Does Three-Dimensional Display of SPECT Data Improve the Accuracy of Technetium-99m DMSA Imaging of the Kidneys?

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Objective: The purpose of this study was to determine if volume-rendered three-dimensional displays could improve the accuracy of reporting renal cortical scars in patients imaged with ^{99m}Tc dimercaptosuccinic acid (DMSA).

Methods: We compared volume-rendered three-dimensional displays of SPECT data for 20 patients, with a total of 37 kidneys, with SPECT data displayed as transaxial, coronal and sagittal slices as well as planar images. All patients were imaged 2–3 hr after administration of a standard dose of 2 mCi (74 MBq) of ^{99m}Tc DMSA and the results were reported using two readings of the images 14 days apart.

Results: SPECT imaging displayed as transaxial, coronal and sagittal views improved the number of scars found by 21%. This was increased to 30% when a three-dimensional display was used. Also the use of a three-dimensional display allowed normal variants such as surface folds and hepatic impressions to be more easily identified.

Conclusion: Volume-rendered three-dimensional display of ^{99m}Tc DMSA SPECT data increases the number of defects reported as renal cortical scars. Further work is needed to determine if this improvement is clinically relevant.

Key Words: SPECT; three-dimensional display; volume-rendered; ^{99m}Tc DMSA; renal scarring

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The accurate identification of renal cortical scars in reflux nephropathy is essential in reducing subsequent morbidity (*1*). Imaging of the kidneys with ^{99m}Tc dimercaptosuccinic acid (DMSA) has been demonstrated as the most sensitive method available for the identification of renal cortical scarring (*2*). Imaging is normally performed 2–3 hr after administration of 2 mCi (75 MBq) of ^{99m}Tc DMSA. Planar images are obtained for between 500k and 1000k counts using a high-resolution or pinhole collimator. The standard images obtained include a posterior, left and right posterior obliques and often an additional anterior view.

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SPECT has been suggested as a method by which the accuracy of identification of renal scarring can be improved. Early results were disappointing (*3,4*) but more recent results, in which images have been obtained using dedicated high-resolution multiheaded gamma cameras, have demonstrated an increased sensitivity in finding small scars in both adults and children (*5*). Images are usually displayed in three views as series of coronal, sagittal and transaxial slices. As a consequence many images must be viewed to ensure that no part of the renal cortex is missed. Since renal scars occur on the surface of the kidney, we hypothesized that a further improvement in reporting of scars would be obtained if the SPECT data were displayed as a three-dimensional image.

The aim of this study was to compare the number of renal cortical scars identified from ^{99m}Tc DMSA scintigraphy using planar imaging, SPECT data displayed in three views as coronal, sagittal and transaxial slices and SPECT data displayed as a three-dimensional image.

METHODS

Study Design

Planar and SPECT images were obtained prospectively from 20 consecutive patients imaged with ^{99m}Tc DMSA. To check for consistency in the reporting of renal scars by the observers and for the identification of normal variants, the studies were reported on two separate occasions. Two observers, blinded to the patient's history and clinical condition, were used on the first reading and they were joined by a third observer, also blinded, for the second reading. Because it was not possible to perform histological examination of the kidneys after imaging, the number of scars consistently seen on planar, three-view SPECT (coronal, sagittal and transaxial) and three-dimensional display were compared.

Patients

Twenty consecutive patients referred for ^{99m}Tc DMSA scintigraphy for the identification of renal cortical scarring were imaged. Though renal cortical scarring was suspected in all patients this had not been diagnosed before ^{99m}Tc

DMSA imaging. The mean age was 32 (range 8–54 yr). Thirty-seven kidneys were imaged (two patients had received a renal transplant and one patient had a single kidney). All patients had a history of at least one documented urinary tract infection but were not included if this infection had occurred in the six weeks preceding the ^{99m}Tc DMSA scintigraphy.

Imaging

All patients were imaged 2–3 hr after the administration of 2 mCi (75 MBq) of ^{99m}Tc DMSA. Planar imaging was performed using a 400AC Starcam gamma camera and computer system (International General Electric, Paris, France) fitted with a low energy, high-resolution collimator. Posterior and left and right posterior oblique images of 600K counts each were obtained. Following this, high-resolution SPECT images were acquired in 128 × 128 word for 16 min using a three-headed GCA-9300A gamma camera computer system (Toshiba Medical Systems BV, Delft, The Netherlands) fitted with parallel hole, low energy, high-resolution collimators. A total of 4–5M counts were obtained per patient. Tomographic data were acquired continuously over 360°. This data was then binned into 60 projections.

