**Dynamic renal imaging
in obstructive renal pathology**

A Technologist's Guide

Contributors

Hans François

EANM TC Secretary
Hogeschool Universiteit Brussel
Belgium

Suzanne Dennan

Chair, EANM Technologist Committee
Department of Diagnostic Imaging
St. James's Hospital Dublin
Ireland

Ariane Boubaker

Department of Nuclear Medicine
Centre Hospitalier Universitaire Vaudois et
Université de Lausanne
Switzerland

Greet Lapeirre

Department of Nuclear Medicine
AZ Groeninge Hospital Kortrijk
Belgium

Anne Richardson

Radiopharmacy
Leeds Teaching Hospitals Trust
United Kingdom

Iris Van den Heuvel

Inholland Hogeschool Haarlem
The Netherlands

Campbell McCullough

InHealth Medical / InHealth Limited
Buckinghamshire
United Kingdom

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EANM

Foreword
Suzanne Dennan

Nuclear Medicine Technologists are required to adapt to the rapidly changing Nuclear Medicine environment within which they work. Additionally, education schemes and scope of practice for Nuclear Medicine Technologists vary considerably throughout Europe. The EANM Technologist Committee has an important role to play in the improvement of professional skills for Nuclear Medicine Technologists in Europe and in the development of educational initiatives for Technologists.

The Technologist Committee has produced a successful series of brochures "Technologists Guides" on a yearly basis since 2004. A key aim of the "Technologists Guides" is to assist in the development of high standards of practice for Nuclear Medicine Technologists. This year's guide, already the sixth in the series, is dedicated to dynamic renal imaging in obstructive renal pathology.

Renowned authors with expertise in the field have been selected to provide an informative and comprehensive guide for Technologists. I am grateful for the effort and hard work of all the contributors. Special thanks are also extended to the coordinator of this guide, Hans François for his dedication to this project.

I hope that this new brochure will improve the quality of daily practice and benefit patients by optimising care and management. This guide will also serve as an invaluable reference point for Technologists performing dynamic renal imaging in obstructive renal pathology.

Suzanne Dennan
Chair, EANM Technologist Committee

Introduction
Hans François

Radionuclide evaluation of the genitourinary system includes quantitative estimates of renal perfusion and function. With the widespread use of ultrasound and computed tomography, the evaluation of renal anatomy by radionuclide imaging has diminished, and the role of nuclear renal imaging has become more confined to functional analysis. Indications for renal scanning include sensitivity to radiographic contrast material, assessment of renal blood flow, and differential or quantitative functional assessment of both native and transplanted kidneys. Nuclear techniques have also proved of value in examining ureteral and renal pelvic obstruction, vesicoureteral reflux, and suspected renovascular hypertension.

The diagnoses of urinary tract obstructions and assessment of its functional significance are common indications for radionuclide imaging in both adults and children. Obstruction may be suspected on the basis of clinical findings or as an incidental finding of a dilated renal collecting system on IVP, CT, ultrasound or radionuclide renal imaging. Standard imaging techniques , such as IVP and ultrasound, evaluate structure but do not depict urodynamics.

This technologist guide focuses on dynamic imaging techniques in obstructive renal pathology. Chapter 1 will bring a clear overview of renal anatomy and function. Chapter 2 is all about the radiopharmaceuticals we can use for dynamic renal imaging. Chapter 3 gives a description of the patient preparation and the imaging protocol. Image and curve interpretation is included in chapter 4. The last chapter (5) is dedicated to special considerations with pediatric patients.

I hope that this guide will provide a clearer understanding about dynamic renal imaging in obstructive renal pathology and can be a useful tool in your daily practise.

Chapter 1: Renal anatomy and function
Greet Lapeirre

Anatomy

The urinary system (also called the excretory system) is the organ system that produces, stores and eliminates urine. We distinguish the kidneys and the urinary tract. The kidneys make the urine, which is collected in the kidney pelvis. The urinary tract takes care of the further excretion. The urinary tract contains both ureters, the bladder and the urethra.

© Thieme: Atlas van de anatomie, Inwendige organen, p. 231
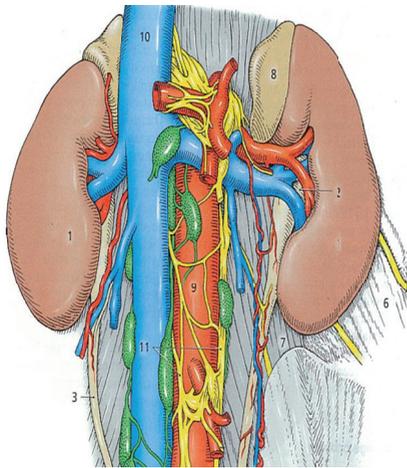
A: Organs in the retroperitoneal cavity
4. kidney
5. peylum
6. ureter
8. glandula adrenal
9. aorta
10. vena cava inferior
11. nervus sympathicus

Macroscopical

The kidneys are red-brown colored organs shaped like beans. They lie in the abdominal cavity, retroperitoneal to the organs of diges-tion and situated on both sides of the spinal column outside Th 11 – L2. The kidneys are approximately 11 cm by 7 cm and 3 cm thick. Their weight is 120 – 160 grams. The position of the right kidney is a little bit lower than the left one, because of the liver, which is on top of it. Each kidney is surrounded by an envelope of peri-nephric fat, which protects these very important organs and keeps them on the right place. When this fat becomes weaker and thin-ner, the kidneys can move, even descend into the pelvis, this can result in the pinching off of the ureter. On top of the kidneys, the adrenal glands are situated. These glands are part of the endocrine system.

The kidneys receive their blood supply from the renal arteries which are fed by the abdomi-nal aorta. In the kidney, the artery branches further. Filtered blood returns by the left and right renal veins to the inferior vena cava and then the heart.

When we look at a kidney section, we see a cavity, the renal pelvis or the pyelum. This is where the produced urine is collected and where the ureter starts. The renal arteries also come close to the pyelum. The outer layer of the kidney is called the kidney cortex, the inter-nal layer is the medulla. The medulla is striped and shows kidney columns (Columns of Bertin), which are bound the kidney pyramids. The base of the pyramids (8 – 15) is situated next to the cortex, their top, the papillae, reaches out into the pyelum, into which they empty.

© Thieme: Atlas van de anatomie, Inwendige organen, p. 233
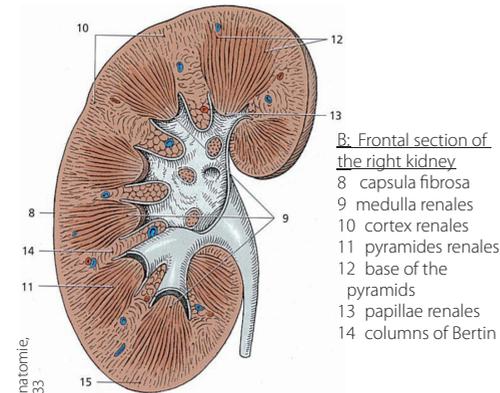
B: Frontal section of the right kidney
8 capsula fibrosa
9 medulla renales
10 cortex renales
11 pyramides renales
12 base of the pyramids
13 papillae renales
14 columns of Bertin

The pyelum continues in the ureter. This is a narrow tube (25 – 30 cm long) that enters the bladder at the bottom. The ureter enters the bladder through the back, running within the wall of the bladder for a few centimetres. Small flaps of mucosa cover the openings of the ureters and act as valves. The ureters are locked when the bladder contracts by urinat-ing – preventing the backflow of urine into the kidneys. The flow down of the urine is possible due to gravity and facilitated by peristaltic movements of the ureter.

Microscopical

Kidney channels

In the cortex and medulla there are the kid-ney channels. Such a channel is known as a nephron and is composed by :

- **The Bowman's capsule.** This is a little sack with a double wall. There are approximately over a million capsules in each kidney.

- The walls of the capsule continue in **the first convoluted tubule, also called the proximal tubule** and are situated in the cortex.

- The proximal tubule continues in **the Loop of Henle** which is situated in the medulla. The Loop of Henle consists off a descending leg and an ascending leg.

- The ascending leg continues in **the second convoluted tubule also known as the distal tubule**. This part lies in the cortex.

- The distal tubule ends in **the collecting channel** in the medulla. The collecting channel collects the urine from the cap-sules and excretes in the pyelum by the papillae of a pyramid.

