Parathyroid Imaging Using Simultaneous Double-Window Recording of Technetium-99m-Sestamibi and Iodine-123

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Technetium-99m-sestamibi represents an important advance in the scintigraphic location of parathyroid neoplasms. However, the optimal procedure for ^{99m}Tc-sestamibi parathyroid scanning has not been defined. The first objective of this work was to optimize the technical aspects of subtraction scanning, using simultaneous double-window recording of ^{99m}Tc-sestamibi and ^{123}I instead of successive image recording. The second objective was to compare two protocols for detecting abnormal parathyroid glands: subtraction scanning and single-tracer double-phase scanning. **Methods:** Thirty patients referred for first surgery of primary hyperparathyroidism had both subtraction scanning and double-phase scanning in the same imaging session. Images of ^{99m}Tc-sestamibi and ^{123}I were recorded simultaneously in nonoverlapping windows and then subtracted. For double-phase scanning, images of ^{99m}Tc-sestamibi, acquired 15 min and 120 min after tracer injection, were visually compared. Surgery disclosed a solitary adenoma in 27 patients, bilateral adenomata in 2 patients and 3 hyperplastic glands in the last patient. No patient had persistent hypercalcemia. **Results:** Preoperative ^{99m}Tc-sestamibi/^{123}I subtraction scanning located 25 of 27 solitary adenomas, the bilateral adenomata and 3 of 3 hyperplastic glands. The overall sensitivity for enlarged parathyroids was 94%, and the false-positive image rate was 3%. The ^{99m}Tc-sestamibi single-tracer technique located 22 of 27 solitary adenomas, the bilateral adenomata and 1 of 3 hyperplastic glands. Overall sensitivity was 79% and the false-positive image rate was 10%. The gamma camera imaging time was 30 min for the subtraction technique and 50 min for the single-tracer double-phase study. An ectopic adenoma in the sheath of the right carotid artery was detected by both techniques. **Conclusion:** These results, together with other data in the literature, indicate that ^{99m}Tc-sestamibi/^{123}I subtraction imaging is accurate in locating enlarged parathyroids. Classical difficulties of this technique (motion artifacts and prolonged immobilization) were avoided by using simultaneous recording of the two isotopes. In this series subtraction imaging was more rapid and more sensitive ($p < 0.04$) than the single-tracer technique.

Key Words: primary hyperparathyroidism; parathyroid; adenoma; hyperplasia; radionuclide study; parathyroid imaging; technetium-99m-sestamibi; MIBI; Iodine-123 subtraction; single-tracer technique; double-phase technique; subtraction scanning; dual-isotope imaging

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Many recent studies have shown that ^{99m}Tc-sestamibi is a useful tracer for locating abnormal parathyroid tissue (*1–8*) and offers advantages over other noninvasive methods, such as ultrasound, CT, ^{201}Tl/^{99m}Tc subtraction scanning and MRI. However, the optimal conditions for ^{99m}Tc-sestamibi parathyroid scanning have not been defined.

To differentiate the uptake of ^{99m}Tc-sestamibi in an enlarged parathyroid from that in the thyroid, several different scanning protocols have been used. Basically there are two techniques. In the subtraction technique, a complementary ^{123}I thyroid image is recorded and digitally subtracted from the ^{99m}Tc-sestamibi image (*2,4,5,7*). In the single-tracer, double-phase technique, ^{99m}Tc-sestamibi is used alone. An early image is recorded 15 min after tracer injection and a second, late image, is recorded 2 hr after injection (*3*). Interpretation then is based on prolonged retention of ^{99m}Tc-sestamibi in the enlarged parathyroid in comparison with the thyroid. A variant of the first technique uses ^{99m}Tc-pertechnetate instead of ^{123}I-iodide (*8*). There is also a single-tracer protocol that uses factor analysis to assess differential tissue washout of ^{99m}Tc-sestamibi (*6*).

The current study had two objectives. The first was to optimize technical aspects of the subtraction technique, using simultaneous double-window recording of ^{99m}Tc-sestamibi and ^{123}I instead of successive image recording (*2,4,5,7*). The second objective was to compare two methods for detecting abnormal parathyroid glands: subtraction scanning and single-tracer double-phase scanning. An image set combining the two techniques was used in 30 patients, and the results were compared prospectively.