SPECT Data Processing

A Shepp Logan back projection filter (cut-off frequency 0.8 cycles/cm) was applied and data reconstructed using a Butterworth filter (filter number 18). Images were displayed as three views (transaxial, coronal and sagittal slices) and recorded on x-ray film for reporting.

Three-dimensional volume-rendered images were obtained from the transaxial data set. A standard cut-off of 40% of maximum pixel activity was used (as recommended by Toshiba and kept unchanged to ensure a consistent result in all images). Sixty-four projections were produced over 360°. Images were rotated through an axis parallel to the long axis of the patient's body and a 10% gradient shading was used.

Reporting

The planar and the three-view SPECT slices were reported from x-ray film. The three-dimensional image was reported directly from a video monitor which was part of the gamma camera computer system. Initially two observers were used to report the images simultaneously. They were unaware of the patient's history or any results from previous investigations. As a kidney may have multiple lesions, each kidney was divided into five similar-sized zones from the upper to the lower poles. A scar was defined as a renal cortical defect that could not be explained by an anatomical variant. If a defect, which was thought to be a scar, extended into two or more zones then all zones affected were reported positive. Any disputes between observers were discussed until concensus was reached.

For each patient the three-dimensional image was reported first, followed on a separate day by the three-view SPECT slices, followed on a third day by the planar images. This order was chosen so that the observers would not be biased by seeing the more familiar planar images first.

To check for consistency, the images were re-reported, using the same sequence, two weeks later. To reduce the chance that the original observers would be biased by their previous reading of the studies, they were joined by a third observer who had not seen the images before. Again the images were reported simultaneously. All observers had experience in viewing all three types of display of ^{99m}Tc DMSA data.

TABLE 1
Number of Zones with Scars Seen on Planar, on Transaxial, Coronal and Sagittal SPECT Slices and on Three-Dimensional Display of ^{99m}Tc DMSA Renal Images

	1st Reading			2nd Reading		
Patient	Planar	SPECT	3-D	Planar	SPECT	3-D
1	0	0	1	0	0	1
2	0	1	1	0	0	0
3	0	0	0	0	0	0
4	0	2	1	0	0	1
5*	0	3	3	0	3	3
6	0	2	0	0	0	0
7	5	7	6	6	6	6
8*	5	5	5	5	5	5
9	0	2	2	0	2	2
10	3	6	6	3	6	6
11	5	5	6	5	5	5
12*	2	2	3	3	4	4
13	1	1	0	1	1	1
14	0	0	0	0	0	0
15	2	2	4	2	4	4
16	0	0	0	0	0	1
17	0	1	0	0	0	0
18	1	2	1	1	2	2
19	3	2	3	3	3	3
20	7	6	8	6	6	8

*Single kidney only

RESULTS

When we compared the results of planar imaging and SPECT in this study, more renal cortical scars were seen with SPECT, both when displayed as transaxial, coronal and sagittal slices and when displayed as a three-dimensional image (Table 1, Fig. 1). Thirty-three scars were seen on planar imaging but the three-view SPECT data allowed an additional 15 scars (45%) to be seen on the first reading. On the second reading 13 more scars (39%) were seen as compared to planar imaging. Seven of the defects first reported as scars on the first reading were re-reported as normal on the second reading. Forty scars were consistently seen on both readings, hence an increase of seven scars (21%) were consistently seen on both readings compared with planar imaging (Table 2). In addition five new scars, not seen on planar imaging, were identified on the second reading alone.

