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# Pinhole Versus Parallel-Hole Collimators for Parathyroid Imaging: An Intraindividual Comparison

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This study was undertaken to determine the effects of collimators on the accuracy of preoperative sestamibi parathyroid imaging of the neck. **Methods:** Forty-nine patients with primary hyperparathyroidism underwent preoperative  $^{99m}\text{Tc}$ -sestamibi parathyroid imaging. The protocol included early and late pinhole and parallel-hole imaging. One experienced nuclear physician, without knowledge of other test results or final diagnoses, interpreted studies. For both pinhole and parallel-hole images, focally increased sestamibi accumulation outside the normal tracer biodistribution that persisted or increased in intensity from early to late images was interpreted as positive for a parathyroid lesion. Final diagnoses were operatively confirmed in all patients. **Results:** Fifty-four parathyroid lesions were resected from the 49 patients. Forty-five patients had single-gland disease. Four patients had multigland disease: 3 had 2 lesions and 1 had 3 lesions. Median lesion weight was 840 mg. Pinhole imaging was significantly more sensitive than parallel-hole imaging (89% vs. 56%;  $P = 0.0003$ ) for all 54 lesions. Specificity did not significantly differ between pinhole and parallel-hole imaging (93% vs. 96%,  $P = 0.29$ ). Pinhole imaging was significantly more sensitive than parallel-hole imaging for lesions above (100% vs. 68%,  $P = 0.003$ ) and below (77% vs. 42%,  $P = 0.03$ ) the median weight and for single-gland disease (96% vs. 67%,  $P = 0.001$ ). Pinhole imaging also was more sensitive for multigland disease, although the difference was only marginally significant (55% vs. 0%,  $P = 0.037$ ). **Conclusion:** Because sensitivity is significantly higher, sestamibi parathyroid imaging of the neck should be performed with a pinhole collimator.

**Key Words:** primary hyperparathyroidism; scintigraphy; collimators; image processing; lesion detection

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**P**rimarily hyperparathyroidism is a common endocrine disorder that is important to diagnose and to treat, because untreated disease can result in numerous medical complications

associated with reduced life expectancy (1–5). Although bilateral neck surgery successfully treats most cases of primary hyperparathyroidism (2,3),  $^{99m}\text{Tc}$ -sestamibi imaging has facilitated minimally invasive surgery (4–6), a procedure that significantly reduces the cost and length of hospitalization (7). Eighty percent to 85% of primary hyperparathyroidism cases are due to a solitary parathyroid lesion (8), and unilateral neck exploration usually is sufficient to cure this disease.

Sestamibi imaging is sensitive for detecting parathyroid lesions because it offers high image contrast (9). This test is based on the principle that generally there is rapid clearance of activity from thyroid tissue and delayed clearance from parathyroid lesions. A pinhole collimator, though providing a smaller field of view than a parallel-hole collimator, offers the highest spatial resolution among the collimators available in conventional nuclear medicine imaging and is well suited to imaging the small structures of the neck, including the thyroid and parathyroid glands (10,11). Despite the recognized advantages of pinhole collimators for imaging smaller structures, there continue to be many different parathyroid lesion imaging protocols in use. One review reported that some centers perform parallel-hole imaging while others use pinhole imaging for localizing parathyroid lesions, as if the choice of collimator were irrelevant (6). Protocols that combine pinhole planar information with parallel-hole acquisitions require moving the patient between  $\gamma$ -cameras multiple times or else changing collimators multiple times if all image acquisitions are performed on the same camera. This raises the question of whether using a pinhole collimator is actually worth the additional effort or whether acquiring planar data with a parallel-hole collimator is sufficient (12). For this reason, we performed a direct intraindividual comparison of parathyroid imaging on pinhole and parallel-hole collimators.

