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^{99m}Tc-DMSA renal cortical scanning: a comparison of planar, SPECT, and SPECT/CT imaging for the detection of renal cortical scarring

Nsreen R. A. Mohamadien[1], Marwa S. Mohamed[2], Mohamed A. Mekkaway[1], Wageeh A. Ali[3*] and Waleed A. Diab[1]

Abstract

Background The best way to assess renal cortical scarring is planar scintigraphy with ^{99m}Tc-dimercaptosuccinic acid (DMSA), while the value of single-photon emission computed tomography/computed tomography (SPECT/CT) is not well validated. The aim of the present study was to assess the value of planar, SPECT, and SPECT/CT scanning using ^{99m}Tc-DMSA in detecting renal cortical scarring.

Methods Patients with clinically suspected renal cortical scar were included in this prospective cohort. ^{99m}Tc-DMSA Planar images were obtained approximately 3–4 h after intravenous injection (IV) of 185 MBq of the tracer. SPECT/CT scans were obtained immediately after the planar ones. An expert nuclear medicine doctor who was unaware of the patient's clinical history or any previous imaging results analyzed the images. Each kidney was given a score of 0 for no obvious defects, 1 for equivocal lesions, 2 for a single defect, 3 for several defects, and 4 for non-visualized/non-functioning kidney (in CT images). The results of each method were then compared to each other.

Results One hundred eighty-six kidneys from ninety-three individuals were eligible for assessment. Planar scans detected 21 kidneys with equivocal lesions, 5 with single and 7 with multiple defects. SPECT scans detected 17 kidneys with single and 40 with multiple defects, while SPECT/CT scans revealed 5 with single and 11 with multiple defects. Only 5 of the 17 kidneys with single defects diagnosed by SPECT imaging had a scar in the SPECT/CT scans, whereas the remaining 12 had a solitary cortical cyst in the CT images. Only 11 of 40 kidneys with multiple defects on SPECT were shown to have a scar in the corresponding SPECT/CT images, whereas the rest matched to either hydro-nephrotic changes or multiple cortical cysts. Four kidneys with multiple defects on the SPECT/CT images were normal in the planar readings, were ascribed to an increase in renal background activity and a reduction in renal function.

Conclusions In cases with suspected renal cortical scar, ^{99m}Tc-DMSA SPECT/CT scanning outperformed both planar and SPECT imaging by reducing the number of false-positive SPECT readings and false-negative planar readings.

Keywords Renal scarring, Cortical defects, ^{99m}Tc-DMSA, SPECT/CT

*Correspondence:
Wageeh A. Ali
Drwageeh@Yahoo.Com; Drwageeh_abdelhafeez@Aun.edu.eg
Full list of author information is available at the end of the article

Background

Renal scarring is a well-known, severe renal condition that can lead to life-threatening complications such as chronic renal failure and hypertension. Typically, a biopsy is performed to ascertain the cause of renal scarring; however, this invasive technique is not advisable [1, 2]. Severe pyelonephritis is the primary cause of renal scarring in childhood [3].

Renal scarring can be detected using various diagnostic techniques, such as urography, ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), and radionuclide scintigraphy [4]. CT has a similar sensitivity and specificity to cortical scanning; but comes with a larger risk of contrast reaction and higher radiation exposure. MRI is a promising non-ionizing way, yet it is costly[5].

Renal cortical scintigraphy is used to detect cortical abnormalities associated with acute and chronic pyelonephritis. Cortical scintigraphy can detect twice as many abnormalities as ultrasound and four times as many as intravenous urography[6].

Traditionally, a Tc-99 m DMSA renal scintigraphy has been performed as a planar image. However, because planar imaging is a projection image, the photon-deficient area located behind the normal renal parenchyma may be obscured. In addition, planar scans have inadequate resolution and can miss tiny kidney abnormalities. SPECT scanning may detect relatively small photon-deficient regions with three-dimensional information and a rather homogenous background. Thus, renal SPECT imaging is a useful diagnostic technique. Recent investigations have demonstrated that Tc-99 m DMSA renal SPECT imaging offers no diagnostic advantage over planar imaging for detecting cortical abnormalities in children and adults, despite SPECT imaging has demonstrated superiority over planar imaging in a variety of clinical scenarios[7, 8].