The different channels (loops of Henle and collecting channels) pass right through the medulla. The cortex on the contrary is spot-ted because of the Bowman's capsules and the twisted channels. A kidney channel is ap-proximally 50 mm long. The total length of all the channels in both kidneys is about 100 km.
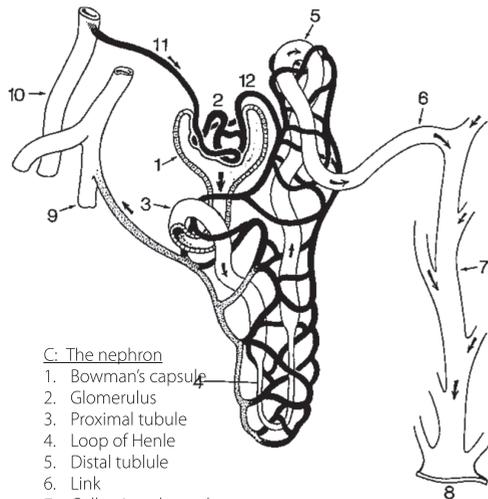
C: The nephron
1. Bowman's capsule
2. Glomerulus
3. Proximal tubule
4. Loop of Henle
5. Distal tublule
6. Link
7. Collecting channel
8. Papillae
9. Little arterie
10. Little vene
11. Vas afferens
12. Vas efferens

Glomerulus and Bowman's capsule
As mentioned before, the kidneys are provided with blood from the renal artery. In the kidney, the artery branches further into thousands of ramifications, which become smaller and smaller. An afferent arteriole (the vas afferens) enters each capsule by the open site and branches immediately into little, twisted capillaries. They form a tuft of blood vessels, the glomerulus. These capillaries come back together to one efferent arteriole (the vas efferens) that exits the Bowman's capsule. The internal wall of the capsule encloses the glomerulus real tight.

The body of Malpighi
The glomerulus and the Bowman's capsule are together known as Malpighien corpuscle or renal corpuscle. When the vas efferens has left the capsule, it branches back into the net of capillaries. These are locked in by the proximal and distal tubule and a little bit further by the Loop of Henle. Even here the contact of the blood flow and the urinary tract are very close.

The arterial capillaries go into the venous capillaries, which ultimately empties into the renal vene.

Physiology
Task
In former days, people thought that the urinary tract had only one job: to get rid of the waste products of the body. During the last decennia, this opinion has changed thanks to profound examinations. The real job of the kidneys is to maintain the balance and the volume of the different body fluids. The excretion of some substances is only a part of it.

→ Homeostasis
The body fluids can be split into the intracellular and the extracellular fluid. The extracellular fluids are the interstitial fluid, the blood plasma and the lymph. It is very important that the composition of this fluid stays as constant as possible (homeostasis) to keep the cells alive. The major homeostatic control point for maintaining this stable balance is renal excretion.

→ Water- and salt balance
The liquid measure and the concentration of the dissolved products have to be kept up to the mark. These two notions combined make up the water- and salt balance. A stabile water balance results in a stabile blood volume and pressure.

→ Balance between acid and base
Not only the liquid measure and the concentration of the dissolved products, but also the balance between acids and bases has to remain stable. The products that are offered to the kidneys can be split into two groups:

• The group of products that is either noxious or of no use for the body. These are the waste products of proteins, of which is best known urea. They must be eliminated by the kidneys.

• The electrolytes: a group of products that is very important for the body. It is necessary that the body fluids contain the right doses of electrolytes. The kidneys will excrete as much as necessary to keep the right balance.

→ Disturbed kidney function
When the kidney function is disturbed, the products of the first group will not be excreted efficiently and they will accumulate in the body fluids because there is no other way of elimination. On the contrary, the electrolytes balance can be disturbed by other reasons.

These products are not only excreted by the kidneys but electrolytes can also be lost by vomiting and diarrhea.

When the kidney function is seriously impaired, the regulating function of the kidneys is also lost. This results in important changes of the volume and the composition of the different body fluids.

The nephron: functional unit of the kidney
The blood stream through the kidneys is very high. Every minute, almost one litre of blood is flowing through the kidneys, when a person is resting. Our whole quantity of blood (4 à 5 litres) passes the kidneys, every 4 à 5 minutes. This way, the blood is continuously cleared by the kidneys. There are three processes:

(Ultra) Filtration:
In the glomerulus and the Bowman's capsule, the vascular system and the urinary tract meet each other. Due to the high arterial blood pressure, almost all of the blood plasma is squeezed into the Bowman's capsule. Only large proteins don't pass. This process is the ultra filtration of the blood plasma. The product is known as the glomerular filtrate. The kidneys produce almost 170 liters of glomerular filtrate a day.

Reabsorption by the renal tubule and the loop of Henle:

A normal adult produces 1.5 – 2 litres urine a day. This means that from the tubule and the loop of Henle about 170 liters of water and dissolved products like NaCl are reabsorbed into the bloodstream. The reabsorption is very selective: all of the glucose is transported back into the blood, but only a part of the urea follows the same path.

Difference in the proximal part and the distal part of the nephron:

There is a difference in resorption in the proximal part and the distal part of the nephron for water and electrolytes.

The proximal tubule and the descending legs of the loops of Henle resorb 85 % of the water, the natrium, a big part of the phosphates and all of the glucose. These products then enter the capillaries.

The distal tubule with the ascending legs of the loop of Henle takes care of the right quantity of water that needs to be excreted from the body. This quantity depends on the amount of water uptake through food and drinking, and loss of fluid by diarrhea and transpiration.

Dynamic renal imaging requires the use of radiopharmaceuticals with specific characteristics. The three main characteristics are binding to the renal parenchyma, excretion into the urine via tubular secretion, and excretion by glomerular filtration.

The two most widely used in practice which will be discussed in this chapter are Technetium-99m-diethylenetriaminepenta-acetic acid (^{99m}Tc-DTPA) and Technetium-99m-mercaptoacetyltriglycine (^{99m}Tc-MAG3.).

1.Technetium-99m-diethylenetriamine penta-acetic acid (^{99m}Tc-DTPA)

Chemistry and radiolabelling:

DTPA for the preparation of ^{99m}Tc-DTPA is supplied as a sterile non-pyrogenic, lyophylised powder kit. The exact formulation of the kit varies depending on the manufacturer. The DTPA used is usually in the form of the sodium salt of calcium diethylenetriaminepentaacetate. Pentetate calcium trisodium is also known as trisodium calcium diethylenetriaminepenta-acetate and is commonly referred to as Ca-DTPA. It has a molecular formula of $Na_3CaC_{14}H_{18}N_3O_{10}$. It is represented by the following structural formula:

The use of the calcium salt is thought to lessen the risk of calcium depletion in the plasma following administration. [1]
All commercial kits contain stannous chloride as the reducing agent and some also contain an anti-oxidising agent such as gentisic acid to improve the stability of the ^{99m}Tc-DTPA complex once formed.

^{99m}Tc-DTPA is simply prepared by adding a sterile solution of sodium pertechnetate (TcO$_4$-) to the dry kit in accordance with the manufacturers product specification, usually up to 11,100MBq in a volume of 2 – 10ml.

Addition of the sodium pertechnetate solution (TcO$_4$-) to the cold DTPA kit dissolves the lyophilized powder. The stannous ions act to reduce the oxidation state of the Technetium from Tc^{+7}. The exact final oxidation state of the technetium in the complex is unknown but has been reported as III, IV ,V or a combination of all three.[1] As a result of this reduction reaction, the reduced technetium binds to the DTPA molecule to form ^{99m}Tc-DTPA.
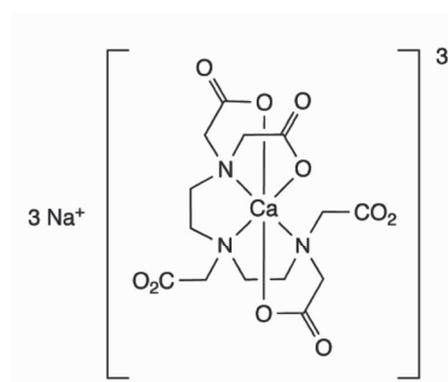

Figure 1:
Calcium trisodium pentetate = CaNa$_3$-DTPA

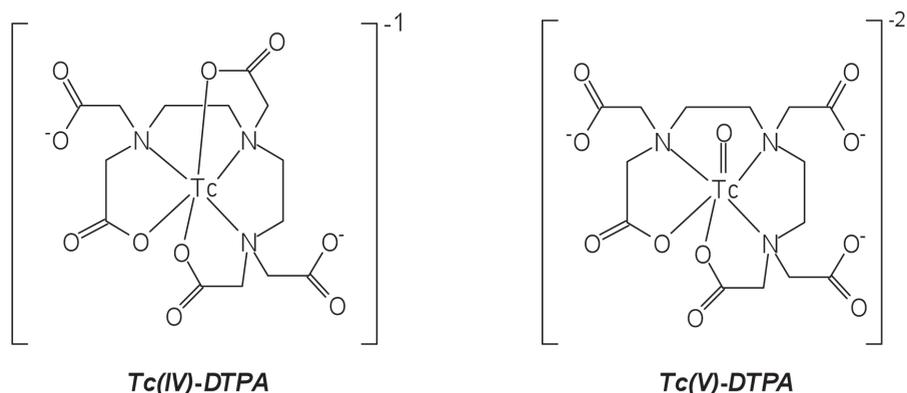**Tc(IV)-DTPA**   **Tc(V)-DTPA**

Figure 2: Proposed structures for Tc-DTPA

The labelling process takes between 15 – 30 minutes at room temperature to achieve optimal binding of the Tc-99mto the DTPA ligand. Present in the final kit along with the ^{99m}Tc- DTPA complex, there may also be potential impurities such as unbound pertechnetate (TcO4-) which would result in thyroid, stomach and salivary gland uptake, and reduced hydrolised technetium (TcO$_2$.xH$_2$O) which would show liver and spleen uptake.