## MATERIALS AND METHODS

### Patient Population

This retrospective investigation was compliant with the Health Insurance Portability and Accountability Act and was approved by an Institutional Review Board, which waived the need to obtain

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informed consent from the patients. The requirements for inclusion in this investigation were as follows: biochemical evidence of primary hyperparathyroidism; sestamibi parathyroid imaging consisting of early and late planar imaging, with both a pinhole collimator and a parallel-hole collimator; surgical confirmation of final diagnosis, including disease limited to the neck; and a record of the weight of resected parathyroid lesions. Forty-nine patients, 32 women and 17 men with a mean age of  $59 \pm 12$  y, met these inclusion criteria.

### Imaging Protocol

Approximately 10 min after injection of 740–925 MBq (20–25 mCi) of  $^{99m}\text{Tc}$ -sestamibi, the patients underwent 10-min pinhole imaging (“early” imaging) of the neck using a single-detector  $\gamma$ -camera (Argus; Philips Medical Imaging, Inc.) equipped with a pinhole collimator with a 5-mm aperture. The patients were imaged with the head in a neutral position using a standard foam head immobilizer. The pinhole collimator was brought as close as possible to the neck in the anterior position, using no caudal tilt, and then was moved away until the salivary glands were visible in the upper 10% of the field of view. A 10-min image was then acquired using a low-energy high-resolution parallel-hole collimator, for which system resolution was 7.4 mm at the surface of the collimator. Both parallel-hole and pinhole planar images were acquired as  $128 \times 128$  matrices, using a zoom of 1.85 (pixel size of 3.1 mm), which was the maximum zoom factor permitted by the data acquisition computer. Approximately 90 min after injection, pinhole imaging and parallel-hole imaging (“late” imaging) were performed using the same acquisition parameters used for early imaging. In order to match the late image positioning with the early image positioning, the early image was reviewed by the technologist while positioning the patient for the late image acquisition.

### Image Interpretation

One nuclear physician with 10 y of experience in parathyroid imaging interpreted all images, with no knowledge of other test results or surgical or pathology results, grading images dichotomously (0 = definitely negative or 1 = definitely positive). Two separate readings, 1 for pinhole images and 1 for parallel-hole images, were performed on 2 different occasions. Early and late images were reviewed together, and for both pinhole images and parallel-hole images, focally increased uptake outside the normal sestamibi biodistribution that persisted or increased in intensity from early to late was interpreted as a parathyroid lesion.

### Surgery

The mean interval between imaging and surgery was  $14 \pm 18$  d (range, 1–90 d). Minimally invasive surgery was planned if sestamibi imaging indicated single-gland disease and there was no suspicion of multiple endocrine neoplasia syndrome, familial hyperparathyroidism, or lithium ingestion (13). Bilateral neck exploration was planned if sestamibi imaging indicated multigland disease. Intraoperative parathyroid hormone levels were monitored routinely, both immediately before tissue resection and at 5-min intervals after tissue removal. Surgery was considered adequate if intraoperative parathyroid hormone levels decreased by more than 50% from preoperative baseline and into the reference range. If intraoperative parathyroid hormone levels did not decrease sufficiently after removal of scintigraphically identified lesions, more extensive exploration was performed. The

surgical report included statements by the surgeon regarding the anatomic location of the resected glands.

All excised tissue was submitted for histopathologic analysis and weighing. Histologic examination included identification of whether an extracted tissue sample was parathyroid tissue or other tissue, identification of whether the parathyroid tissue was pathologic or normal, and the weight of each excised tissue sample. Histology was performed by 1 of 4 pathologists, the experience of whom ranged from 10 to 35 y.

### Lesion Scoring Classifications

Scintigraphically identified lesions that were subsequently confirmed histopathologically to be abnormal parathyroid tissue were classified as true-positive. Scintigraphically identified lesions that were subsequently confirmed histopathologically to be other than abnormal parathyroid tissue were classified as false-positive. Histopathologically confirmed parathyroid lesions that were not detected scintigraphically were classified as false-negative.

### Statistical Analysis

Statistical analyses were performed using commercially available software (MedCalc; version 7.5.0.0; MedCalc Software, Inc.). Values are reported as means  $\pm$  1 SD. The normality of data distributions was determined by the Kolmogorov–Smirnov test. Continuous variables that were not normally distributed were converted by the natural logarithm (ln) transformation (14). Frequencies and percentages were used to characterize categorical variables.