The aim of the present study was to evaluate the value of planar, SPECT, and SPECT/CT imaging using ^{99m}Tc-DMSA in detecting renal cortical scar.

Methods

Patients

Following approval by our Institutional Review Board for this prospective study, we obtained informed consent from all study's participants (parents in case of children). The study was conducted during the period from 16 August 2020 till 16 August 2022.

Inclusion criteria

- Patients with history of pyelonephritis and clinically suspected cortical scar.

Exclusion criteria

- Patients with significant pyelonephritic changes in the US.
- Patients who cannot lie down comfortably without movement during the imaging period.
- Pregnant females.

Timing of the scan: Functional changes associated with acute renal infection cannot be easily distinguished from scarring, so a delay of 3 to 6 months between the last episode of UTI and DMSA scan is acceptable[9].

Imaging protocol

- *Preparation of the patient for scintigraphy:* No special patient preparation is required.
- *Planar acquisition:* Planar imaging of the abdomen was taken 2 to 4 h after intravenous injection (IV) of 185 MBq of the tracer [10] (The pediatric dose was modified according to recent guidelines; 1.85 MBq /kg with a minimum dose of 18.5 MBq) [11, 12]. Using a Siemens Symbia T dual-head gamma camera fitted with a low energy all-purpose (LEAP) collimator and a 20% energy window set to 140 keV. Patients were scanned while lying on their backs and every effort was made to keep them from moving. Matrix: 256 × 256 pixels with magnification set to obtain a preferred pixel size of 2–4 mm. At least 200,000 total counts per view were obtained. Views include an anterior, posterior, 45° anterior oblique, and 45° posterior oblique.
- *SPECT/SPECT/CT acquisitions*: SPECT imaging of the abdomen is performed immediately following planar imaging using the same camera and patient's position. Total of 32 frames, each frame lasting for 25 s and utilizing a 128 × 128 matrix size in a non-circular 360-degree arc. Every care was taken to avoid movement. Following the acquisition of the SPECT, a low-dose, non-contrast CT was obtained for attenuation correction and anatomical localization. The CT parameters used were; tube voltage of 130 kV, 80 mA tube current, and 5 mm slice thickness. In children, the ALARA (As Low As Reasonably Achievable) principle was followed, aiming

to minimize radiation exposure to the lowest level necessary for accurate diagnosis (tube voltage of 80 kV, 20 mA tube current)[13]. The entire SPECT/CT acquisition took about 20–25 min. SPECT, CT, and fused images produced in the three conventional projections (axial, coronal, and sagittal) should be co-registered to facilitate reliable comparison between the image sets for optimal display.

- *After imaging:* The patient was advised to empty his bladder frequently during the day of imaging, to reduce radiation dose to the urinary system.

Image interpretation

A nuclear medicine consultant (10 years of experience after residency training) blindly interpreted the images.

Planar images: were reviewed visually for the presence or absence of both kidneys in their normal anatomical site and size. Tracer accumulation in each kidney was graded in score points where; score 0 (normal) uniform tracer distribution with no defects, score 1; equivocal defect, score 2; single defect, score 3; multiple defects and score 4; non-visualized/non-functioning (in CT images).

SPECT and SPECT/CT scans were scored in the same way as in planar images.

Statistical tests

SPSS; 26.0 software (IBM Corp, Armonk, NY, USA) was used for data interpretation. The quantitative data were summed and reported as means ± standard deviations, while the qualitative data were expressed as frequencies and percentages. The Cohen Kappa test was used to measure the degree of agreements between the imaging methods where the degree of agreement was considered almost perfect (Kappa value: 0.81–1), substantial (Kappa value: 0.61–0.80), moderate (Kappa value: 0.41–0.60), fair (Kappa value: 0.20–0.40), slight (Kappa value: 0.00–0.20) and poor (Kappa value: < 0.00). *P*-Value < 0.05 was considered significant.

Results

Patients

This study recruited a total of 186 kidneys from 93 patients (55 men and 38 females, mean age: 31.9 ± 18.5, age range: 2–79 years), 24/93 patients were less than 18 years. The mean total GFR was 80.6 ± 24.7 ml/min (15–125 ml/min). The CT characteristics of each kidney are illustrated in Table 1.