The radiochemical purity of the resulting product is easily determined by using simple radiochromatography procedures as described in the manufacturers' product specification. The radiochemical purity of the final product should be no less than 95 %; and it should have a pH of 4.0 - 5.0. Once prepared, depending on the manufacturer, it has a recommended shelf life of 6-8hrs.

Pharmacokinetics :
^{99m}Tc-DTPA was first introduced into clinical use in 1970 and since then has remained one of the agents of choice for diagnosing urinary tract obstruction.

DTPA is a relatively small molecule which can pass through the endothelial membrane. Following intravenous injection ^{99m}Tc-DTPA rapidly diffuses through the extracellular fluid with little (less than 5 %) of the activity injected and binds to plasma protein and negligibly to red blood cells.

Plasma clearance is multi-exponential and exhibits half-times of 3.8 minutes,15.6 minutes, 118 minutes and13.6 hours representing 58, 24, 16 and 2 percent of the injected dose respectively.

Renal clearance from the body is by glomerular filtration with 96 % of the injected dose being cleared in the first 24 hrs. Due to the small amount of plasma protein binding and tubular secretion which occurs, glomerular filtration rate is underestimated by approximately 8 % and must be accounted for when measuring absolute GFR. Peak renal activity is reached after 3 minutes when 5 % of the injected activity is present in each kidney.

There is little or no secretion of ^{99m}Tc-DTPA by the renal tubules, nor is there any notable degree of tubular reabsorption. The complex remains stable in vivo with more than 98 % of the activity in the urine taking the form of the chelate. [2]

2. ^{99m}Tc-MAG3 (mercaptoacetyltriglycine)
Chemistry and Radiolabelling:
MAG3 for the preparation of ^{99m}Tc-mertiatide is supplied as a sterile non-pyrogenic, lyophylized powder. There are two slightly different formulations commercially available, an American formula developed for use with American Tc-99mgenerators and a European formula. In this chapter, it will be the European formulation which is discussed.

The European formula of the kit contains:
betiatide 1mg
stannous chloride 40µg
disodium tartrate 16.9mg
Betiatide has the chemical formula C$_{15}$H$_{17}$N$_3$O$_6$S and the molecular structure as shown in the equation below.

The kit is prepared by adding 10mL of sodium pertechnetate solution containing a maximum of 1,100MBq to the cold MAG3 kit. As the lyophilized powder dissolves, the stannous ions act to reduce the oxidation state of the Technetium from Tc^{+7} to Tc^{+5} and the MAG3 molecule reacts with the reduced technetium to form a negatively charged ^{99m}Tc-MAG3 complex.[1]

A bis ligand complex may also be formed which requires a heating phase to convert it to the single ligand complex. The presence of disodium tartrate in the kit holds the reduced technetium prior to the heating stage.[3]

Figure 3: Equation showing the chemical reactions during the preparation of ^{99m}Tc-MAG3.
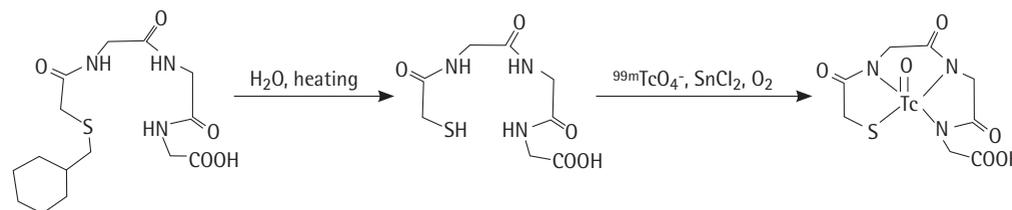
The kit is heated in a boiling water bath for 10 minutes to complete the final binding phase (see figure 3) and is then transferred to cool water to reach room temperature. The heating process also increases the rate of hydrolysis of the benzoyl group. [1]

The formation of labelled impurities is increased by using sodium pertechnetate solution of low radioactive concentration. The kit should therefore be prepared using the eluate of the highest possible radioactive concentration.[4]

Radiochemical purity is easily measured following the simple chromatography method as recommended in the manufacturers product specification. The final product should be a minimum of 90 % bound and have a pH of 5.0 – 6.0.Once prepared the manufacturer recommends that the kit has a shelf life of 4hrs.

Pharmacokinetics:
MAG3 was developed in the 1980's as an alternative for [131]Iodine ortho-iodohippurate (OIH), which had poor imaging properties, could not be used for renal perfusion imaging and also had a high radiation dose per imageable photon. [5]

Following intravenous injection, ^{99m}Tc-Tiatide (MAG3) is highly bound to plasma protein. This binding is however reversible; and the ^{99m}Tc-MAG3 is rapidly excreted by the kidneys. Active tubular secretion accounts for approximately 89 % of the excretion of the administered dose with the remaining 11 % of the dose excreted via glomerular filtration.

With normal renal function 70 % of the administered dose is excreted within 30 minutes of injection and over 95 % after 3 hours.

Peak renal activity is seen within 3 minutes of injection. MAG3 has a high first pass extraction efficiency which is three times greater than DTPA giving a good organ to background ratio.[6] As a consequence, the administered activity is less than with DTPA. [See table 1] reducing the radiation dose to both patients, inparticular paediatrics and staff.

It also gives better image detail even at low levels of renal function.

Table 1: Diagnostic reference levels for dynamic renal imaging using ^{99m}Tc-DTPA and ^{99m}Tc- MAG3 [7]

Investigation	Diagnostic reference level DTPA	Diagnostic reference level MAG3
Renal imaging/renography	300 MBq	100 MBq
First pass blood flow imaging	800 MBq	200 MBq

Table 2: Summary of pharmacokinetic properties of ^{99m}Tc-DTPA and ^{99m}Tc-MAG3 in dynamic renal imaging

Pharmacokinetic properties	DTPA	MAG3
Plasma binding	<5 %	> 80 %
Glomerular filtration	98 %	2 %
Tubular excretion	0 %	> 98 %

Figure 4: A comparison of dynamic renal images using (a) ^{99m}Tc-DTPA and (b) ^{99m}Tc-MAG3

(a) ^{99m}Tc-DTPA   (b) ^{99m}Tc-MAG3
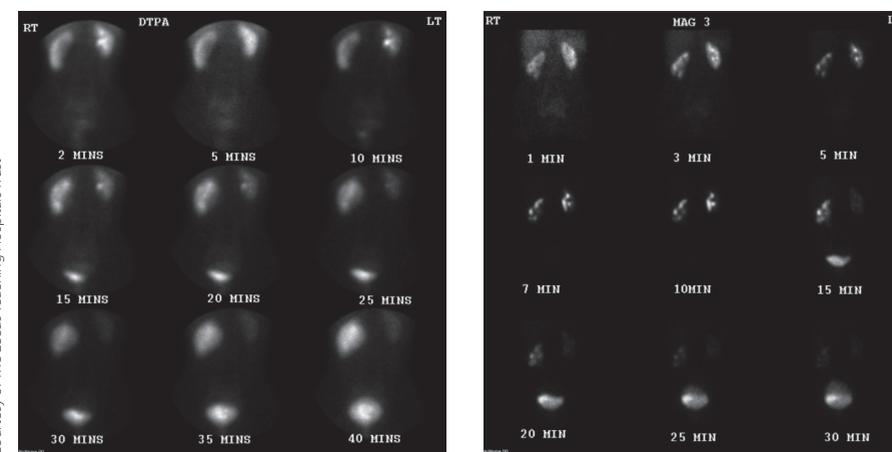
Courtesy of The Leeds Teaching Hospitals Trust

Patient preparation

Patients can be required to send in a list of medication, appropriate weight and height. A full, verbal as well as a written explanation of the procedure should be given, including risks, medication, contraindications and possible side effects of used radiopharmaceutical and furosemide, time taken for scan, the need to remain still during the scan etc.

Ideally, patients should be phoned prior to the appointment to remind them of their appointment and to give them an opportunity to discuss any concerns they may have.

