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Renal imaging

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Renal imaging with compounds labelled with the radionuclide technetium-99m (^{99m}Tc) is widely performed to evaluate the renal system and provide mainly functional but also some anatomical information. There are primarily two types of imaging: static and dynamic.

Static renal imaging

^{99m}Tc-dimercaptosuccinic acid (DMSA) is the tracer used in static imaging. Following intravenous (iv) injection, it is taken up in the proximal tubules where it is fixed. Imaging is performed three hours later and should include anterior, posterior and right and left lateral oblique views to give the best depiction of outline. The scan gives good definition of the cortical outline of the kidney.

A normal study shows smooth homogeneous uptake of tracer with a lower concentration in the collecting system (Fig 1). Normal variants include prominent columns of Bertin and flattening of the left superolateral aspect due to splenic impression. DMSA studies can be used to identify and diagnose many conditions, including horseshoe kidney (Fig 2), cross-fused renal ectopia, duplex systems and kidneys outside the normal anatomical location (eg pelvis), all of which may have been missed on ultrasound.

The main abnormality assessed with DMSA is cortical scarring due to reflux and infection. This appears as areas of decreased uptake in the cortex, with cortical thinning and volume loss (Fig 3). The major pitfall is that acute pyelonephritis may give this appearance for up to three months following infection. It is therefore necessary to know whether there has been a recent urinary tract infection; if so, follow-up studies at 3–6 months should be performed. Defects due to the acute infection will resolve, whereas scars are permanent.

DMSA also provides non-invasive accurate assessment of the differential function of the kidneys (normal range for each 45–55%) (Fig 1); it may also be used to measure the differential function within one side (eg a duplex).

Single-photon emission computed tomography or pinhole imaging is sometimes performed; this enables visualisation of smaller lesions/scars and may increase the level of certainty.[1,2]

Dynamic renal imaging

The two most commonly used tracers in dynamic renal imaging are ^{99m}Tc-mercaptoacetyltriglycine (MAG-3) and

Key Points

- **Nuclear medicine renal imaging provides important functional information on the kidneys**
- **Dynamic renography can be used to evaluate many conditions, including obstruction, renal artery stenosis and vesico-ureteric reflux**
- **^{99m}Tc-dimercaptosuccinic acid identifies renal scarring and gives differential function**
- **In renal transplants, acute rejection can be differentiated from acute tubular necrosis**
- **Glomerular filtration rate can be evaluated by non-imaging studies with low radiation dose**

KEY WORDS: captopril renogram, ^{99m}Tc-dimercaptosuccinic acid (DMSA), glomerular filtration rate, ^{99m}Tc-mercaptoacetyltriglycine (MAG-3), obstructive uropathy, renal scarring