Table 1 Kidney features as shown on CT

CT parameter	Frequency (%)
Anatomical site of the kidney	
Normal	180 (96.8%)
Ectopic	6 (3.2%)
Size of the kidney	
Normal	130 (69.9%)
Small sized	15(8.1%)
Enlarged	41(22%)
Cortical thickness	
Normal	129 (69.4%)
Decreased	57 (30.6%)
Stones	
Present	44(23.7%)
Absent	142 (76.3%)
Cortical cyst	
Solitary	12 (6.45%)
Multiple	21 (11.9%)
Hydronephrotic changes	8 (4.30%)

Image analysis

On kidney-based analysis, planar images revealed 145 normal kidneys (Fig. 1), 8 non-visualized kidneys, 21kidneys with equivocal lesions, 5 with single and 7 with multiple defects. Regarding SPECT images it showed 121 normal kidneys, 8 non-visualized kidneys, no equivocal lesions, 17 kidneys with single and 40 with multiple defects, however SPECT/CT images detected 162 normal kidneys, 8 non-functioning kidneys, no equivocal lesions, 5 kidneys with single and 11 with multiple defects. Most cases with cortical defects (81.25%) had lesions in the upper or lower pole of the kidney, yet only 3 lesions were found in the middle lobe.

Planar and SPECT scans agreed on the reading of 132 kidneys (115 normal kidneys, 2 with single defect, 7 with multiple defects and 8 non functioning kidneys) and disagreed in the reading of 54 ones with a fair degree of agreement (Kappa value of 0.40 and $P < 0.01$). Planar and SPECT/CT images agreed on the readings of 151 kidneys (138 normal kidneys, one with single defect, 4 with multiple defects and 8 non functioning kidneys), they disagreed on the readings of 35 ones with a moderate degree of agreement (Kappa value of 0.41 and $P < 0.01$). SPECT and SPECT/CT images agreed in the reading of 141 kidneys (120 normal kidneys, 3 with single defects, 10 with multiple defects and 8 non functioning kidneys), and disagreed in the readings of 45 ones with a moderate degree of agreement (Kappa value of 0.42 and $P < 0.01$) (Tables 2, 3 and 4).

On SPECT scans; six out of the 21 kidneys with equivocal readings on the planar imaging were confirmed to be normal, 7/21 had a single defect, and 8/21 had multiple defects, whereas 19/21 were confirmed to be normal, 1/21 had a single defect, and 1/21 had multiple defects on SPECT/CT scans.

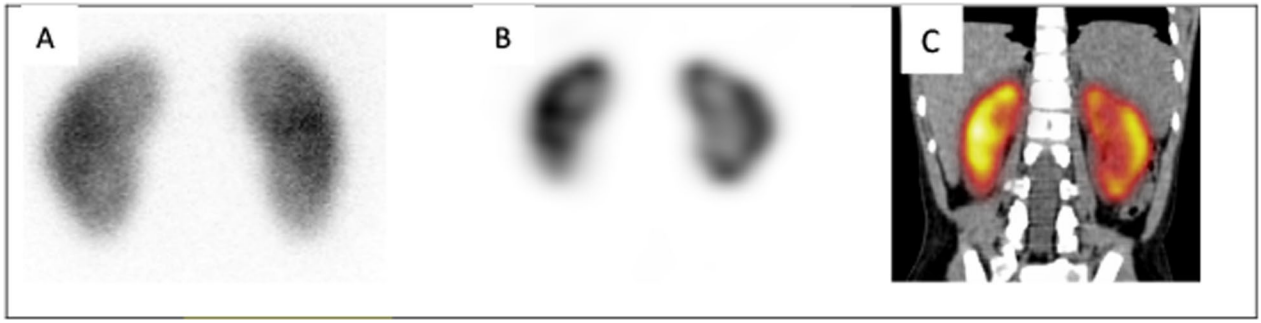

Fig. 1 A 18-year-old, female patient, presented with right loin pain. **A** ^{99m}Tc-DMSA planar image (posterior view) demonstrating uniform tracer uptake over both kidneys. **B** Coronal SPECT and **C** the corresponding fused SPECT/CT image shows uniform tracer distribution with no detectable defects in both kidneys