Diuretic medication should be withheld 72 hours prior to the examination to obtain information about the original renal function. Prior to examination, the patient should be given 0.5 L of liquid/water to obtain adequate hydration.

Emptying the bladder just before acquisition decreases pressure in the urinary tract.

To minimise the risk of a misadministration:
a) Establish the patient's full name and other relevant details prior to administration of radiopharmaceutical and furosemide;
b) Corroborate the data with information provided on the diagnostic test referral.
If the information on the referral form does not match the information obtained by the identification process, then the radiopharmaceutical and furosemide should not be administered to the patient. This should be explained to the patient and clarification sought as soon as possible by contacting the referral source (Taylor and Fernando, 2005).

The patient, parent, guardian or escort should be asked for the following information, which should then be checked against the request form and ward wristband in the case of an in-patient:
a) Full name (check any spellings as appropriate)
b) Date of birth
c) Address
d) If there are any known allergies or previous reactions to any drug, radiopharmaceutical, iodine-based contrast media or products such as micropore or band-aids (Taylor and Fernando, 2005).

The following information should be checked with the patient, parent, guardian or escort where appropriate:
a) Referring clinician, GP and/or hospital
b) Any relevant clinical details (e.g. drain, stoma, surgery)
c) Confirmation that the patient has complied with the drug restrictions
The result of correlative imaging (e.g. ultrasound, earlier renography) and tests (e.g. reports on serum creatinine and urea levels) are available prior to the study, and noting of any recent interventions.

If in doubt, do not administer the radiopharmaceutical and furosemide and seek clarification.

Ideally, patients who for any reason are unable to identify themselves should wear an identification wristband. Different kinds of difficulties that influence communication are hearing difficulties, speech difficulties, language difficulties, unconscious patient and confused patient. Each difficulty has its own approach which should be considered to be used.

If a relative, friend or interpreter provides information regarding the patient's name, date of birth etc., it is advisable for them to sign a written evidence of confirmation of the relevant details (Martin and Taylor, 2004).

Women of child-bearing potential should have their pregnancy status checked using a form for confirmation.

Although the examination is followed by voiding and the subsequent activity in the patient is of a minimal level, the operator administering the radiopharmaceutical should advise the patient regarding minimising contact with pregnant persons and children. In addition, the operator administering the radiopharmaceutical should check that any accompanying person is not pregnant (e.g. guardian) (Taylor and Fernando, 2005).

Patient positioning

To be able to start acquisition immediately after administering of the radiopharmaceutical, the patient needs to be positioned prior to the injection in supine position. The gamma camera should be positioned posterior to the patient because of the anatomical location of the kidneys. Knee support is also helpful; patient comfort is essential to minimise movement. The field of view should be verified with a marker prior to injection to ensure that both kidneys are included. Anatomical reference is the processus xiphoideus.

Both kidneys and bladder need to be in the field of view to overview the complete urinary tract. If the camera is positioned too caudal, the kidneys are displayed in the most upper pixel rows in the frame that can lead to misinterpretations of the number of counts within regions of interest of the kidneys.

Although patient movement can be corrected before drawing regions of interest, it must be avoided during acquisition. Therefore supine positioning is recommended over erect (seated) positioning. In obstructive renal pathology, acquisition in the erect position can be preferable because of the hydrostatic pressure. More realistic results will be achieved.

Radiopharmaceutical dose

The radiopharmaceutical dose for [99mTc]-MAG3 and [99mTc]-DTPA in obstructive pathology varies from 40 up to 200 MBq and depends on preferred acquisition parameters. Prior to intravenous administering, the content of the syringe (radiopharmaceutical, dose, calibration time, etc.) needs to be confirmed by the operator. A butterfly needle may be retained for the purpose of furosemide administering during acquisition.

The effective dose equivalent is approximately 0.5 mSv when 75 MBq is administered if the renal function is normal without any extravenous administered radiopharmaceutical.

Image preparation en acquisition

Quality control procedures that must be performed satisfactorily before renal imaging

The goal of any gamma camera quality control programme is the production of high-quality images as well as high-quantity examinations, for the best possible diagnostic service to the patient. After acceptance testing, a quality control programme (protocol) must be set up in each department and followed in accordance with national guidelines. The following routine quality control test schedule is typical and necessary for planar scintillation (Jorge and Lecoultre, 2005):

a) Energy peaking (daily)
b) Flood uniformity tests (daily)
c) Gamma camera sensitivity measurement (daily)
d) Linearity and resolution assessment (weekly)

A routine quality control programme for a gamma camera includes procedures appropriate to planar scintillation cameras quality controls. Further, more complex tests should be undertaken on a less frequent basis (Jorge and Lecoultre, 2005).

a) Daily energy peaking

This quality control procedure consists of 'peaking' the gamma camera for the relevant energy of 140 keV prior to obtaining flood images. It is mandatory that the energy peaking is undertaken on a daily basis and for the used radionuclide.

Checking the peaking is needed to ascertain that:
• the camera automatic peaking circuitry is working properly
• the shape of the spectrum is correct
• the energy peak appears at the correct energy
• there is no accidental contamination of the gamma camera

It is recommended that the spectrum obtained during peaking tests is recorded.

b) Daily flood uniformity tests

After a successful peaking test, it is recommended that a uniformity test is performed on a daily basis. The flood field is acquired; and camera uniformity can be evaluated on the basis of a visual assessment. Quantitative parameters should also be computed regularly and recorded in order to demonstrate sudden variations from normal and to alert the technologist to progressive deterioration in the equipment.

c) Daily gamma camera sensitivity measurement

A practical means of measuring sensitivity is the recording of the time needed to acquire the flood field using the known activity. It should not vary by more than a few percent from one day to another.

d) Weekly linearity and resolution assessment

Linearity and resolution should be assessed weekly. This may be done using transmission phantoms.

Collimator

The choice of a collimator for a given study is mainly determined by the tracer energy and activity. This will influence the statistical noise content of the images and the spatial resolution. The number of counts needs to be maximised, possibly at the expense of some resolution.

Collimators vary with respect to the relative length and width of the holes. The longer the hole length, the better the spatial resolution obtained, but at the expense of a lower count sensitivity. Conversely, a larger hole gives a better count sensitivity but with a loss of spatial resolution (Jorge and Lecoultre, 2005).

So traditionally a low-energy general purpose collimator is recommended. Quantitative analyses in dynamic renal imaging are more important than qualitative high resolution images. The number of counts needs to be as high as possible for better statistical quantification accuracy. Thus a general-purpose collimator is currently recommended for dynamic renal imaging.

Although the choice of collimator is crucial, it should be borne in mind that other technical aspects play an important role in determining optimal spatial resolution, such as the matrix size, time per frame and radiopharmaceutical dose.

Matrix size

Each dynamic frame is collected into a matrix. This matrix is characterised by the number of pixels. Each pixel represents a part of the object. Pixels are square and organised typically in arrays of 64x64 or 128x128. In renal imaging, the number of counts per pixel is more important than a high resolution of the images.

In fact, the choice of matrix is dependent on four factors:
a) The resolution of the organ: The choice should not degrade the intrinsic resolution of the object. Though the kidneys

are anatomically situated in the back of the body, the distance from the camera face does not degrade the resolution. A pixel size of 6-8 mm is sufficient, which, for a typical large field of view camera, leads to a matrix size of 64x64 (Jorge and Lecoultre, 2005).

b) The radiopharmaceutical dose: The administered amount of MBq needs to be considered ALARA. A higher radiopharmaceutical dose leads to more acquired counts and gives better statistical results. If a matrix size of 128x128 is preferred a radiopharmaceutical dose needs to be at the level of the allowable upper limit (the allowable upper limits of radiopharmaceuticals differ from country to country).

c) The noise: This is caused by the statistical fluctuations of radiation decay. The lower the total counts, the more noise is present and, if the matrix size is doubled (128 instead of 64), the number of counts per pixel is reduced by a factor 4 (Jorge and Lecoultre, 2005).

d) Time per frame: This factor is equivalent in results compared with the factor noise, described above. The time per frame can not be varied in a large scale because of the total renal function time. Time per frame determines the number of counts that can be acquired. If the time per frame increases, the number of counts increases. If the matrix size is doubled (128 instead of 64), the number of counts per pixel is reduced by a factor of 4.

Zoom factor

A zoom factor of 1.0 is recommended in renal imaging in adults because of the fact that both kidneys as well as the urinary bladder need to be in the UFOV of the camera.

Sometimes, set protocols restrict the software options available to the technologist. This restriction may be needed to ensure that results can be compared with reference studies (e.g. follow-up) or databases. It is very important to ensure reproducibility in this way before setting up individual acquisitions. The processing cannot replace information lost in the acquisition (Jorge and Lecoultre, 2005).