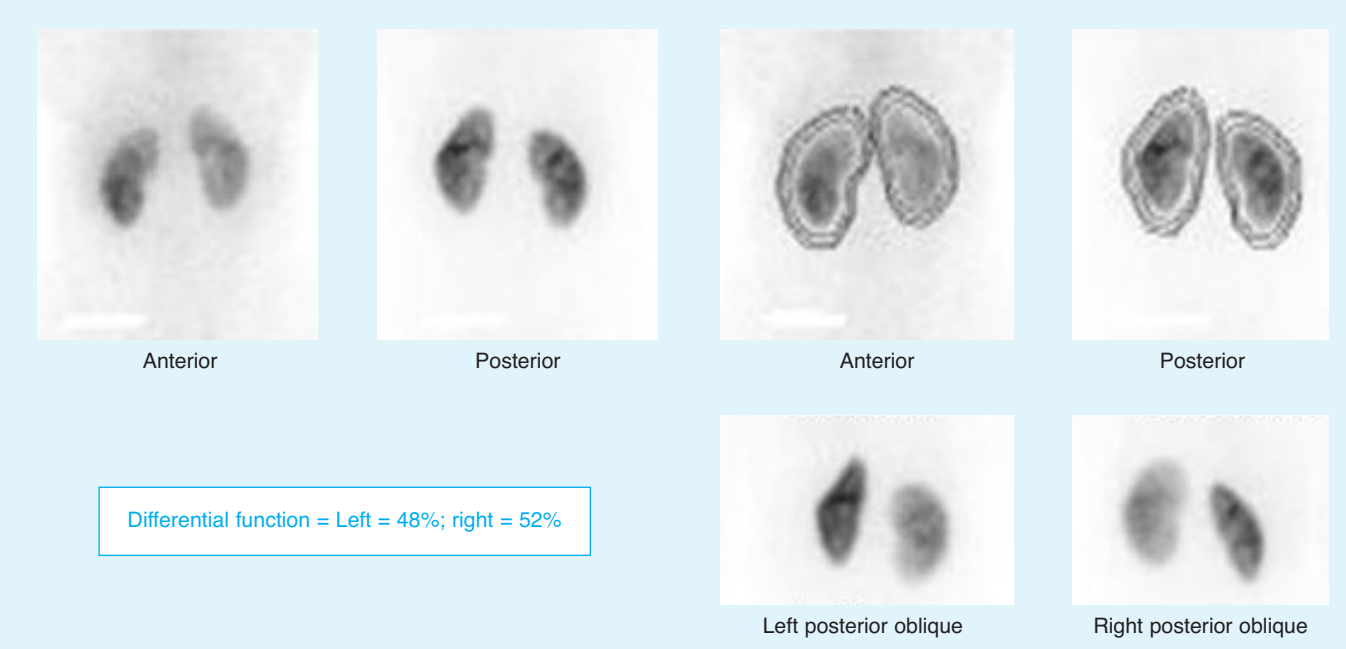


Fig 1. Normal ^{99m}Tc-dimercaptosuccinic acid study showing homogeneous tracer uptake throughout both kidneys with no cortical defects. Regions of interest drawn around images on the upper right will give differential uptake of radioactive tracer in each kidney and allow calculation of differential function.

diethylenetriaminepentaacetic acid (DTPA). MAG-3 is now largely replacing DTPA as it has better extraction efficiency and therefore offers better imaging with a lower absorbed radiation dose.

The dose is given as an iv bolus; the first 30 sec represent the vascular phase and blood flow to the kidney. The tracer is then extracted by the kidney and renal function assessed at two minutes when there is good renal visualisation and depiction of the relative distribution in each kidney. This gives a differential function estimate for the kidneys, although not as accurate as by DMSA imaging. The tracer is then rapidly excreted by the kidney, cortical activity therefore decreases and is seen in the collecting system (by 5 min). Continuing to image up to 20–30 min will show progressive excretion of the tracer with bladder accumulation. Abnormality at each phase provides diagnostic information. A renogram curve is generated from the data which involves drawing regions of interest (ROIs) around the kidneys, bladder and background. The number of counts in each ROI is counted for each image frame, the counts are plotted against time and background is subtracted. The results for a normal kidney are shown in Fig 4.

Obstructive uropathy

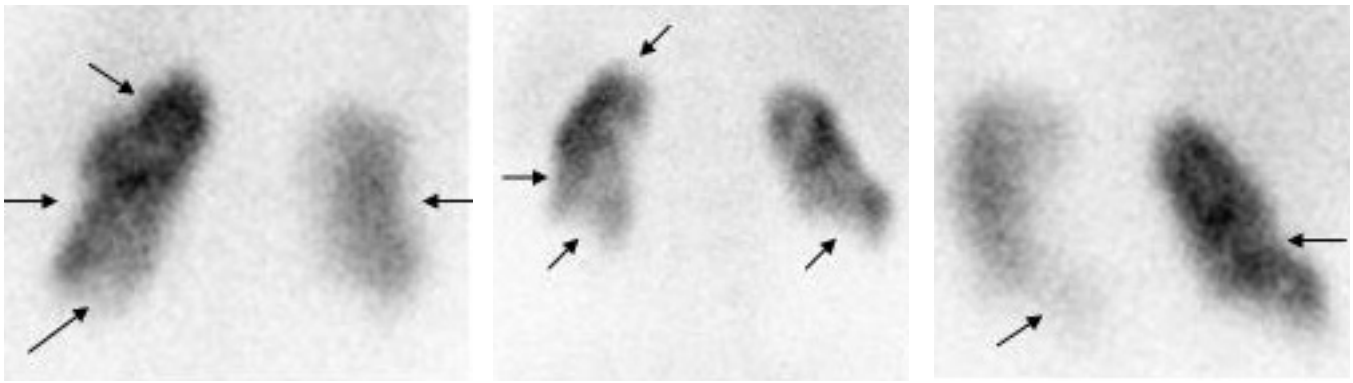
One of the commonest indications for renography is diagnosis and evaluation of obstruction. The cause is not always elucidated and, because of its functional nature, the value of renography lies in its ability to help decide whether intervention is necessary. When intervention is appropriate, serial studies can be performed for subsequent monitoring. Upper tract obstruction, idiopathic hydronephrosis and pelvi-ureteric junction obstruction are the most common indications for renography in this context. It can also be useful in:

- patients with renal calculi for assessment of acute obstruction, monitoring of progress and timing of intervention
- ureterocoele
- cases of differential obstruction in a kidney (eg duplex kidney, where obstruction is more likely in the upper pole moiety), and
- possible obstruction in urinary diversions.

In obstruction, the scan shows retention of tracer in the pelvicalyceal system. The first change on the curve is flattening

Fig 2. ^{99m}Tc-dimercaptosuccinic acid study showing a horseshoe kidney.

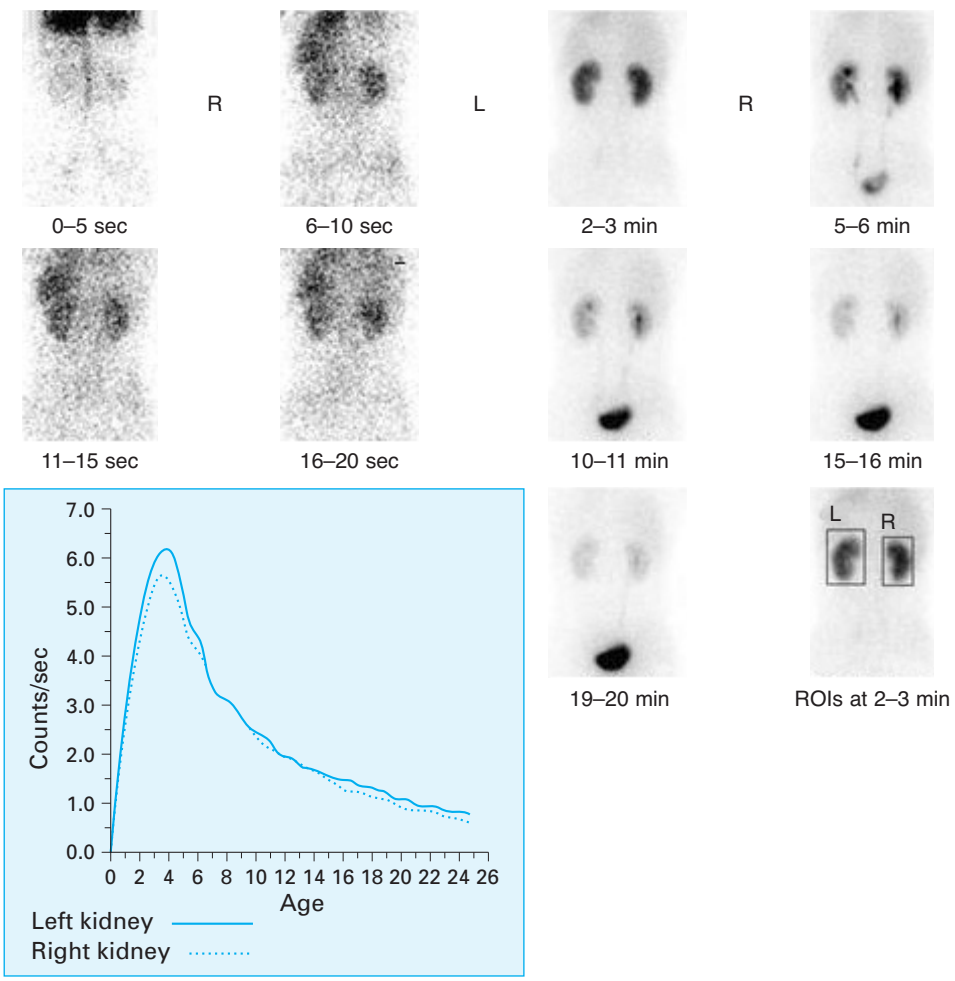
Fig 3. ^{99m}Tc-dimercaptosuccinic acid study showing cortical scarring (arrows) due to reflux and infection.