Table 2 Agreement between Planar and SPECT readings

	SPECT readings				P-Value
	No defect	Single defect	Multiple defects	Non-functioning	
Planar Readings					
No defect	115	8	22	0	< 0.01*
Equivocal	6	7	8	0	
Single defect	0	2	3	0	
Multiple defects	0	0	7	0	
Non visualized	0	0	0	8	

*Kappa test

Table 3 Agreement between Planar and SPECT/CT readings

	SPECT/CT readings				P-Value
	No defect	Single defect	Multiple defects	Non-functioning	
Planar Readings					
No defect	138	3	4	0	< 0.01*
Equivocal	19	1	1	0	
Single defect	2	1	2	0	
Multiple defects	3	0	4	0	
Non visualized	0	0	0	8	

*Kappa test

Table 4 Agreement between SPECT and SPECT/CT readings:

	SPECT/CT readings				P Value
	No defect	Single defect	Multiple defects	Non-functioning	
SPECT Readings					
No defect	120	0	1	0	< 0.01*
Single defect	14	3	0	0	
Multiple defects	28	2	10	0	
Non visualized	0	0	0	8	

*Kappa test

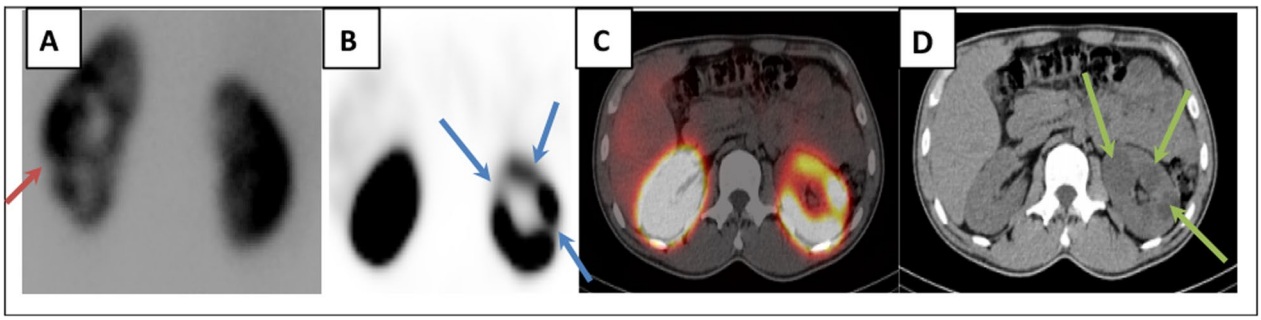

Fig. 2 A 25-year-old, male patient, presented with left loin pain. **A** ^{99m}Tc-DMSA planar image (posterior view) demonstrating equivocal defect at the lower outer aspect of the left kidney (red arrow), **B** axial SPECT image revealed multiple left cortical defects (blue arrows), **C** the corresponding fused SPECT/CT and **D** the CT images shows that these defects are corresponding to multiple simple cortical cysts (yellow arrows)

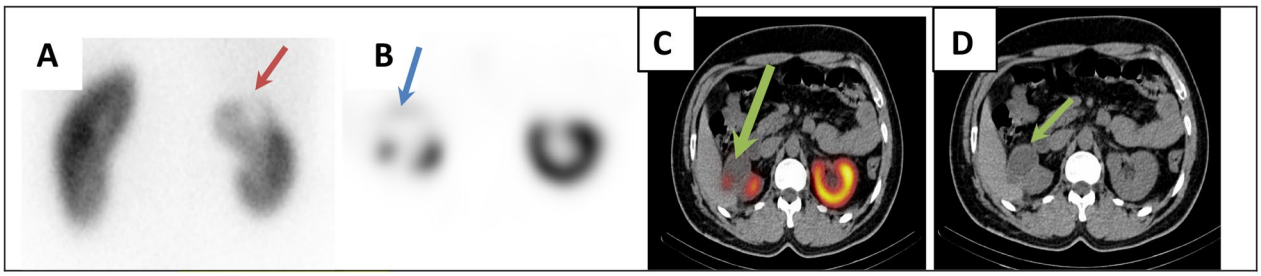

Fig. 3 A 43-year-old, male patient, presented with right loin pain. **A** ^{99m}Tc-DMSA planar image (posterior view) demonstrating defect at the upper outer aspect of the right kidney (red arrow), **B** axial SPECT image revealed right cortical defects (blue arrow), **C** the corresponding fused SPECT/CT and **D** the CT images shows that the defect is corresponding to simple cortical cyst (yellow arrows)