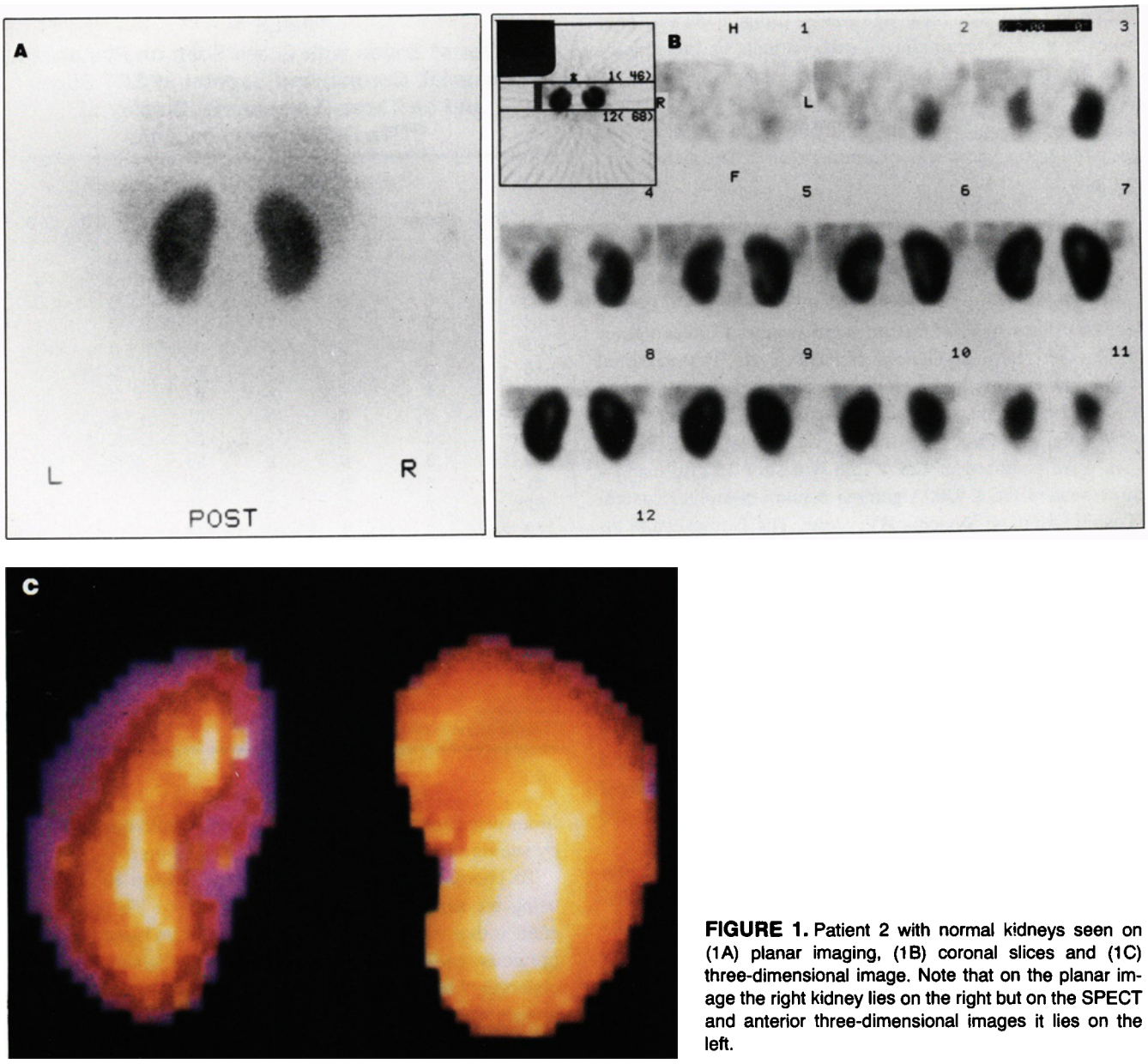

FIGURE 1. Patient 2 with normal kidneys seen on (1A) planar imaging, (1B) coronal slices and (1C) three-dimensional image. Note that on the planar image the right kidney lies on the right but on the SPECT and anterior three-dimensional images it lies on the left.

TABLE 2
Comparison of the Number of Renal Cortical Scars Seen with Planar Imaging, with Transaxial, Coronal and Sagittal SPECT Slices and with Three-Dimensional Display

	Planar	SPECT	3-D
Scars seen consistently on both 1st and 2nd readings	33	40	43
Scar only seen on 1st reading, normal variants	1	7	2
Defect only seen on 2nd reading	1	5	5

Using the three-dimensional SPECT display, 17 more scars (51%) were seen on the first reading and 19 more scars (57%) were seen on the second reading (Fig. 2). Only two scars were re-reported as normal on the second reading compared with the planar imaging. An additional five scars, not seen on planar imaging, were identified on the second reading alone. Therefore, 43 scars were consistently reported in both first and second readings using a three-dimensional display, an increase of 10 (30%) over planar imaging and three (9%) over three-view SPECT.