MATERIALS AND METHODS

Phantom Study

Before clinical studies, a phantom study was performed to select the appropriate energy windows for simultaneous double-isotope acquisition. The phantom used as a radioactive source was a flat plastic flask (5 × 4 × 1 cm) placed 5 cm from the pinhole collimator at the center of the field of view of the camera.

The phantom first was filled with 3.7 MBq ^{123}I in 20 ml of water. Counts from the ^{123}I source were measured in the ^{123}I window but also in the ^{99m}Tc window. Photon scatter contaminating the standard symmetric 20% energy window of ^{99m}Tc was 7% of the counts in the ^{123}I window itself. Contamination was < 5% when the window for ^{99m}Tc was narrowed to 14% (140 keV ± 7%, energy interval 130–150 keV). Compared to the sensitivity using standard 20% energy windows, the reduction in sensitivity in detecting ^{99m}Tc itself was only 5%.

The same experiment was repeated with the phantom containing 3.7 MBq ^{99m}Tc. Counts from the ^{99m}Tc source contaminating the standard symmetric 20% energy window of ^{123}I was found to be as high as 17% of the counts in the ^{99m}Tc window itself. Contamination then was studied while gradually restricting the lower part of the ^{123}I energy window. The corresponding loss in sensitivity for ^{123}I itself also was studied. A good compromise was obtained when the window for ^{123}I was set asymmetrical around 159 keV with 4% lower and 10% upper limits (energy interval 153–175 keV). Using this setting, the ^{99m}Tc counts contaminating the ^{123}I window were less than 3% of the counts in the ^{99m}Tc window itself. Compared

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to the sensitivity using standard symmetric 20% energy windows, the reduction in sensitivity for ^{123}I was 15%.

Uniformity was tested, for the different energy windows, using the ^{57}Co plate, a general-purpose, parallel-hole collimator and the gamma camera preset correction matrix. Five million counts were acquired in a 256 × 256 matrix. For a standard symmetric 20% energy window, arround the 122-keV peak of ^{57}Co, the uncorrected and corrected integral uniformity values were 5.7% and 4.8%, respectively. For a symmetric window with lower and upper limits of 7%, the values were 5.6% and 4.2%, respectively. For an asymmetric window with 4% lower and 10% upper limits, the values were 5.4% and 4.8%, respectively. Acquisition of new uniformity flood corrections for these energy windows did not seem necessary.

Patients

Thirty consecutive patients referred for surgical management of primary hyperparathyroidism had prospective radionuclide scanning and surgery. All the patients had biochemical confirmation of hyperparathyroidism based on accepted diagnostic criteria. An image set combining the subtraction technique and the double-phase technique was used in each patient.

Data Acquisition

The patient received an intravenous injection of 10 MBq ^{123}I-iodide and 2–4 hr later, 550 MBq ^{99m}Tc-sestamibi. The patient was then positioned for imaging. Images of both isotopes were acquired simultaneously using two separate energy windows. Window limits were 140% ± 7% keV for ^{99m}Tc and 159 keV with a 4% lower limit and a 10% upper limit for ^{123}I. (The ^{123}I window was set asymmetric to avoid any crossover from ^{99m}Tc.) The image matrix was 256 × 256 × 16.

Five minutes after injection of ^{99m}Tc-sestamibi, a large anterior view of the neck and mediastinum (from the salivary glands to the heart) was obtained for 5 min using a general-purpose, parallel-hole collimator. A pinhole collimator then was mounted and an anterior view of the thyroid region was recorded for 10 min. Images of both isotopes were simultaneously recorded for all views (producing at the same time the distribution image of ^{99m}Tc-sestamibi and that of ^{123}I). Total camera time for parathyroid scanning using the ^{99m}Tc-sestamibi/^{123}I subtraction technique was 30 min. This included the time required for patient positioning and collimator exchange.

For the single-tracer, double-phase technique, an additional pinhole image of ^{99m}Tc-sestamibi was recorded 2 hr postinjection. (The corresponding ^{123}I image was simultaneously recorded to verify that the 5% crossover of iodine in the technetium window did not impair the reading of the late sestamibi image.) Camera occupation time for parathyroid scanning using the single-tracer technique was 50 min.