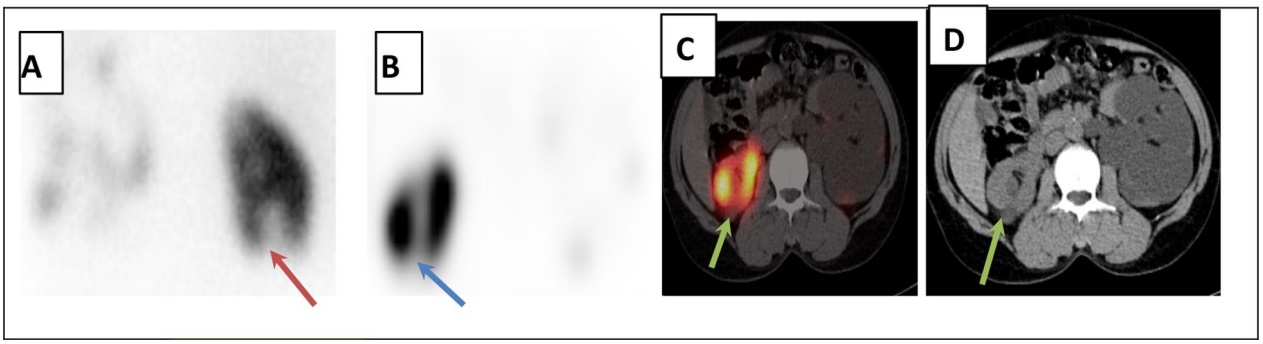

Fig. 4 A 50-year-old, female patient, presented with left loin pain. **A** ^{99m}Tc-DMSA planar image (posterior view) demonstrating defect at the lower pole of the right kidney (red arrow) and hardly visualized left one, **B** axial SPECT image revealed right lower cortical defect (blue arrow) and non functioning left kidney, **C** the corresponding fused SPECT/CT and **D** the CT images shows that the defect is corresponding to small exophytic right cortical cyst (yellow arrows) as well as hydronephrotic left kidney

Only five of the 17 kidneys with single defects identified by SPECT scanning had a scar in the SPECT/CT scans, while the 12 remaining kidneys matched a single cortical cyst in the CT images (Figs. 2, 3 and 4). 11 out of 40 kidneys with multiple positive defects in the SPECT imaging were confirmed to have a scar in SPECT/CT scans. The remaining kidneys corresponded to either hydro-nephrotic changes or multiple cortical cysts. Four kidneys with multiple defects in the SPECT/CT scans were normal in planar imaging, which were ascribed to reduced renal function and increased extra-renal background activity.

Discussion

Urinary tract infection is regarded as one of the most common bacterial infections in children, acute pyelonephritis may lead to renal scarring which may cause later renal sequel, such as hypertension and renal insufficiency [14].

^{99m}Tc- DMSA scan is currently the gold standard for detecting renal parenchymal abnormalities, particularly scarring in pyelonephritis [15]. Various acquisition techniques, such as planar parallel-hole collimator imaging, planar high-resolution parallel-hole collimator imaging, pinhole collimator imaging, SPECT, and pinhole SPECT, have been utilized [16].

Planar imaging is the most widely used approach; however, it is limited to two-dimensional data. SPECT is employed in certain centers as it is thought to be more sensitive and add some specificity. However the 3D aspect of SPECT alone suffers from a lack of precision and accuracy in diagnosis due to lack of accurate anatomical information, the use of hybrid imaging techniques with SPECT-CT may help in diagnostic accuracy and ultimately patient management[17].

In the present study, we assessed the value of ^{99m}Tc-DMSA renal cortical planar, SPECT and SPECT/CT imaging in detecting renal cortical scarring.

In concordance with ours, several studies found a higher percentage of cortical defects to be located at the upper and lower zones of both kidneys and attributed this predominant polar distribution of renal cortical scarring to be related to the reflux of sterile or infected urine into compound or refluxing papillae situated at the renal poles [18–21].