Total time and frame time

Dynamic acquisition is necessary for generating time activity curves so that quantitative analysis can be made. The phases in renal function, determine the multiphase dynamic acquisition parameters. Total time and frame time are of greatest importance and should be adapted to the renal function. There is no consensus about total time and frame time; and they vary within a range from department to department.

In obstructive renal pathology, a total acquisition time of at least 30 minutes is recommended. If a total time of 20 minutes (normal renogram) is acquired, effects of diuretic administering into the study can be missed because of the effect that can occur after finishing the dynamic acquisition. Recommended

is a post void or delayed static image(s) to compare with the last frame(s) of the excretion images. Acquisition time should be corresponding with radioactive decay in case of delayed images.

The first two phases need a short frame time to detect differences within time (range: 1-4 seconds/frame). If the frame time is too long, small differences can not be detected and visualised. The most common used and recommended frame time is 2 seconds/frame.

The third phase has a longer time interval than the first two phases. Therefore the frame time is longer than the first minutes of acquisition (range: 10-60 seconds/frame). The longer the frame time, the higher the count rate and the accuracy; although small changes in function can be missed using a longer frame time. The most common used and recommended frame time is about 20 seconds/frame. Frame time always should be based on the goal to measure a high number of counts. Factors of influence are the amount of dose, type collimator and matrix size.

Diuretic administration

To differentiate between obstruction and delayed clearance, intervention into the renal study can be performed. The diuretic furosemide (Lasix) is commonly used. The recommended dose rate of intravenous furosemide in adults is 0.5 mg per kg body weight (maximum of 40 mg).

Currently, there is no consensus as to the time of furosemide administration. This varies from 15 minutes prior to renal acquisition (F -15), the beginning moment of the acquisition (F 0) to 10 minutes after acquisition started as a fixed time for administration (F +10, F +15). It can also be 20 minutes after acquisition started (F +20), when the collecting system appears to be full; and effects of furosemide should be detected before the end of the acquisition.

Processing

Visual inspection prior to quantification

The images should be inspected immediately after acquisition in order to identify technical or physiological problems that might require repeat examination. Motion correction necessitated by patient motion or internal motion of the organs, can be implemented before quantification by shifting. If the motion is irregular and/or too much caused by patient motion, the curves and analysis results are less accurate and totally invalid. The renogram curves then should be discarded and the relative function should be calculated manually from ROI analysis on selected frame from the uptake phase.

Drawing regions of interest

For quantitative analysis, regions of interest (ROI's) need to be defined so that curves can be generated. Curves are representative of renal function. ROI's should be defined in a summed image in order to obtain a better signal-to-noise ratio.

Different sets of regions are available (e.g. rectangular, irregular, elliptical). Irregular ROI's are recommended for all regions. ROI's should be defined for both kidneys, background for both kidneys and the aorta. For kidney ROI's, there are 2 options: complete kidneys (general renal function, including pelvis) or cortical regions (cortical function). Cortical time activity curves are not influenced by pelvic activity (figure 1).

The background ROI's have to be defined caudal-lateral of the kidneys. If the background ROI's are defined cranial of the kidneys (liver and spleen activity), background subtraction shows underestimated results.

Figure 1: Composite image of dynamic frames. ROI's are defined for: kidney left and right, cortex left and right, background left and right and aorta.

Courtesy of MBRT Haarlem/Amsterdam
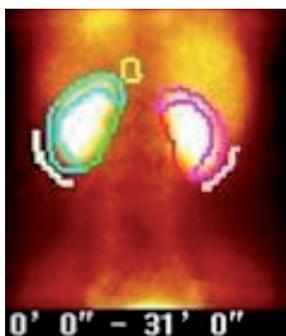
Generating time activity curves

Time activity curves (renogram) are size-normalised before background subtraction (figure 2).

Figure 2: Time activity curves (normal renal function).

Courtesy of MBRT Haarlem/Amsterdam
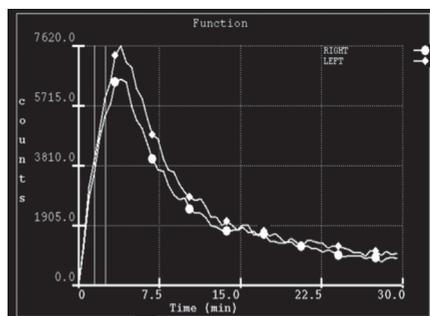
The time activity curves show 3 parts: initial rise, ascending limb and descending limb. The first part reflects arrival of the radiopharmaceutical. While the second part reflects extraction before it begins to leave the ROI of the kidney. Peak time accurately reflects the point at which the accumulation trend is reversed. The third part reflects the drainage process. Curves can be normalised by frame time, counts per second, counts per pixel and counts per MBq. Curves for flow and function can be displayed separately as well as for left and right. Quantitative parameters are presented with the curves. Common displayed parameters are time to peak (TTP or Tmax), T1/2 clearance time (T½), upslope and downslope ratio. Every department uses own display parameters and choice for displayed curves (figure 3). If furosemide is used, the time of the administering should be pointed in the displayed curves (figure 4) and parameter chart.
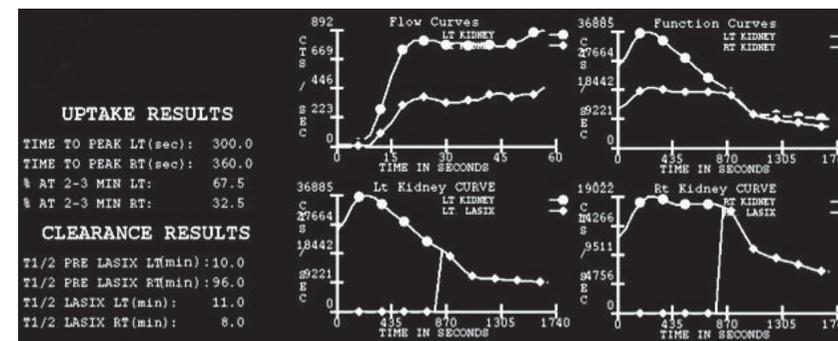
Figure 3: Statistical renal function results.

Courtesy of MBRT Haarlem/Amsterdam

Figure 4: Time activity curve. The arrow shows the time of administering furosemide.

Courtesy of MBRT Haarlem/Amsterdam

Visual presentation

Curves and quantitative analysis should be provided along with visual presentation. An example overview for visual evaluation is displayed in figure 5. Frames are displayed by summed frames (composite) for flow and function. If acquired, residual or delayed images also should be presented. Time range of the composite should be mentioned with the composite frames.

Figure 5: Visual presentation of renal function.

Courtesy of MBRT Haarlem/Amsterdam
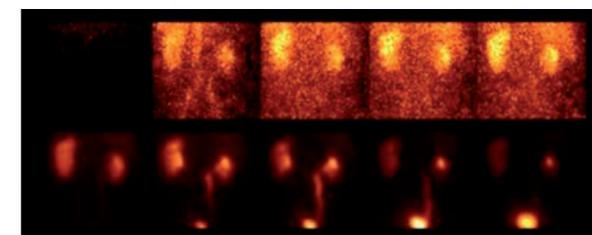
Protocol summary

	Recommended	Remarks
Patient preparation	Prior to examination: - Withheld diuretic medication 72 hrs Prior to acquisition: - Hydration: 0.5 L of water (30 minutes) - Emptying bladder (after hydration)	
Patient positioning	Supine, posterior	Erect (seated) posterior
Radiopharmaceutical	^{99m}Tc-MAG3 / ^{99m}Tc-DTPA	
Dose	40-200 MBq iv bolus	Body weight > 100 kg, standard dose should be increased
Intervention drug	Furosemide (Lasix) iv 0.5 mg/kg body weight	Prior to radiopharmaceutical administering (F -15) or during acquisition (e.g. F 0, F +10, F +20)
Dose	0,5 mg per kg body weight (iv)	
Collimator	LEGP or LEHR	
Energy	140 keV, 20 % window	
Matrix	64x64 or 128x128 (word)	
Zoom	1.0	
Frame time (flow)	1-5 seconds/frame (2 seconds/frame)	Displayed as composite images (e.g. 10 second images)
Frame time (function)	10- 60 seconds/frame (20 seconds/frame)	Displayed as composite images (e.g. 2 minute images)
Total time	30-40 minutes	Additional images after voiding or delayed images (isometric/isotime)
Processing	Quantitative: time activity curves, statistics and analysis parameters Qualitative: visual evaluation	

Diuresis renography is the primary diagnostic tool in upper urinary tract obstruction in both adults and children (4).

Acute obstructive uropathy is a commonly encountered condition, occurring in both inpatient and outpatient settings. Unilateral obstruction to urinary outflow typically occurs, with little if any change in measured renal function in a healthy individual. However, the less common bilateral form results in measurable changes in kidney function(3).