Scan Interpretation

Interpretation of the subtraction scan was based on the early ^{99m}Tc-sestamibi image, the ^{123}I image and the computer subtraction image. Increasing percentages of the ^{123}I image are subtracted from the ^{99m}Tc-sestamibi image, and the degree of subtraction is chosen interactively based on user satisfaction with the resulting difference image. Thyroid nodules suspected on the ^{123}I scan were indicated clearly as such.

Interpretation of the double-phase scan was based on visual comparison of the early and late ^{99m}Tc-sestamibi images. A positive double-phase scan for the presence of an enlarged parathyroid was defined as a focal area of increased uptake of ^{99m}Tc-sestamibi which showed, relative to the surrounding thyroid, either a gradual increase over time or a fixed uptake which persisted on delayed imaging contrary to the uptake in the surrounding thyroid tissue which gradually decreases over time (*3*). A drawing of the results obtained by each of the two protocols was established, before surgery, by the nuclear physician and the surgeon together.

Surgery

All 30 patients underwent surgery. An 88-yr-old patient with hemiplegia had unilateral neck exposure under local anesthesia. The remaining patients had standard formal bilateral neck exploration.

A total of 34 enlarged glands were resected; 65 normal parathyroids were inspected at surgery and some were biopsied. A solitary adenoma was found in 27 patients. The weight of these adenomas ranged between 60 mg and 4442 mg. One of these adenomas was ectopic, being located in the sheath of the right carotid artery. The remaining 3 patients had multiple parathyroid enlargement. All four parathyroid glands in these patients were inspected at surgery. Parathyroid glands which appeared normal and whose weight was estimated as being well below 50 mg were not removed. Of the patients with multiple parathyroid enlargement, 2 had bilateral adenomas (double adenomata) together with two normal parathyroid glands, and the third had hyperplasia with three enlarged glands. Nine patients in this series had concomitant thyroid nodules confirmed at surgery. None of the patients had persistent or recurrent hypercalcemia after 6–24 mo of follow-up.

Data Analysis

The preoperative sketch was compared to surgical findings. A location on a scan was considered true-positive only if it precisely corresponded to the surgical location. Lateralization alone was not sufficient. Sensitivity was defined as the ratio of true-positive locations to the sum of true-positive plus false-negative locations. The false-positive image rate was defined as the ratio of false-positive locations to the sum of true-positive plus false-positive locations. A scan was considered accurate if it detected all enlarged parathyroid(s) without giving false-positive images.

The sign test (*9*) was used to compare the results of subtraction scanning versus single-tracer double-phase scanning. The p value was obtained considering a binomial distribution with the probability 1/2 (*9*).

RESULTS

Technetium-99m-Sestamibi/Iodine-123 Subtraction Scanning

The subtraction technique located 25 of the 27 solitary adenomas (Table 1). In one of the patients, ectopic uptake of ^{99m}Tc-sestamibi, lateral to the upper right thyroid pole, allowed the resection of a gland in the sheath of the carotid artery. The subtraction technique predicted multiple gland disease in the three patients concerned, in whom it detected all seven enlarged glands (Table 2). In total, 32 of the 34 enlarged glands were located, providing an overall sensitivity of 94%. One false-positive image was due to misinterpretation of a thyroid nodule. The false-positive rate was 3% (1 of 33).

Technetium-99m-Sestamibi Single-Tracer Study

The single-tracer, double-phase technique identified 22 of 27 solitary adenomas, including the ectopic one (Table 1), the enlarged glands in the two patients with double adenomata, and only 1 of the 3 enlarged glands in the patient with hyperplasia (Table 2). In total, 27 of the 34 enlarged glands were identified (sensitivity 79%). There were three false-positive images, giving a false-positive image rate of 10% (3 of 30). All three false-positive images were attributed to thyroid nodules. The difference in sensitivity between the two scanning techniques was significant ($p < 0.04$).