Readings were compared with histopathologic results, and the sensitivity, specificity, accuracy, positive predictive value, and negative predictive value were computed (15). The  $\chi^2$  test was used to determine the significance of differences between pinhole readings and parallel-hole readings for lesions of all weights and for lesions grouped by larger weights and smaller weights. The  $\chi^2$  test for comparisons of 2 proportions was used to compare results (sensitivity, specificity, etc.) among methods. For all tests, a *P* value of less than 0.05 was considered to be statistically significant.

## RESULTS

Fifty-four parathyroid lesions were resected from the 49 patients. Forty-five patients had single-gland disease. Four patients had multigland disease: 3 patients had 2 lesions, and 1 patient had 3 lesions.

Lesion weights were not normally distributed and were heavily skewed to the right ( $P < 0.0001$ ; skewness = 4.0 [ $P < 0.0001$ ]; kurtosis = 17.03 [ $P < 0.0001$ ]). The ln(weight) values, however, were normally distributed ( $P = 0.55$ ; skewness = 0.3 [ $P = 0.32$ ]; kurtosis =  $-0.2$  [ $P = 0.65$ ]), and so, these transformed values were used for subsequent analyses (14).

Pinhole image readings were significantly different from parallel-hole image readings ( $P = 0.0002$ ). Pinhole imaging was significantly more sensitive than parallel-hole imaging (89% [48/54] vs. 56% [30/54],  $P = 0.0003$ ). There was no significant difference in specificity between pinhole and parallel-hole imaging (93% [43/46] vs. 96% [44/46],  $P = 0.29$ ). The negative predictive value of pinhole imaging

(88% [43/49]) was significantly higher than that of parallel-hole imaging (65% [44/68]) ( $P = 0.01$ ) (Table 1).

Thirty parathyroid lesions were identified on both pinhole and parallel-hole imaging (Fig. 1). Six lesions were not identified on either. Eighteen lesions were detected only on pinhole imaging. All parathyroid lesions detected on parallel-hole imaging also were detected on pinhole imaging.

### Effects of Lesion Weight

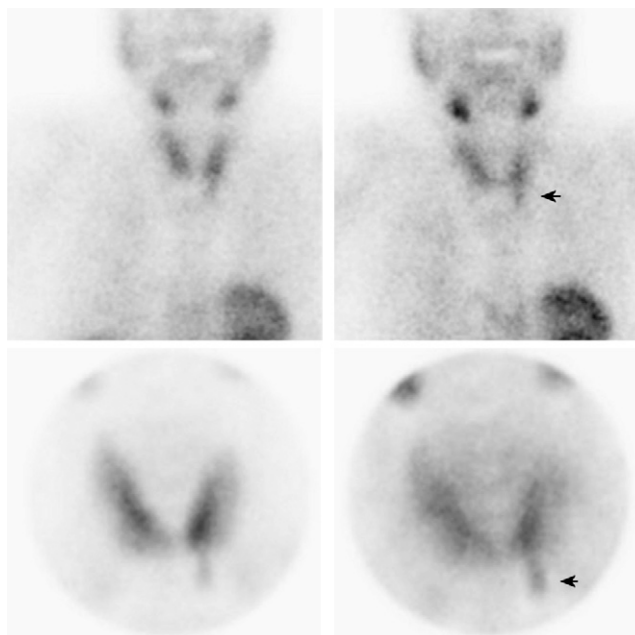
To investigate the effects of lesion weight on test sensitivity, parathyroid lesions were divided into 2 groups: Group 1 ( $n = 28$ ) was lesions weighing more than the median weight of 840 mg, and group 2 ( $n = 26$ ) was lesions weighing less than the median weight. It was not possible to form 2 groups of the same size because 3 lesions weighed 800 mg. Pinhole image readings were significantly different from parallel-hole image readings both for lesions of greater weight ( $P = 0.0001$ ) and for lesions of lesser weight ( $P = 0.0003$ ). Although both pinhole imaging and parallel-hole imaging were more sensitive for group 1 (larger) lesions than for group 2 (smaller) lesions, pinhole imaging was significantly more sensitive than parallel-hole imaging for both groups (Figs. 2 and 3; Table 2).