Normally, two kidneys are present in the human body. These are situated in the back of the body, on either side of the spinal column at about the level of the 1st Lumber vertebra. Normally each kidney has a single arterial blood supply fed directly from the abdominal aorta. Venous drainage flows directly into the inferior vena cava. The kidneys can take up to 20 % of cardiac output at any given moment (6). Their primary function is to filter the blood to remove various substances that would be toxic if allowed to build up. The kidneys are also important in electrolyte and fluid balance. They also have endocrine functions and are central in the regulation of blood pressure. This section will however only be concerned with the mechanisms of renal excretion, how this functions and malfunctions, and how the renogram is used as a diagnostic tool. The kidney produces urine through a blood filtering process. The urine forms in the renal calyx system and flows through to a collecting system. The collecting system drains via the ureter. Normally, this is a continuous process, in which further peristalsis moves the fluid from boluses into the bladder(3).

Urine is normally prevented from refluxing from the bladder by a non return valve system.

The use of tracers which are taken up and excreted by the kidney allows the estimation of renal perfusion, divided function, drainage and assessment of the lower urinary tract(1).

^{99m}Tc-MAG3 is the agent of choice in children and patients with impaired renal function. It is cleared by a combination of glomerular filtration and tubular secretion(1).

Problems arise when the urinary outflow system becomes blocked.

One of the most common indications for renographic examination is in suspected obstruction, and in post surgical evaluation of the system(1). Obstructive uropathy occurs in a well characterised set of symptoms.

A patient with a calculus lodged in the urinary tract can suffer from acute, colicky flank pain that radiates to the groin. Initial management usually involves pain control and aggressive hydration. Patients generally are treated as outpatients unless a complicated course necessitates hospitalisation(2).

Although there can be many causes of renal outflow obstruction, one of the main causes is stone impaction. Stones produced high up in the system can become lodged in the outflow to cause an obstruction to urine flow. This generally causes a pressure build up and dilatation within the collecting system and renal pelvis. Other causes of obstruction can be malignant disease, fibrosis, injury or surgery.

With other causes of acute obstruction, no symptoms may be present. If bilateral obstruction is present, anuria or oliguria may be the earliest indication. Often, especially in inadvertent ligation of a single ureter, no detectable change in urine output occurs. As a result, the obstruction remains unrecognised for 10-30 days post surgery, at which time flank pain and fever alert the physician to this complication(2).

Varying degrees of obstruction are possible. Apart from complete obstruction, which often apprears as an acute medical emergency, partial obstruction may occur. A partial obstruction may present the same symptomology as that of the complete obstruction.

The most common error in initial investigation is equating hydronephrosis with obstructive uropathy. (5)

In the case of obstruction by renal calculus, impaction usually occurs at a number of well recognised sites. At the ureterovesical junction (UVJ), the ureter is most narrow; it also narrows at the PUJ, the area overlying the iliac bifurcation, and the point where the right ureter passes through the root of the mesentery(2).

The radionuclide renogram, along with other imaging techniques, is a key technique used to determine and characterize the nature of a renal outflow obstruction. Plain radiography may be able to demonstrate the presence of a renal calculus.Intravenous urography may also demonstrate site and nature of obstruction.

The radionuclide renogram provides a sensitive measure of the dynamics of urinary excretion.

Figure 1 shows the left kidney to be dilated with a thin cortex and a slow continous accumulation of tracer in the collecting system; this is the characteristic, hydronephrotic presentation of an obstructed kidney. The rising curve, generated from a region of interest over the renal cortex as well as the collecting system demonstrates that drainage is impaired on the left side. In contrast the right kidney shows good uptake and excretion in the image and in the curve, which has the normal pattern.

In acute obstruction, the pressures within the collecting system and ureters above the point of obstruction can increase dramatically. (3) On occasion an obstruction may not be complete. In order to demonstrate this, a diuretic, e.g. frusemide, can be given dur-

Figure 1

University Medical Centre Nijmegen, the Netherlands
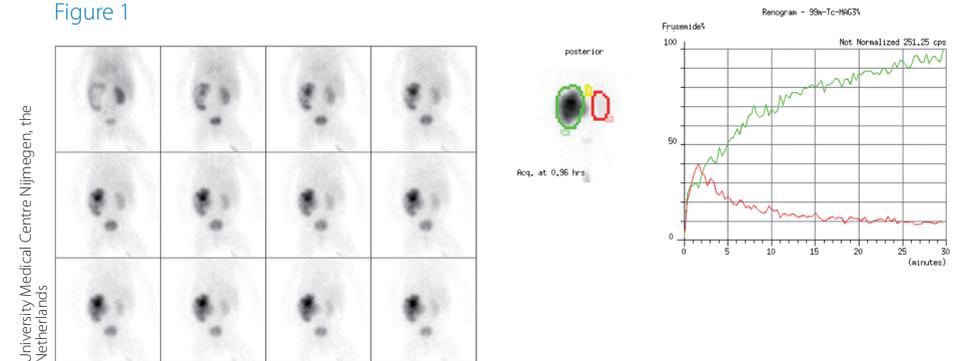
ing the course of the renogram acquisition. The drug can force drainage of the system. Frusemide can be given at various times during a renogram study. If the first part of the study shows possible obstruction (as assessed from the P-scope/computer or from "real-time" curves if available), then frusemide can be administered(1). There is still some debate as to the best time for administration(1).

Figure 2 shows three schematic renogram curves. Curve one shows a normal pattern of tracer uptake and excretion. Curve 2 shows the afore mentioned obstructive pattern with the characteristic rising curve – despite the administration of diuretic 15 minutes into the acquisition. Curve 3 demonstrates drainage after administration of diuretic, indicating an incomplete obstructive pattern.
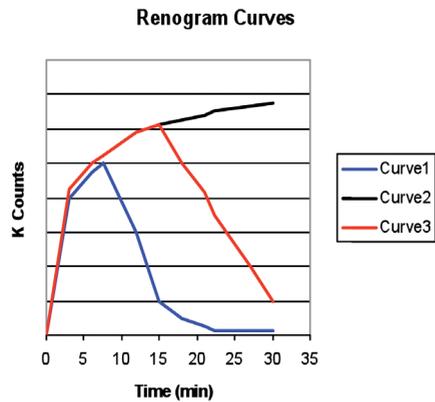
The degree of obstruction is an important determining factor in the development of nephropathy, with impairment of function occurring in a more complete obstruction(3).

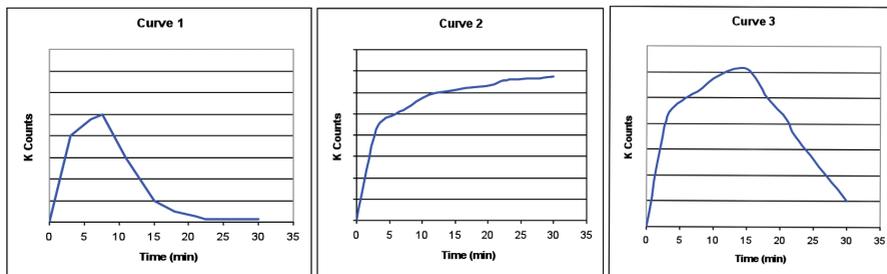Care should be taken when administering diuretic in suspected obstruction as severe renal colic may be induced.

Figure 2

Renogram Curves

Possible obstruction is assessed from the diuretic response provided there is an adequate urine output rate(1).

Source: Campbell McCullough

Introduction

Approximatively 60 % of nuclear medicine procedures performed in children is aimed to examine the urinary tract [1]. The two main causes for this high proportion of nephro-urological studies in paediatrics are: the routine use of prenatal ultrasound and the frequency of urinary tract infections in children. Urinary tract malformations are the second most common structural foetal anomaly accounting for 20 % of all congenital abnormalities [2-5]. Prenatal hydronephrosis is detected in 0.3 to 4.5 % of pregnancies and almost half of them will spontaneously resolve during the first months of life. A persisting unilateral hydronephrosis is most commonly due to pelviureteric junction stenosis but may also be secondary to vesico-ureteral reflux (Table 1).

Table 1. Reported incidence of the most common causes of prenatally detected hydronephrosis in neonates and infants.

Transient hydronephrosis	48 %
Physiological hydronephrosis (extrarenal pelvis)	15 %
Pelviureteric junction stenosis	11 %
Vesico-ureteral reflux	9 %
Megaureter	4 %
Ureterocoele and duplex kidney	2 %
Multicystic kidney disease	2 %
Posterior urethral valves	1 %

Although a grading system of renal pelvic dilation has been elaborated by the Society for Fetal Urology (SFU), no consensus has been reached with respect to significance of mild to moderate dilation and the need of post-natal examinations. Nevertheless, there is strong evidence that diuretic renography is helpful for the post-natal management of fetal hydronephrosis allowing to assess both renal function and normal or abnormal urinary flow in response to hyperdiuresis [6-10]. Being a safe and minimally invasive procedure, diuretic renography is a method of choice to follow-up children with structural abnormalities of the urinary tract and provides useful information for the clinician with respect to conservative or surgical management of these children.