TABLE 1
Solitary Adenomas Classified in Decreasing Weight: Comparison of Technetium-99m-Sestamibi/Iodine-123-Subtraction Versus Technetium-99m-Sestamibi Single-Tracer Imaging

Adenoma weight (mg)	Surgical location	Sestamibi/ ^{123}I	Sestamibi single tracer	Thyroid nodule(s)	Number of glands seen by surgeon	Ca (mmol/liter)	PTH (ng/liter)	Ca postsurgery (mmol/liter)
4442	R upper	+	+	No	3	2.7	71	2.3
2000	R upper	+	+	No	4	2.63	74	2.35
1870	R upper	+	+	No	4	2.92	80	2.2
1860	R lower	+	+	No	4	3.1	186	2.4
1600	R upper	+	+	No	3	2.8	75	2.28
1250	L lower	+	+	No	2	2.75	275	2.2
1163*	R lower	+	+	No	3	2.9	82	2.28
1150	R upper	+	+	No	3	2.9	160	2.33
995	L upper	+	+	No	4	2.65	90	2.4
995	L lower	+	+	No	2	2.98	109	2.28
938	L lower	+	+	No	4	2.9	114	2.28
817	L lower	+	+	No	3	2.73	90	2.5
757	L lower	+	+	Yes	3	2.88	63	2.2
720†	R lower	+	+	Yes	2	3.3	409	2.2
700	L lower	+	+	No	4	2.63	133	2.25
646	L lower	+	+	No	4	2.63	120	2.33
600	L upper	+	FN	No	3	3.25	80	2.5
562	R lower	+	FN	Yes	2	2.7	190	2.45
517	R upper	+	+ & FP	Yes	3	2.75	50	2.35
500	R lower	+	+	Yes	4	2.7	87	2.38
459	R lower	+	+	Yes	4	2.63	90	2.45
448	L lower	FN	FN & FP	Yes	4	2.88	206	2.28
398	L upper	+	+	No	3	2.75	71	2.4
390	R lower	+	FN	No	3	2.63	50	2.33
260	L upper	FN & FP	FN & FP	No	2	2.6	131	2.35
196	R lower	+	+	No	3	2.6	82	2.25
60	R lower	+	+	No	4	2.8	96	2.3

*Ectopic undescended gland located in the sheath of right carotid artery.
†Unilateral surgery.
Thyroid nodule(s) found on ^{123}I scan and verified at surgery are indicated. Number of glands seen by surgeon are the total number of parathyroids identified at surgery, including the solitary adenoma. Normal range for calcium, 2.2–2.6 mmol/liter and for PTH, 10–58 ng/liter. The PTH values of patients are those before surgery. The postoperative values for serum calcium were those recorded at 6 mo or more following surgery. FN = false negative; FP = false positive.

DISCUSSION

Two protocols for parathyroid scanning were compared: ^{99m}Tc-sestamibi/^{123}I subtraction and ^{99m}Tc-sestamibi double-phase scanning. One imaging set combining the two techniques was used in each of the 30 patients. Thus, biases due to interinstitution methodological variations and/or interseries variations were avoided. Although the comparison might have been better if we had performed two separate studies in each patient, this would have raised logistical problems.

Technetium-99m-sestamibi/^{123}I-iodine subtraction imaging had excellent overall sensitivity. Of 34 enlarged glands, 32 were detected (94%), and surgical removal of these glands was curative. There was no size limit for the detection of abnormal glands, as all six glands weighing less than 100 mg were detected (Tables 1 and 2).

Early work with the subtraction technique used successive separate image recording (*2,4,5,7*). Four hours after administration of ^{123}I-iodide, and after ensuring absolute neck immo-

TABLE 2
Detection of Enlarged Glands (≥ 50 mg) in Patients with Multiglandular Disease: Comparison of Technetium-99m-Sestamibi/Iodine-123-Subtraction Versus Technetium-99m-Sestamibi Single-Tracer Imaging

Patient no.	Enlarged glands	Weight (mg)	Sestamibi/ ^{123}I	Sestamibi single	Thyroid nodules	Number of glands seen by surgeon	Ca (mmol/liter)	PTH (ng/liter)	Ca postsurgery (mmol/liter)
1	L lower	446	+	+	Yes	4	2.3	61	2.2
	R upper	75	+	FN					
	R lower	71	+	FN					
2	L lower	90	+	+	Yes	4	2.68	78	2.3
	R upper	60	+	+					
3	L upper	2370	+	+	No	4	2.75	2086	2.2
	R upper	70	+	+					

FN = false-negative. Number of glands seen by surgeon are the total number of parathyroids identified at surgery. The normal parathyroids all were inspected. Their individual weight was estimated as ≤ 30 mg. The first patient had parathyroid hyperplasia. The actual diagnosis in the other two is double adenomata. The normality of postsurgery calcium level has been documented at 24 mo for the first patient, at 12 mo for the second and at 18 mo for the last patient.