### Single-Gland Versus Multigland Disease

Both pinhole imaging and parallel-hole imaging were significantly more sensitive for single-gland disease than multigland disease ( $P = 0.005$  and  $P = 0.001$ , respectively). Pinhole imaging was more sensitive than parallel-hole imaging in patients with single-gland disease and in those with multigland disease. Forty-three of 45 (96%) lesions in patients with single-gland disease were identified on pinhole imaging, whereas only 30 of 45 (67%) were identified on parallel-hole imaging ( $P = 0.001$ ). Five of 9 (55%) lesions in patients with multigland disease were identified on pinhole imaging, whereas none (0%) were identified on parallel-hole imaging ( $P = 0.037$ ) (Fig. 4).

### DISCUSSION

Preoperative localization of parathyroid lesions has assumed increasing importance with the growing popularity of minimally invasive parathyroid surgery. The selection of patients for minimally invasive surgery and the success of



**FIGURE 1.** A 1,100-mg left inferior parathyroid lesion. Lesion is seen on both parallel-hole and pinhole imaging (arrows). (Early images are on left; late images are on right.)

the procedure itself depend on accurate preoperative identification and localization of the offending lesions. Introduced for parathyroid imaging by Coakley et al. (4), sestamibi imaging has become the radionuclide procedure of choice for preoperative parathyroid lesion localization (9). The optimal method of performing this test, including the type of collimator used, is still the subject of debate. In most studies reported to date, parallel-hole collimators were used. These collimators permit a large area to be imaged at once, facilitating the detection of ectopic lesions, especially those in the mediastinum.

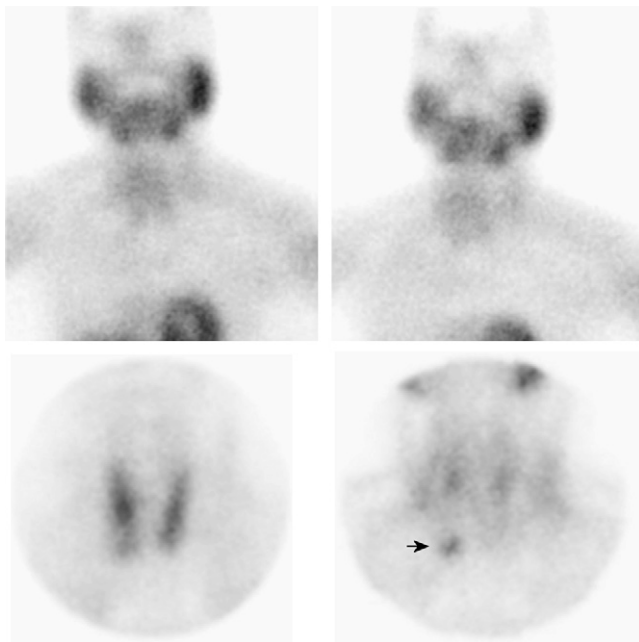
Pinhole imaging produces greater separation of parathyroid counts from nonparathyroid counts, because sensitivity is greatest closest to the pinhole aperture. Consequently, parathyroid counts concentrated in small volumes close to the pinhole aperture have the greatest sensitivity, whereas more peripheral counts have lower sensitivity and are projected over a wider image area. The result is greater image

**TABLE 1**  
Parathyroid Lesion Localization: Pinhole Versus Parallel-Hole Imaging

Index	Pinhole	Parallel-hole	Difference (%)	$\chi^2$ ( $df = 1$ )	Confidence interval (%)	$P$
Sensitivity	48/54 (89%)	30/54 (56%)*	33	13.1	17 to 49	0.0003
Specificity	43/46 (93%)	44/46 (96%)	2	0.001	-7 to +11	0.29
Accuracy	91/100 (91%)	74/100 (74%)*	17	8.9	7 to 27	0.003
PPV	48/51 (94%)	30/32 (94%)	0	0.23	-11 to +11	0.78
NPV	43/49 (88%)	44/68 (65%)*	23	6.8	9 to 38	0.01