In meta-analysis comparing DMSA SPECT to planar imaging revealed that the former had small number of true-positive results at the expense of larger percentage of false-positive with the overall test performance is not demonstrably superior to planar DMSA, similarly we found a high number (41) of false-positive lesions [22].

In line with our results, Everaert et al. reported that SPECT detected more defects than planar imaging, although there was no statistical significance [23].

Several studies have evaluated the value of Tc-99 m DMSA renal triple-detector SPECT compared to planar imaging and revealed promising results for SPECT and that high-resolution SPECT scanning increase the ability to detect cortical defects and depict the asymmetry of renal cortical thickness, the discrepancy in results may be attributed to the better image resolution provided by the triple-detector SPECT with ultra-high-resolution collimators; however, this triple-detector system is currently not widely available[24, 25].

Shah et al., stated that the utilization of SPECT/CT with DMSA can help to identify the etiology of the photopenic defect, for example, due to fetal lobulation, scarring, cyst or renal tumors[26]. Einarsdóttir et al., concluded that SPECT/CT may boost reader confidence further by defining renal structures and enhancing specificity by offering diagnostic hints to lesions that are not scarring [27], in line with the previously mentioned studies we found that SPECT CT accurately ruled out scaring in 41 kidneys where the defects corresponded to a solitary renal cortical cyst, hydro-nephrotic changes or multiple cortical cysts,.

Tc-99 m DMSA uptake in the thin cortex of hydronephrotic kidney was susceptible to partial volume effects in SPECT that it appears as reduced uptake regions resembling renal scar. In such case, regional uptake defects shown by DMSA scintigraphy may include renal scars as well as some false positives and other problems like fetal lobulation and splenic impression[18]; according to that, we interpreted our results, where only 5/17 kidneys with single lesions and 11/40 with multiple lesions had been proved to have scars in the SPECT/CT scans while the remaining lesions corresponded to a solitary renal cortical cyst, either hydro-nephrotic changes or multiple cortical cysts, so SPECT CT accurately ruled out scaring in 41 kidneys.

SPECT CT successfully diagnose scarring (multiple defects) in four kidneys with normal planar imaging, and this was ascribed to reduced renal function and increased renal background activity; these figures come in agreement with those of Farghaly et al.[28].

Limitations and recommendations

The small sample size and the heterogeneous age of the study population were the current limitations of our study. On the contrary, the advantage of our study was the use of SPECT/CT imaging, which helped reduce false results of SPECT and planar imaging. We recommend further prospective study with a larger sample size to validate our results; additionally, we recommend using SPECT/CT in cases with equivocal readings in planar images and patients with decreased renal function and subsequently raised background activity.

Conclusion

In cases with suspected renal cortical scar, ^{99m}Tc-DMSA SPECT/CT scanning outperformed both planar and SPECT scanning by reducing the number of false-positive SPECT readings and false-negative planar readings.

Abbreviations

^{99m}Tc-	Technetium 99 m
DMSA	Dimercaptosuccinic acid
SPECT	Single-photon emission computed tomography
SPECT/CT	Single-photon emission computed tomography/computed tomography

IV	Intravenous
MBq	Mega Beqrel
LEAP	Low energy all-purpose

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Author contributions
All authors contributed to study concepts and design; WAA, NRAM, WAD, MAM. MMA, MSM contributed to case recruitments, imaging data interpretation and analysis. All authors contributed to literature research, manuscript drafting, revision and editing. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author reasonable on request.

Declarations

Ethics approval and consent to participate
The study has been approved by the Ethical Committee of the Faculty of Medicine, Assiut University, assigned the approval IRB number: 17101168. An informed written consent was obtained from all the participants in the study. Confidentiality and data anonymity were maintained during all steps of the study.

Consent for publication
Not applicable.

Competing interests
The authors of this study state clearly that there is no actual or potential competing of interests.

Author details
[1]Department of Clinical Oncology and Nuclear Medicine, Faculty of Medicine, Assiut University, Assiut, Egypt. [2]Department of Radiotherapy and Nuclear Medicine, South Egypt Cancer Institute, Assiut University, Assiut, Egypt. [3]Department of Diagnostic and Interventional Radiology, Department of Radiodiagnosis, Faculty of Medicine, Assiut University Hospital, Assiut, Egypt.

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