bility, a pinhole image of the thyroid was recorded. Then, avoiding patient movement, ^{99m}Tc-sestamibi was injected, the energy window was changed and an image was acquired starting 5 min after injection. Finally, a large field-of-view image of the neck and mediastinum was obtained using a parallel-hole collimator. Processing included movement correction of the pinhole ^{99m}Tc-sestamibi image in relation to the pinhole ^{123}I image and then image subtraction. The overall sensitivity for parathyroid detection was 89% in our experience (*7*). The main drawback of successive imaging was the need for absolute neck immobilization during the time necessary for registration of the two pinhole images, including the critical phase of injecting the second tracer and, hence, susceptibility to motion artifacts (*3,10*). In this study, we used simultaneous recording of the two isotopes. Artifacts on the subtraction image due to patient movement are completely avoided. The imaging time is halved. There is also a small difference in sensitivity in favor of the simultaneous technique (94% versus 89%).

The energy peaks of ^{99m}Tc and ^{123}I are close, and one should carefully check for the absence of energy drift of the detector and select the windows for simultaneous acquisition. With the experimental setting used here (^{99m}Tc = 140 keV ± 7%, ^{123}I = 159 keV, with 4% lower and 10% upper limits), the cross-talk interference of each isotope into its nonprimary energy window is reduced to less than 5%. The reduction in count statistics due to the use of a narrow window for ^{99m}Tc-sestamibi acquisition is only 5%, and that of the asymmetric window of ^{123}I, 15%. Altogether, the imaging time for a double-isotope parathyroid study using simultaneous acquisition is half the time necessary for successive imaging.

The ^{99m}Tc-sestamibi single-tracer double-phase method was less efficient than the subtraction technique in detecting enlarged parathyroids (sensitivity = 79% versus 94%, $p < 0.04$). No lesion seen on double-phase scanning was missed by the ^{99m}Tc-sestamibi/^{123}I subtraction technique, while the opposite was true for five enlarged parathyroids (Tables 1 and 2). The single-tracer technique missed three adenomas that were detected easily by the subtraction method. The weight of these adenomas was 600 mg (Figs. 1 and 2), 562 mg and 390 mg. All three missed glands were in a eutopic location. At surgery, two of them were firm and their gross consistency resembled that of thyroid nodules. Pathologic examination of these parathyroid adenomas showed calcifications and vascular remodeling. For the third adenoma, without sestamibi retention, the only particular feature was an unusually rich capillary network.

In the classical double-phase method, ^{99m}Tc-sestamibi is the only injected tracer. Therefore, for each of the three patients, we verified that the ^{123}I signal in the thyroid did not compromise the loss of signal expected in a double-phase scan. Analysis of the late ^{99m}Tc-sestamibi images and ^{123}I images showed, in each of the three patients, that the total count for ^{99m}Tc in the thyroid ROI was superior to that of ^{123}I while, as stated before, the counts from ^{123}I contaminating the technetium window were negligible (< 5%).

Rapid washout of ^{99m}Tc-sestamibi from some solitary adenomas has been reported (*11,12*). In the case reported by Bénard et al., the adenoma was poor in oxyphil cells (*11*). We did not find such a correlation. Differences in the expression of p-glycoprotein also have been incriminated (*13*). In our series, however, the only parathyroid adenoma out of 17 that stained positively for p-glycoprotein was nevertheless visualized and retained ^{99m}Tc-sestamibi (*13*). Based on our observation, we think that other factors, such as the degree of blood turnover in the tumor, also could be responsible for tracer washout.

The ^{99m}Tc-sestamibi single-tracer, double-phase technique failed to recognize the patient with multiglandular hyperplasia, missing two of the three enlarged glands. Low sensitivity (<40%) of the double-phase protocol for primary hyperplasia has been reported by several authors (*3,6*) and is a clear disadvantage of this scanning technique.