Five patients (25%) were reported as normal on planar imaging but had consistent scars found with SPECT on both first and second readings. In two patients a single scar was only seen on the three-dimensional display. A third patient with a normal planar study had three scars seen with three-view SPECT and with a three-dimensional display. A fourth patient had two scars only seen with SPECT using both

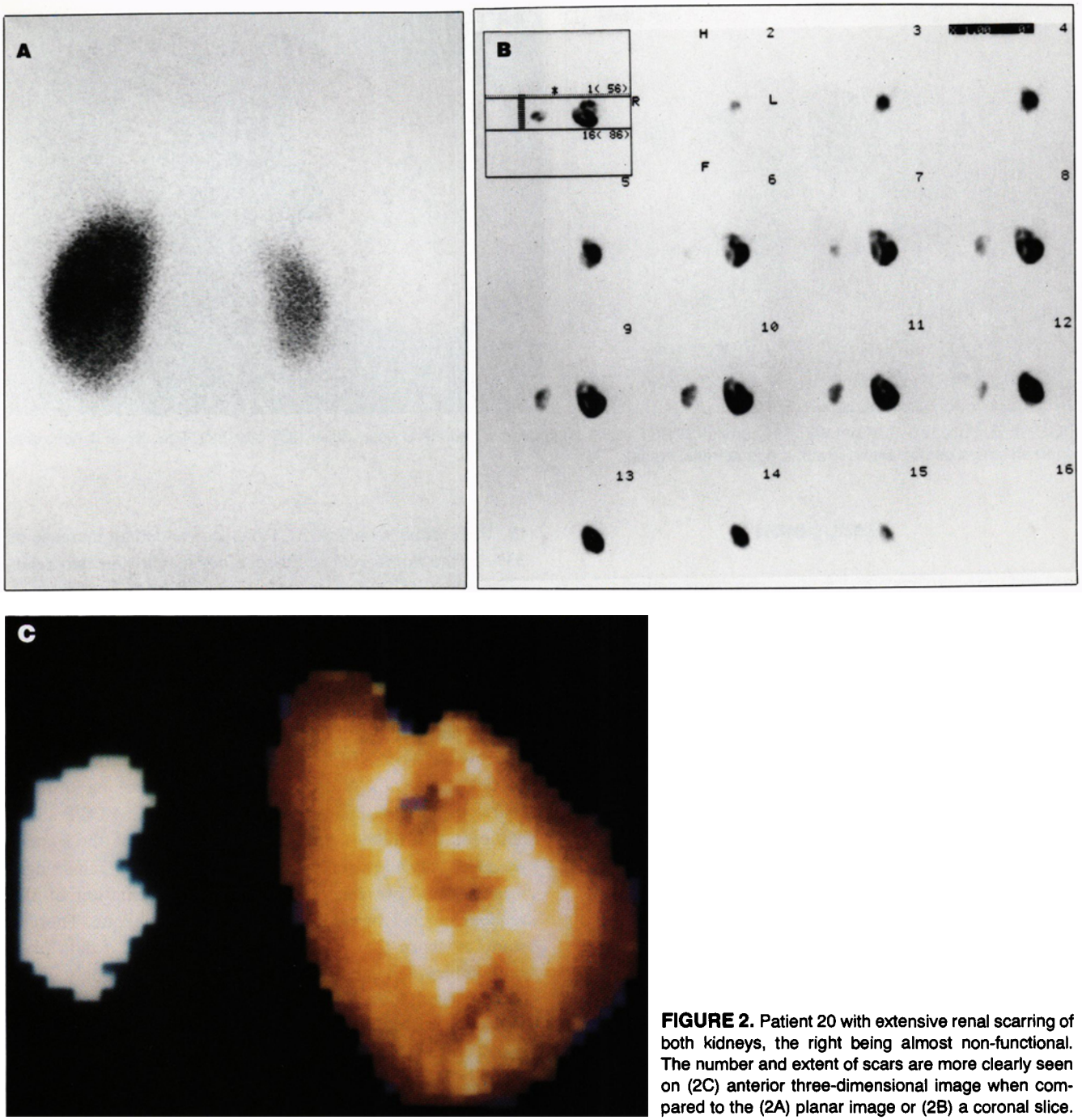

FIGURE 2. Patient 20 with extensive renal scarring of both kidneys, the right being almost non-functional. The number and extent of scars are more clearly seen on (2C) anterior three-dimensional image when compared to the (2A) planar image or (2B) a coronal slice.

types of display and the fifth patient had one scar only seen with SPECT using both types of display.