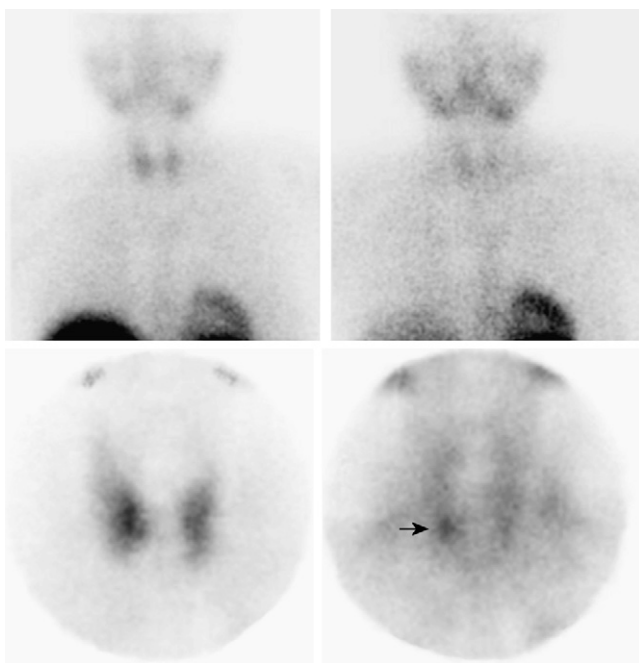
\* $P < 0.05$  for parallel-hole vs. pinhole imaging values.

$df$  = degrees of freedom; PPV = positive predictive value; NPV = negative predictive value.



**FIGURE 2.** An 870-mg right inferior parathyroid lesion. Parallel-hole imaging (top) has negative findings. There is focally increased sestamibi accumulation, just below lower pole of right thyroid lobe (arrow) on pinhole imaging (bottom). (Early images are on left; late images are on right.)

contrast for pinhole images than for corresponding parallel-hole images. In addition, the pinhole collimator offers the highest spatial resolution among the collimators available in conventional nuclear medicine imaging and is well suited to



**FIGURE 3.** A 680-mg solitary right inferior parathyroid lesion. Lesion is not identified on parallel-hole imaging (top) but is clearly seen on pinhole imaging (arrow) (bottom). (Early images are on left; late images are on right.)

imaging the small structures of the neck, including the thyroid and parathyroid glands (11,16).

Improved image contrast and superior spatial resolution, however, come at the expense of a limited field of view. The parathyroid glands can be found anywhere from the angle of the mandible to the base of the heart. Although it is possible to include this entire region in a single image using a parallel-hole collimator, if a pinhole collimator is used, multiple images, and likely collimator changes, would be needed to accomplish this goal. It is important, therefore, to determine the incremental value, if any, of the pinhole collimator for parathyroid imaging.

In this investigation, which was limited to the neck, pinhole imaging was significantly more sensitive than parallel-hole imaging (89% vs. 56%,  $P = 0.0003$ ) and had comparable specificity (93% vs. 96%,  $P = 0.29$ ). Although both pinhole imaging and parallel-hole imaging were more sensitive for larger (group 1) lesions (100% and 68%, respectively) than for smaller (group 2) lesions (77% and 42%, respectively), pinhole imaging was significantly more sensitive than parallel-hole imaging for both groups ( $P = 0.003$  and  $P = 0.03$ , respectively).

Multigland disease, which occurs in 10%–15% of all cases of sporadic primary hyperparathyroidism, can adversely affect the sensitivity of the test (16). Although both pinhole imaging and parallel-hole imaging were less sensitive for multigland disease than for single-gland disease, pinhole imaging was more sensitive than parallel-hole imaging for detecting multigland disease.