Hyperparathyroidism often is associated with nodular thyroid disease (*14*). Nine patients in this study (30%) had nodular thyroid abnormalities clearly evident on the ^{123}I image and confirmed at surgery. The vast majority of hot thyroid nodules

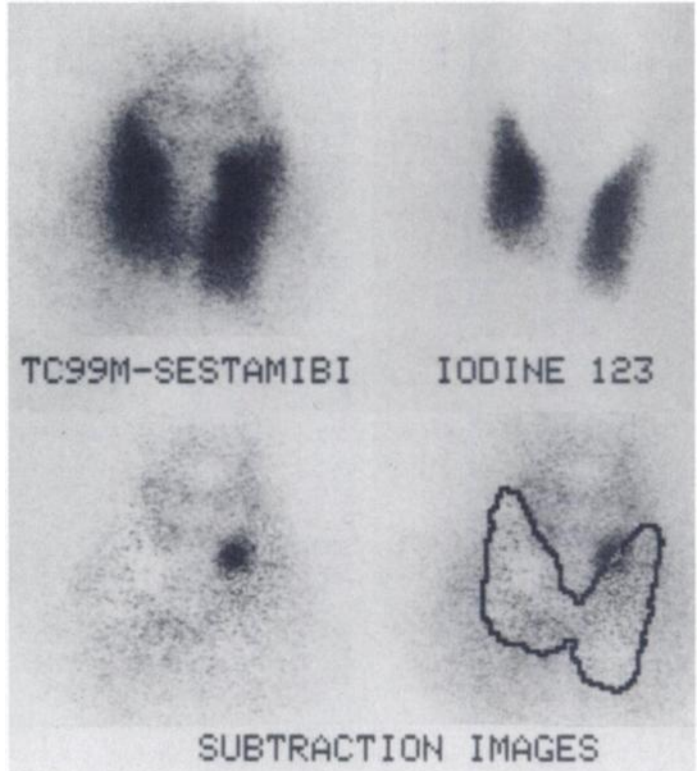

FIGURE 1. Simultaneous double-window acquisition of ^{99m}Tc-sestamibi and ^{123}I in a 62-yr-old woman with primary hyperparathyroidism (Ca, 3.25 mmol/liter; PTH, 80 ng/liter). These images of the neck were acquired with a pinhole collimator 15 min after ^{99m}Tc-sestamibi injection. Comparison of the ^{99m}Tc-sestamibi image and the ^{123}I image shows preferential uptake of ^{99m}Tc-sestamibi internal to the upper half of the left thyroid lobe. This is clearly seen on the computer subtraction image. For drawing the thyroid region of interest on the subtraction image (lower right), the ^{123}I image was smoothed and a threshold was applied.

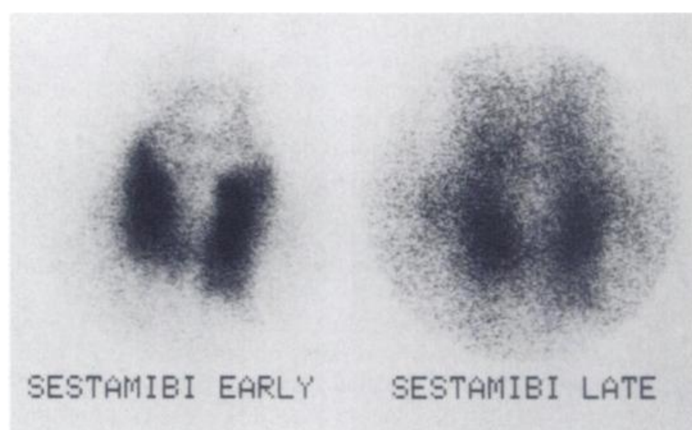

FIGURE 2. Technetium-99m-sestamibi single-tracer, double-phase image (on same patient as in Figure 1). Comparison of the early (15 min) and late (120 min) ^{99m}Tc-sestamibi images shows no site of preferential tracer retention suggestive of an enlarged parathyroid (negative scan). Surgery disclosed an upper left parathyroid adenoma of 600 mg (calcemia 6 mo after surgery, 2.33 mmol/liter).

