B, Gilbertson D, Ishani A, Kasiske B, Liu J, Mau LW, McBean M, Murray A, St Peter W, Xue J, Fan Q, Guo H, Li Q, Li S, Li S, Peng Y, Qiu Y, Roberts T, Skeans M, Snyder J, Solid C, Wang C, Weinhandl E,

- Zaun D, Zhang R, Arko C, Chen SC, Dalleska F, Daniels F, Dunning S, Ebben J, Frazier E, Hanzlik C, Johnson R, Sheets D, Wang X, Forrest B, Constantini E, Everson S, Eggers P and Agodoa L: Excerpts from the United States Renal Data System 2007 annual data report. *Am J Kidney Dis* 51(1 Suppl 1): S1-320, 2008. PMID: 18086389. DOI: 10.1053/j.ajkd.2007.11.001
- 11 Tantawy MN, Jiang R, Wang F, Takahashi K, Peterson TE, Zemel D, Hao CM, Fujita H, Harris RC, Quarles CC and Takahashi T: Assessment of renal function in mice with unilateral ureteral obstruction using ^{99m}Tc -MAG₃ dynamic scintigraphy. *BMC Nephrol* 13: 168, 2012. PMID: 23228112. DOI: 10.1186/1471-2369-13-168
- 12 Blafox MD: Renal background correction and measurement of split renal function: The challenge: Editorial Comment: EJNM-D-15-00322, M Donald Blafox, MD, PhD. *Eur J Nucl Med Mol Imaging* 43(3): 548-549, 2016. PMID: 26572761. DOI: 10.1007/s00259-015-3253-9
- 13 Lipowska M, Klenc J, Jarkas N, Marzilli LG and Taylor AT: Monoanionic ^{99m}Tc -tricarboxyl-aminopolycarboxylate complexes with uncharged pendant groups: Radiosynthesis and evaluation as potential renal tubular tracers. *Nucl Med Biol* 47: 48-55, 2017. PMID: 28110124. DOI: 10.1016/j.nucmedbio.2016.12.008
- 14 Werner RA, Wakabayashi H, Chen X, Hirano M, Shinaji T, Lapa C, Rowe SP, Javadi MS and Higuchi T: Functional renal imaging with 2-Deoxy-2- ^{18}F -fluorosorbitol PET in rat models of renal disorders. *J Nucl Med* 59(5): 828-832, 2018. PMID: 29242399. DOI: 10.2967/jnumed.117.203828
- 15 Drost WT, Henry GA, Meinkoth JH, Woods JP, Payton ME and Rodebush C: The effects of a unilateral ultrasound-guided renal biopsy on renal function in healthy sedated cats. *Vet Radiol Ultrasound* 41(1): 57-62, 2000. PMID: 10695882. DOI: 10.1111/j.1740-8261.2000.tb00428.x
- 16 Schaap GH, Alferink TH, de Jong RB, Oe PL, Roos JC and Donker AJ: ^{99m}Tc -MAG₃: dynamic studies in patients with renal disease. *Eur J Nucl Med* 14(1): 28-31, 1988. PMID: 2968259. DOI: 10.1007/BF00252614
- 17 Hanssen O, Erpicum P, Lovinfosse P, Meunier P, Weekers L, Tshibanda L, Krzesinski JM, Hustinx R and Jouret F: Non-invasive approaches in the diagnosis of acute rejection in kidney transplant recipients. Part I. *In vivo* imaging methods. *Clin Kidney J* 10(1): 97-105, 2017. PMID: 28643821. DOI: 10.1093/ckj/sfw062
- 18 Othman S, Al-Hawas A and Al-Maqtari R: Renal cortical imaging in children: ^{99m}Tc MAG₃ versus ^{99m}Tc DMSA. *Clin Nucl Med* 37(4): 351-355, 2012. PMID: 22391703. DOI: 10.1097/RLU.0b013e3182443f68
- 19 Itoh K: ^{99m}Tc -MAG₃: review of pharmacokinetics, clinical application to renal diseases and quantification of renal function. *Ann Nucl Med* 15(3): 179-190, 2001. PMID: 11545186. DOI: 10.1007/BF02987829
- 20 Esteves FP, Taylor A, Manatunga A, Folks RD, Krishnan M and Garcia EV: ^{99m}Tc -MAG₃ renography: normal values for MAG₃ clearance and curve parameters, excretory parameters, and residual urine volume. *AJR Am J Roentgenol* 187(6): W610-W617, 2006. PMID: 17114514. DOI: 10.2214/AJR.05.1550

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