Paediatric nuclear medicine is different from adult practice and one should remember that "children are not simply microadults" (I.J. Wolf in Aphorisms and Facetiae of Béla Schick, "Early Years") [11-13]. Actually, practising paediatric nuclear medicine requires a dedicated environment and a well-trained staff able to examine a newborn baby as well as a toddler or a teenager. Many departments routinely encourage the parents and/or siblings to remain with the child in the examination room during the study in order to provide a feeling of security and safety. Children may not be able to understand why they have to stay still and to go through apparently terrifying and possibly painful procedures. But in any circumstances they will be sensitive to honesty and respectful attitude. One should not say "I will do a venous puncture but you will

not feel any pain", but rather "I will do a venous puncture, it may be painful and you can cry and shout but please do not move your hand and it will be easier and probably less harmful". Providing detailed and clear information to the parents and the child about the preparation, procedure and final goal of the study will allow examining most of the paediatric patients without sedation. Major efforts have been made in order to standardise and optimise nuclear medicine procedures in children and the guidelines edited by the European Association of Nuclear Medicine (EANM) and the Society of Nuclear Medicine (SNM) provide very useful information also dedicated to departments not routinely involved with children [14-16].

Patient preparation

Renography is a simple and non invasive procedure which requires only minimal preparation. Bladder catheterisation is not mandatory and has to be restricted to particular clinical situations, for example to children with neurological bladder and unclear dilation of the upper urinary tract. Sedation is not deprived of risks and should not be used to replace an adequate preparation of the child and parents. Almost all children addressed for diuretic renography are outpatients. An information letter should be sent to the parents emphasising on the need of fluid intake during the hours preceding the examination. As a local anaesthetic cream should be applied 45 to 60 minutes before injection this time will give

an opportunity to further hydrate the child and provide additional information about the procedure (Figure 1).

Courtesy of Centre Hospitalier Universitaire Vaudois

Figure 1: Local anaesthetic cream has to be applied 45 to 60 min before tracer injection in order to be effective. The staff may seize this time to explain the procedure, prepare the child and its parents and provide additional oral fluid intake.

Continuous intravenous hydration with saline is not required, and oral fluid intake (15 ml/10 kg) during the 30 minutes before injection is recommended [14]. Urine flow rate has to

be at least 1-3 ml/min to avoid dehydration. Adequate hydration during 30 minutes before tracer injection and systematic use of furosemide in neonates and infants will induce spontaneous voiding during the examination (Figure 2).

Courtesy of Centre Hospitalier Universitaire Vaudois

Figure 2: F0 diuretic renography with I-123-Hippuran performed in a 8 month-old girl with left dilation. One-minute posterior

views show normal tracer extraction by both kidneys and rapid excretion of the tracer in the bladder with normal urinary flow (A). After adequate oral hydration and under the effect of furosemide spontaneous voiding is observed 3 times during the 20-minute dynamic acquisition (B).
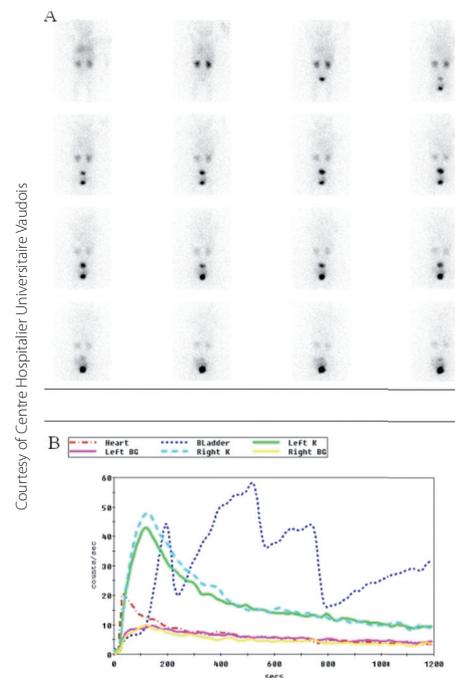
Information obtained during spontaneous voiding (residual bladder volume, urine production rate) may be clinically relevant for the paediatric urologist. Toilet-trained children must void immediately before the beginning of the study and diapers must be changed in neonates and infants. Time interval between tracer injection and voiding should be noted and the volume of urine produced at the end of the study is measured.

Patient positioning and immobilisation

Children have to lie supine with heart and bladder included in the field of view, with the camera underneath in contact with the examination table allowing a free access to the child for both the parents and medical staff (Figure 3).

Movements during acquisition should be minimised; the parents can help to avoid movements during the early phase of the study by being in contact with their child. Patient movement during the acquisition is one pitfall in assessing the diuretic renogram and proper immobilisation before tracer injection is essential (Table 2).

Figure 3: Infants can be immobilised in a soft tissue gutter with Velcro straps. The camera is placed underneath the examination table allowing free access to the child for both the parents and staff. Parents are encouraged to stay during the entire procedure.

Courtesy of Centre Hospitalier Universitaire Vaudois

Table 2. Limitations and pitfalls in performing and assessing diuretic renography.

Source	Limitation/Pitfall
Patient	Hydration status
	Bladder emptying
	Renal function insufficiency
Acquisition	Patient position, movements
	Tracer injection (quality of bolus)
	Radiopharmaceutical
	Change of position, postvoiding/late images
Processing	Regions of interest, background subtraction
	Quantitative parameters used to assess drainage
	Renal function measurement
Reporting	Parenchymal aspect and renal function
	Response to furosemide, change of position and voiding
	Level of urinary drainage impairment

In neonates and infants, a vacuum cushion or acrylic foam gutter and Velcro straps should be used, whereas older children can be supported by sandbags (Figure 4).

Courtesy of Centre Hospitalier Universitaire Vaudois

Figure 4: Older children and adolescents are lying supine; and sand bags may be placed on each side to make them remind not to move during acquisition.

Most of the available software proposes motion-correction programs, but these will not enable correction for improper positioning or torsion movements. Taking time to prepare, explain and position the child before tracer injection will allow to spare time when processing and interpreting the study.

Radiopharmaceutical dose and injection

Due to renal immaturity in the first year of life, tracers with predominant tubular extraction such as Tc-99m-mercaptoacetyltriglyne (MAG3), Tc-99m-ethyllenedicysteine (EC) and I-123-hippuran are generally preferred to agents dependant on glomerular filtration, ie Tc-99m-diethylene triamine pentaacetic acid (DTPA) [16, 17]. Due to their extraction rate, tubular agents have a higher target-to-background ratio when compared to glomerular tracers allowing the use of less activity without affecting the image quality (Table 3).

Table 3. Recommended baseline and minimal activity for dynamic renography according to the new EANM paediatric dosage card [6].

Radiopharmaceutical	Class	Baseline activity (MBq) for calculation purpose only	Minimum recommended activity (MBq)
Tc-99m-MAG3	A	11.9	15
I-123-Hippuran (normal function)	A	12.8	10
I-123-Hippuran (abnormal function)	B	5.3	10
Tc-99m-DTPA (normal function)	A	34.0	20
Tc-99m-DTPA (abnormal function)	B	14.0	20

Minimal activity and recommended dosage based on body weight and class of radiopharmaceutical has been revised by the EANM Dosimetry and Paediatrics Committees and are available online on the website of the EANM [19]. Tracer is injected as a bolus by direct intravenous puncture using a single-use needle in neonates and infants or through a previously inserted catheter in older children. Possible tracer extravasation should be checked by putting the arm or hand in the field of view at the beginning of dynamic acquisition if absolute renal function quantification is performed based on camera-measurements or by simultaneous plasma clearance determination (1 or 2 blood sampling).