TABLE 3
Summary of the Results of Technetium-99m-Sestamibi/Iodine-123 Subtraction and Technetium-99m-Sestamibi Single-Tracer Imaging of 34 Enlarged Parathyroids

	Sestamibi	Sestamibi single tracer ^{123}I
True-positive locations	32	27
False-negative	2	7
Sensitivity	94%	79%
False-positive	1	3
False-positive rate	3%	10%
True-negative*	64	62
Specificity*	98%	95%
Accurate patient scan	93%	77%

*True-negative result and specificity are calculated considering the total number of normal parathyroids seen by the surgeon (65).

and 54% of cold nodules concentrate ^{99m}Tc-sestamibi (*15*) and can show prolonged tracer retention, mimicking parathyroids on late ^{99m}Tc-sestamibi images (*3,6*). In the dual-tracer technique, confusion often can be avoided when reading the ^{123}I image (*7*). However, the decision to attribute a hot area on the ^{123}I scan to a thyroid nodule is direct, while, for cold areas, this may prove more delicate. In difficult cases, lateral views can be of help if they show a lesion posterior to the thyroid. Lateral views can be obtained with either the single-tracer or the dual-tracer study, but interpretation is easier on dual-tracer scans (*16*). In this study, we obtained a lower false-positive rate in the subtraction technique (1 of 33 = 3%) than in the double-phase technique (3 of 30 = 10%). Statistical significance was low.

Considering the rate of accurate imaging results, the ^{99m}Tc-sestamibi/^{123}I subtraction technique was accurate in 93% of patients (28 of 30), while the single-tracer technique was accurate in 77% of patients (23 of 30). The results are summarized in Table 3.

Overall time spent by the patient is equivalent in both protocols. However, camera occupation time is shorter in the subtraction technique (30 min) than in the double-phase technique (50 min). This gain in camera time compensates for the cost of the second isotope (in France, $40 for 10 MBq ^{123}I-iodide). In this series of first-surgery patients, we did not use SPECT. The situation is different in reoperated patients, where a large field-of-view SPECT acquisition is advised routinely in addition to imaging of the thyroid region (*17*).

A further consideration is the radiation dose to the patient. Calculated effective dose-equivalent (EDE) data show that the radiation dose associated with 550 MBq ^{99m}Tc-sestamibi is close to 7 mSv and the additional dose for 10 MBq ^{123}I is 1.5 mSv (*2*). The ^{99m}Tc-sestamibi activity used in this work was intermediate between that used by O'Doherty et al. (200 MBq) (*2*) and that used by Taillefer et al. (740–925 MBq) (*3*). The latter, however, indicated that the injected activity probably could be decreased.

In our institution, radionuclide scanning always is done before parathyroid surgery, while some authors reserve it for patients who have failed an initial attempt at parathyroidectomy (*10,18*). Our rationale is that a preoperative imaging procedure that could reduce the dissection necessary to locate abnormal parathyroid tissue might increase the success rate and reduce the time in surgery (*19*). Detection of mediastinal and other ectopic glands is a clear advantage, and we previously reported the cure at first surgery of patients with ectopic parathyroids (*7,19*). The large field-of-view sestamibi image acquired early after tracer injection is of paramount importance for detecting ectopic glands and should be part of every protocol for parathyroid imaging. The other advantage is the reduction in mean surgery time (*19,20*). In our experience, this is due to the surgeon starting by exploring the suspected site. The tumor is sent for histopathologic examination, and the surgeon proceeds with inspection of the remaining parathyroid glands without extensive dissection.

In this series, preoperative imaging positively influenced surgery for quite a few patients. It permitted detection of an undescended parathyroid gland located in the right carotid sheath. This ectopic adenoma was easily seen on the early sestamibi image. The patient was cured with the first operation. It is quite unusual for an adenoma in this location to be found during first surgery in the absence of preoperative imaging (*21*). Six glands weighing less than 100 mg were all located with subtraction imaging (Tables 1 and 2), thus reducing surgical search and dissection. Limited surgery under local anesthesia was possible in an older patient with hemiplegia.

It should be specified that these results indicating the superiority of the dual-tracer technique over the double-phase technique concerned enlarged parathyroid glands in the thyroid uptake area. The only ectopic parathyroid situated in the right carotid sheath, somewhat above and lateral to the thyroid, was clearly seen on the early sestamibi image and was considered a true-positive result of both techniques. The results of our study comparing the subtraction technique and the single-tracer technique in first-operated patients are in agreement with those obtained by Chen et al. in reoperated patients (*22*). In this more difficult population, both techniques were, however, less sensitive in detecting enlarged parathyroids (subtraction technique 70%, double-phase protocol 59%, low statistical significance). Pooled data from various nonpaired studies (*23*) also indicate a higher sensitivity of the subtraction technique (87%) as compared to the double-phase technique (73%).