Left posterior oblique | Posterior | Right posterior oblique

of the third phase. With established obstruction, the second phase is prolonged and the curve continues to rise. At worst, all phases are affected due to ensuing poor renal function. An initial MAG-3 study may have the appearance of obstruction with retention of tracer in the pelvicalyceal system and an increasing renogram curve where there is no true obstruction (eg in a baggy, slowly excreting pelvicalyceal system). Thus, a basic study with increasing phase 2 on the renogram is not diagnostic for obstruction. To overcome this, diuretic renography is used which involves the administration of furosemide to increase urinary flow rates. The furosemide can be given before the start of the study, at

Fig 4. Normal ^{99m}Tc-mercaptoacetyltriglycine (MAG-3) study with derived renogram curves. ROI = region of interest.



Left kidney contribution to renal function = 52%; no furosemide administered.

the start or afterwards, involving further imaging to derive furosemide clearance curves.

All methods show good results but entail varying patient discomfort levels and scan length (Fig 5). Some units use further derived data for evaluation, including clearance half-time and output efficiency. The clearance half-time is the time taken for half the activity present in the kidney to be excreted. Normal values can be set by various methods: for example, by using linear best fit to the washout curve, in which case obstruction is assumed when clearance half-time is greater than 20 minutes and excluded if less than 15 min. Output efficiency, another frequently measured parameter, is the percentage of tracer entering the kidney excreted in 20 min (normally >80%).[3]

Dynamic studies are also useful in patients with lower tract obstruction (eg vesico-ureteric junction obstruction) and show rapid washout from the upper tract into a dilated lower tract.

Vesico-ureteric reflux

Nuclear medicine imaging can be used to diagnose and monitor vesico-ureteric reflux, an important problem in children and occasionally adults. One option is an indirect study following a dynamic study, where the patient (who must be toilet trained) has a bladder full of radioactive urine and micturates while the dynamic scan is acquired. Because a routine dynamic study is performed first, additional information on renal function is obtained. The other method is a direct study in which a catheter is inserted and radioisotope injected into the bladder.

Both methods achieve good results and the degree of reflux can be quantified (although reflux can be intermittent).[4] A major advantage of both methods, but particularly the direct one, is that a considerably lower radiation dose is delivered than with conventional micturating cystourethrography.

Hypertension

The major role of nuclear medicine in hypertension lies in the screening and diagnosis of renal artery stenosis (RAS). Any changes are noted in standard dynamic renograms performed before and after captopril administration. Qualitative assessment is based on alteration in the appearance of the renogram curve, with prolonged time to peak, and grading is possible according to the severity of change.[5] Scans can be classified as of low, intermediate or high probability for RAS:

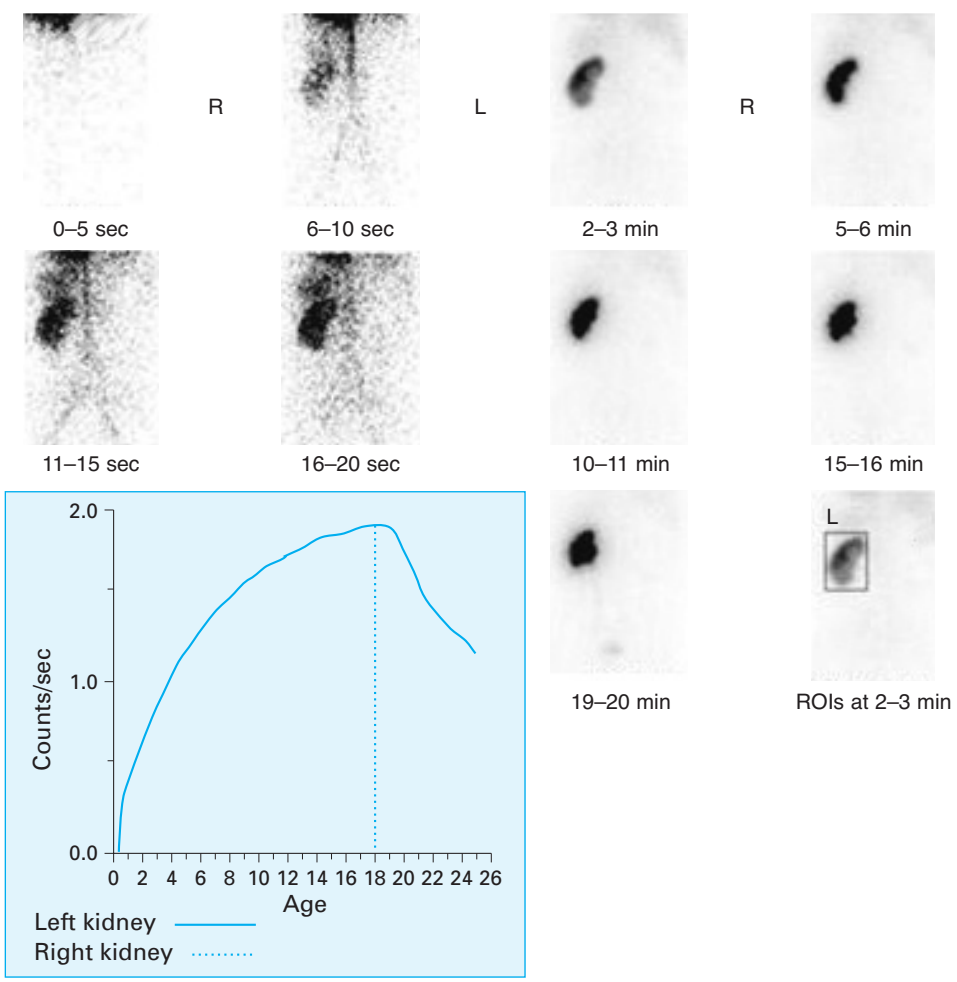


Fig 5. ^{99m}Tc-mercapto-acetyltriglycine (MAG-3) study in a single left kidney. There is prompt perfusion and extraction of tracer. The second part of the renogram curve is abnormal and continues to rise until 18 min, suggesting possible obstruction. Following furosemide administration at 18 min, the curve demonstrates prompt excretion, indicating no obstruction. iv = intravenous; PI = post injection; ROI = region of interest.

Left kidney contribution to renal function = 100%; 40 mg iv furosemide administered at 18 min PI.

- *low probability*: split renal function at baseline greater than 45%, time to peak less than five minutes, residual cortical activity at the end of the study below 45%, no changes after captopril
- *high probability*: increase of 0.15 in the ratio between 20-minute activity and peak activity and of at least two minutes in the time to peak increases post-captopril.[6,7]

Bilateral disease is more difficult to diagnose, but one kidney tends to be affected more than the other. In a poorly functioning kidney, the baseline MAG-3 study is abnormal anyway and the scan may be of intermediate probability. Most studies show a sensitivity of over 90%.[8]

Transplantation

Renal transplants can be monitored by nuclear medicine imaging. Typically, this will involve dynamic studies, with serial studies providing the best information about change. MAG-3 can be useful in differentiating acute rejection from acute tubular necrosis which usually has reasonable perfusion and extraction of tracer but without excretion. The most important feature of acute rejection is impaired perfusion. Dynamic imaging can also identify urinary leaks, lymphocoeles and vascular obstruction. DMSA scans can be of use in identifying scarring and infarcts.

Glomerular filtration rate

Measurement of glomerular filtration rate (GFR) is important in patients with decreasing/changing renal biochemistry and those on renotoxic chemotherapeutic agents. Inulin is the gold standard for measuring GFR. However, inulin is not acceptable for routine human use; other substances, in particular chromium-51 labelled ethylene diamine tetra-acetate, can be used as alternatives. After iv injection of the tracer one or more blood samples are taken over a few hours. The study does not involve imaging; the radioactivity is counted in commercial counter systems and calculations performed to produce an individual GFR when the patient's height and weight are known. The dose of radiation from the procedure is very low, which aids serial studies.

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