Three patients had scarring reported on the first reading with SPECT but this was thought to be a normal variant on the second reading (Fig. 3). These defects were reported as defects in all three patients using three-view display but in only one with the three-dimensional display.

When the images were reread there was more consistency in reporting defects in the planar images with only two changes in the number of scars reported between first and second reading and the least consistency in reporting from the three-view SPECT with 12 changes between first and second readings. The normal variant, which was most commonly reported as a scar on the first reading, was a fold which appeared on the medial surface close to the hilum of the kidney; the remaining normal variants being hepatic and splenic impressions. All of these variants were more clearly seen on the first reading using a three-dimensional display. The size and extent of any scars could be more easily appreciated with the three-dimensional image. This was particularly true in those kidneys which had unusual or abnormal anatomy.

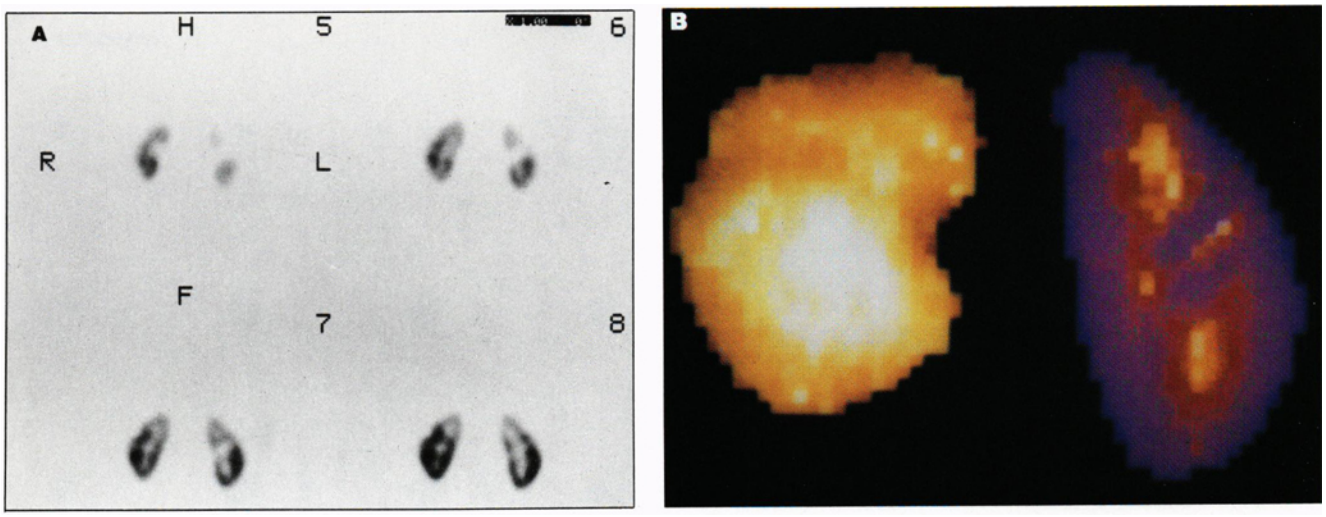

FIGURE 3. Patient 6 in whom the (3A) coronal SPECT slices suggested a peripheral scar, but a (3B) posterior view, three-dimensional rendered image demonstrated it was a normal renal crease.

DISCUSSION

SPECT imaging has developed an important clinical role in the diagnosis of myocardial disease (*6*), bone disease (*7*) and diseases of the brain (*8*). The use of SPECT in renal work has been advocated by many authors but has not become routine (*3–5*). One of the problems of using slices of SPECT data is that surface renal cortical scars can be very small and may therefore only be seen on one or two slices. A technique is required which combines the advantages of the improved contrast resolution of SPECT and the ability to see the surface of the kidney as a whole.