Different protocols, based on a single injection of ^{99m}Tc-sestamibi, have been described. Our study focused on the simple attractive technique of early (15-min) and late (120-min) images. A recent study, comparing different techniques using ^{99m}Tc-sestamibi alone, found no apparent advantage with the more elaborate techniques (*24*).

CONCLUSION

While the differential washout between enlarged parathyroids and the thyroid gland constitutes the rationale for the single-tracer, double-phase method, it appears that some parathyroids have rapid washout that prevents them from being identified as parathyroids, and some thyroid nodules have prolonged retention of ^{99m}Tc-sestamibi, mimicking parathyroids. Addition of the second isotope (^{123}I) improved sensitivity from 79% to 94% and reduced the false-positive rate from 10% to 3%. Technical difficulties of the subtraction technique, due to patient motion, can be avoided by using simultaneous double-window acquisition of the two isotopes, with an additional benefit in terms of imaging time.

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Transmission Imaging for Nonuniform Attenuation Correction Using a Three-Headed SPECT Camera

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Our objective was to build and test a new system for transmission CT (TCT) imaging on a three-headed SPECT camera. The TCT images are intended for use in nonuniform attenuation correction of cardiac SPECT data. **Methods:** The system consists of a transmission line source mounted to the camera gantry at the focal line of a long focal length, asymmetric fanbeam collimator. The focal line is 114 cm from the collimator surface and shifted 20 cm from the detector midline. This asymmetric fanbeam geometry is used to reduce truncation artifacts in the reconstructed TCT image. The line source fixture accommodates a 25-cm long source and contains removable, variable thickness attenuator plates (copper or lead) to modulate the photon flux density and a slat collimator to collimate the TCT source beam in the axial direction. For the TCT reconstruction, an iterative maximum likelihood-expectation maximization algorithm is used that models the asymmetric fanbeam geometry. Our initial studies with this system used a 1850 MBq (50 mCi) ^{123m}Te line source. The evaluation included TCT scans of a resolution phantom, an anthropomorphic thorax phantom and a human subject. For the thorax phantom and human subject, short (2-min) and long (14-min) scans were performed. The SPECT imaging performance of the fanbeam collimator was also characterized. **Results:** For both phantom and human data, high quality TCT reconstructions were obtained with linear attenuation coefficients closely matching narrow beam values. In the images of the resolution phantom, the smallest rods (4.8-mm diam) were resolved. The long scan images of the thorax phantom and human subject demonstrated the high resolution nature of the system and contained no evidence of truncation artifacts. With smoothing to control noise, the short scan images generally retained the attenuation features of the lung and of soft tissue and may provide a practical approach for clinical application. The fanbeam collimator demonstrated high resolution SPECT performance. **Conclusion:** These results suggest this system may provide an effective and practical approach to TCT imaging for nonuniform attenuation correction on a three-headed SPECT camera.

Key Words: SPECT; attenuation correction; transmission CT; maximum likelihood-expectation maximization reconstruction; fanbeam collimation

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With three-headed SPECT cameras, several approaches have been used to acquire transmission CT (TCT) data for nonuniform attenuation correction. One approach uses a short focal length fanbeam collimator (65 cm) and simultaneous TCT/SPECT imaging (*1–3*). In an attempt to increase the field of view and reduce TCT/SPECT crosstalk effects (TCT photons counted in the SPECT data and vice versa), a longer focal length design and sequential TCT/SPECT imaging were investigated (*4*). To further increase the field of view, both slant hole (*5*) and asymmetric fanbeam (*6,7*) designs have been explored. The relative merits of these approaches for a particular clinical application should depend on imaging characteristics in addition to crosstalk and field of view including spatial resolution, detection efficiency, acquisition time constraints and cost.

We have recently investigated, with Monte Carlo simulated data, a design for TCT imaging on a three-headed SPECT camera that uses a long focal length, asymmetric fanbeam collimator (*8*). As with our previous long focal length system design (*4*), the intent is to perform a short TCT scan after which the TCT source is shuttered, and uncontaminated SPECT data are acquired (fast sequential TCT/SPECT). The advantage of the newer design is that the effective field of view is increased as a result of the asymmetric fanbeam geometry and the use of

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