Image acquisition
A dynamic acquisition of 20 minutes is started immediately before tracer injection as a bolus. Matrix should be 128 x 128, a zoom factor from 1 to 2 can be applied when ex-

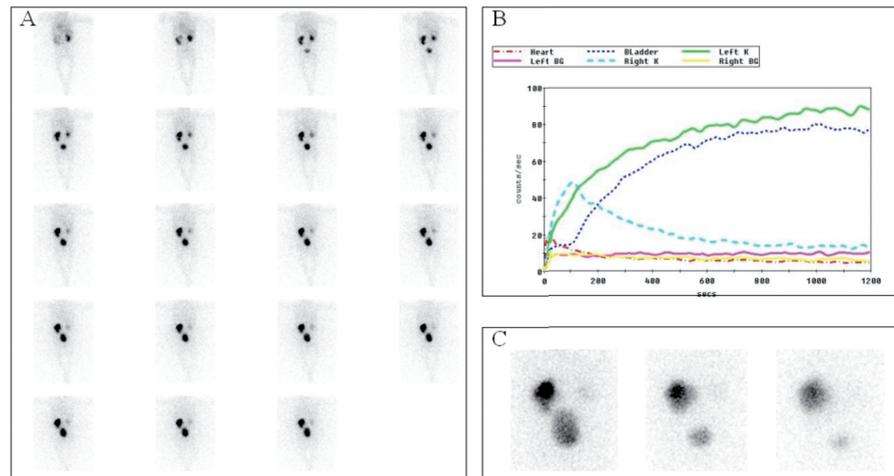*Courtesy of Centre Hospitalier Universitaire Vaudois*

Figure 5: F0 diuretic renography performed in a 3 months old boy presenting a left pelviuretic junction stenosis. One-minute posterior views show asymmetric tracer extraction, the left kidney being less active than the right, with significant urinary flow impairment at the left pelviuretic junction (A). Both left and right renograms show preserved renal function on the initial ascending phase of the curves (B). No voiding is observed during the 20-minute dynamic acquisition, and late post-void static views are mandatory to confirm the level of flow impairment (C).

amining neonates or infants. Most guidelines recommend a frame-duration of 10 to 20 seconds. Some institutions use a 2-phase acquisition, using a more rapid sequence (0.5-1 sec/frame) for the first 30 to 40 seconds to study the renal blood flow. A low-energy all-purpose collimator is used; and the camera is positioned facing-up. In renal transplanted children, an anterior acquisition is performed; and the camera should be tilted in order to come as close as possible to the grafted kidney. Independently of the chosen time for diuretic administration, at least 2 static views of 1 to 2 minutes have to be acquired: the first one immediately after the end of the first dynamic study with the bladder full and the second one just after voiding. In toilet-trained children, the voided volume is measured allowing calculating the flow rate (ml/min) as well as the residual bladder volume. In case of a persistent abnormal delayed urinary drainage, a change of position from supine to standing or prone position should be obtained during 5 to 10 minutes (with or without dynamic acquisition), with a delayed static view using the same parameters as with acquisition of the pre- and post-void images (Figure 5).

Even in the presence of an impaired urinary drainage, a dynamic acquisition of the voiding phase may be helpful by showing a vesico-ureteral reflux in the contralateral kidney or incomplete bladder emptying (Figure 6).

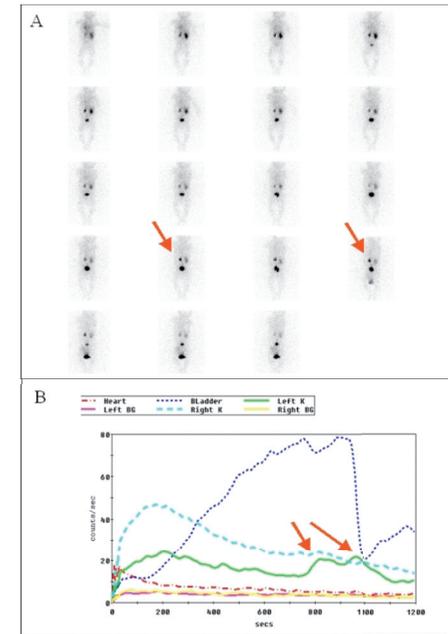*Courtesy of Centre Hospitalier Universitaire Vaudois*

Figure 6: F0 diuretic renography in a 6 months old boy with persisting left moderate hydronephrosis. A previous micturating cystourography did not show any vesico-ureteric reflux. One-minute posterior views show a small heterogeneous left kidney and a normal right kidney (A). Under furosemide, urinary flow is normal for both kidneys. Renal curves show an increase of renal activity (arrows) with a "double-peak" appearance in the left kidney just before micturition (B). These findings correspond to a high-grade vesico-ureteric reflux seen on the reframed one-minute views (arrows) at the 14th and 16th minute, just before voiding, and consistent with the diagnosis of left reflux nephropathy.

Diuretic administration

Furosemide is very effective and one of the least toxic drug used in children [19]. In children with normal renal function a log-dose response curve was demonstrated to a 1 mg/kg dose of intravenously given furosemide suggesting that higher dose may not induce significant increase in diuretic response. The recommended time of furosemide injection is either at 20 min post-injection of the tracer (F+20) or at the same time (F0) [14, 15, 20]. The advantages of simultaneous administration of tracer and diuretic is to provide a shorter examination time and a single intravenous puncture with no need to let an indwelling intravenous catheter which is obviously less invasive in neonates and infants. Another issue is that early furosemide injection will induce spontaneous voiding at least one time during the dynamic acquisition thus minimising radiation burden by accelerating urinary flow and drainage. The F-15 method (furosemide being injected 15 minutes before the tracer) should be restricted to equivocal cases. Up to now no timing has proven to be better than the other, but the F0 method is gaining in popularity and should be recommended because it provides a shorter examination time, avoids repeated intravenous punctures and contributes to decrease the radiation burden to the child [6-8].

Excretion of the radiopharmaceutical

Using the F0 diuretic renogram induces a more rapid transit of the tracer through the renal parenchyma, especially in a normal non-dilated kidney (Figure 2). In a well-hydrated child, time-to-peak may be as low as 100 seconds; and special attention must be paid to the interval chosen for determining split renal function: the usually recommended interval from 1 to 2-2.5 min may not be appropriate under high urinary flow condition emphasising the need for critical look to the study, in particular to the raw dynamic acquisition [21-24]. Regions of interest (ROIs) must include the entire renal parenchyma; and the window level should be modified to enhance the contrast between kidney and background. In newborns and infants with markedly enlarged renal pelvis, the parenchyma of the affected kidney may be difficult to differentiate from liver or spleen activity on initial images. Consensus guidelines recommend the use of perirenal background ROIs which represent the best compromise of the structures overlying the kidneys that may affect the quantification of renal function: the subrenal ROIs generally underscore the vascular component whereas the use of liver/spleen ROIs underestimates the tissular component [21-24]. Special attention must be paid when drawing background ROIs of young children with important hydronephrosis: it may be partially outside the body leading to a falsely increased function of the affected kidney. To provide a coherent report of the study, quantifications of renal function and urinary drainage must be correlated with the images. Despite the efforts made towards standardisation of the acquisition and processing of diuretic renography, there are still major differences in the final reporting of urinary drainage under furosemide [22]. A poor or absent urinary flow has to be interpreted with respect to renal function: a poor functioning kidney may not be able to respond to the diuretic, emphasising the need to obtain postvoid and late images.

Radiation safety

Diuretic renography using tubular tracers is one of the less radiating nuclear medicine procedures due to short biological half-life of the tracer and minimal recommended activity. According to the ICRP 80 and based on minimal recommended activity to be administrated (Tc-99mMAG3 = 15 MBq, I-123-hippuran = 10 MBq, Tc-99m-DTPA = 20 MBq), the effective dose delivered in a child with normal renal function and bladder emptying 30 minutes post injection is 0.12 mSv, 0.19 mSv and 0.28 mSv, respectively [25]. The early furosemide injection (F0 method) will induce spontaneous voiding in neonates and infants resulting in less radiation dose (Table 4).

Table 4. Radiation dosimetry of renal tracers in children according to age. (ICRP 80, Radiation dose to patients from radiopharmaceuticals. Annals. ICRP, Vol 28/3, 1998. Pergamon Press.)

Radiopharmaceutical	Effective dose (mSv/MBq)			
	1 year	5 year	10 years	15 years
Tc-99m-MAG3 (normal renal function)	0.022 (*0.006)	0.012 (*0.004)	0.12 (*0.003)	0.009 (*0.002)
Tc-99m-MAG3 (abnormal renal function)	0.019	0.011	0.01	0.008
Tc-99m-MAG3 (acute unilateral renal obstruction)	0.038	0.022	0.017	0.012
I-123-hippuran (normal renal function)	0.034 (*0.019)	0.019 (*0.011)	0.019 (*0.009)	0.015 (*0.007)
Tc-99m-DTPA (normal renal function)	0.016 (*0.014)	0.009 (*0.008)	0.008 (*0.007)	0.006 (*0.005)

* if bladder is emptied 0.5 hours after administration

Conclusion

Diuretic renography is a common nuclear medicine procedure performed in children and provides useful information to the clinician for the management of children presenting congenital malformations of the urinary tract and/or urinary tract infections. It is safe, simple and minimally invasive. The concomitant administration of the diuretic with the radiopharmaceutical (F0 method) is gaining in popularity and should be recommended because it avoids repeated venous punctures, shortens the duration of the procedure and lowers the radiation burden. By allowing a dedicated space to paediatric patients in the department, a well-trained staff and sufficient time to explain the procedure will allow to examine most children adequately, without any sedation.

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