This study was therefore performed to compare the results of the three-dimensional image built from SPECT slices with SPECT data displayed as transaxial, coronal and sagittal slices as well as planar images. Despite some advantages in this method, there has been little published data on its use in nuclear medicine. Data from use with bone scintigraphy has shown that it was useful in the hips (*9*) but less useful in the spine where a change in bone shape was required before a change in the three-dimensional image could be seen (*10*). One problem is that in the skeleton abnormalities such as metastases are often in the middle of the bone and do not affect the surface seen with a three-dimensional SPECT image. However, this is not the case with scarring of the renal cortex where the defects are on the surface of the organ being imaged. As a consequence, it would seem that a volume-rendered three-dimensional display of SPECT data would be ideally suited to improving the sensitivity of ^{99m}Tc DMSA in finding small renal cortical scars. A recent survey of high-resolution SPECT in renal disease included three-dimensional SPECT data but there was no comment on how that data had improved the reporting of scars. The data from transaxial, coronal and sagittal SPECT slices had been combined with the three-dimensional SPECT images to determine that overall SPECT had a sensitivity 30% higher than planar imaging when looking for renal scars (*5*). In our study the three-dimensional SPECT images yielded an increase of 33% in the number of scars seen consistently in two readings. When SPECT data was displayed in three views, as transaxial, coronal and sagittal slices, the increase in sensitivity was only 21%. The increased sensitivity with SPECT obtained by Tarkington et al may be because a three-dimensional display was used (*5*). This may be why centers which do not use this type of display may not have found a marked improvement of SPECT over planar imaging in finding renal cortical scars (*11*). A further problem when looking for renal scars, using transaxial, coronal and sagittal SPECT slices alone, is that many computer systems, such as the system we used, only allow reconstruction of SPECT data in a single orientation. This can lead to some disorientation of the reader especially if the kidney is lying very oblique. There is some evidence that more scars are visualized if data from each kidney is reconstructed separately and obliquely in the plane of each kidney (*12*).

However problems remain with the use of a three-dimensional SPECT display for ^{99m}Tc DMSA scintigraphy. First there is a definite learning period, as we observed when seven lesions which were first reported as scars on the three-view SPECT display were later felt to be normal structures. This was less of a problem with the three-dimensional display, probably because folds on the surface of the kidney and hepatic and splenic impressions are more easily visualized. Problems also arose seeing the medial surface of the kidney on the three-dimensional image. The software we used did not allow volume clipping so both kidneys had to be imaged together. Consequently the view of the medial surface of one kidney could be obscured by the presence of the second kidney.

Despite these encouraging findings, there remains the problem that the increase in both the number of scars and the number of patients reported as having scarring with SPECT may not be real but artifactual. Great variability remains

particularly with SPECT data displayed as transaxial, coronal and sagittal slices. There is also a problem due to the lack of objective evidence to confirm scarring. Standard non-isotopic imaging techniques are less sensitive in finding renal scars than is planar ^{99m}Tc DMSA scintigraphy (*13,14*). Direct histological examination of the kidney is not acceptable and local renal biopsy would only sample a small part of the renal cortex. A kidney could be recorded as scarred only when the differential function in that kidney fell below 45% of total renal function, but this would require a significant loss of renal tissue and be dependent on only one kidney being affected by reflux uropathy and subsequent scarring.

In pigs, in which renal infections have been induced, SPECT ^{99m}Tc DMSA identified 97% of the renal cortical defects found at autopsy. Planar imaging was only able to find 43% of these defects (*15*). These results have yet to be verified by additional studies, but it is further evidence that ^{99m}Tc DMSA SPECT is superior to planar, and in our experience this is further improved if a three-dimensional display is also used.

CONCLUSION

Three-dimensional display of SPECT data from ^{99m}Tc DMSA scintigraphy appears to consistently improve the sensitivity of the technique in finding both the number of patients with renal cortical scars and the number of scars identified as compared with planar imaging or SPECT data displayed as transaxial, coronal or sagittal slices. Three-dimensional display will also allow the correct identification of those normal structures which may appear as scars on SPECT displayed in three views as transaxial, coronal and sagittal slices. Further work must be done to confirm or refute these findings.

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