Few published investigations have compared parallel-hole and pinhole collimators for preoperative detection of parathyroid lesions (17). Arveschoug et al. (10) compared parallel-hole and parallel-hole-plus-pinhole collimator imaging in patients with hyperparathyroidism. Among 47 patients with primary hyperparathyroidism in their series, the sensitivity of sestamibi using parallel-hole collimation alone was 57%, similar to the 56% we are reporting. Sensitivity improved to 94% using parallel-hole-plus-pinhole collimators, which is similar to the 89% sensitivity that we are reporting for pinhole collimator imaging alone. Although we did not analyze parallel-hole-plus-pinhole imaging, it is unlikely that interpreting both sets of images together would have improved sensitivity in our series, because all lesions identified on parallel-hole imaging also were identified on pinhole imaging. No lesions were identified only on parallel-hole imaging.

Arveschoug et al. (10) found that specificity decreased from 89% for parallel-hole imaging to 77% for parallel-hole-plus-pinhole imaging. In a subsequent investigation, they reported that the addition of oblique pinhole imaging improved specificity from 81% to 94% (11). We found a much higher specificity for both parallel-hole (96%) and pinhole imaging (93%). The explanation for the differences in the 2 investigations is uncertain; it may be related to differences in the prevalence of concomitant thyroid disease in the 2 study populations.

**TABLE 2**  
Parathyroid Lesion Localization: Effect of Lesion Weight

Index	Pinhole	Parallel-hole	Difference (%)	$\chi^2$ ( <i>df</i> = 1)	Confidence interval (%)	<i>P</i>
<b>Group 1 (lesions &gt; 840 mg)</b>						
Sensitivity	28/28 (100%)	19/28 (68%)*	32	8.4	15 to 49	0.003
Specificity	30/32 (94%)	31/32 (97%)	3	0.001	-7 to +13	0.98
Accuracy	58/60 (97%)	50/60 (83%)*	14	5.1	4 to 24	0.04
PPV	28/30 (93%)	19/20 (95%)	2	0.09	-11 to +15	0.76
NPV	30/30 (100%)	31/40 (78%)*	22	5.7	9 to 35	0.01
<b>Group 2 (lesions &lt; 840 mg)</b>						
Sensitivity	20/26 (77%) <sup>†</sup>	11/26 (42%)*	35	5.2	10 to 60	0.03
Specificity	23/24 (96%)	23/24 (96%)	0	0.54	-11 to +11	0.51
Accuracy	43/50 (86%)	34/50 (68%)	18	3.6	2 to 34	0.06
PPV	20/21 (95%)	11/12 (92%)	3	0.17	-15 to +21	0.78
NPV	23/29 (79%) <sup>†</sup>	23/38 (61%)	18	1.7	-34 to +39	0.17

\**P* < 0.05 for parallel-hole collimator vs. pinhole collimator.

<sup>†</sup>*P* < 0.05 for lesions > 840 mg vs. lesions < 840 mg.

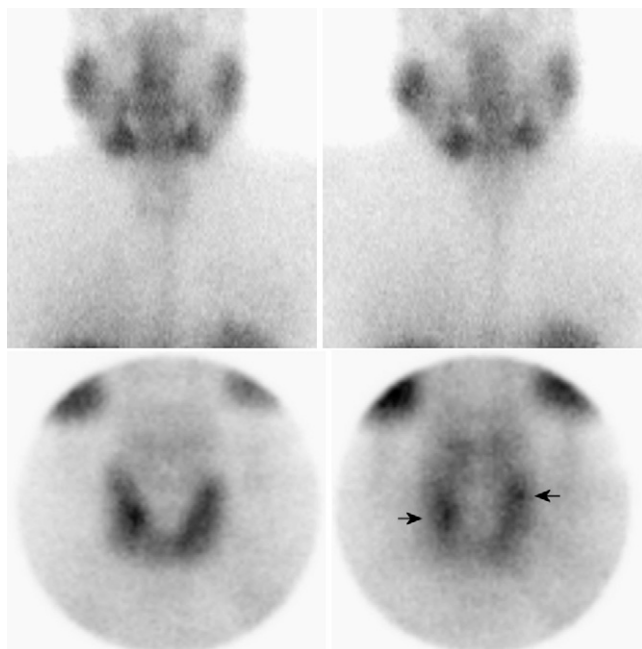
*df* = degrees of freedom; PPV = positive predictive value; NPV = negative predictive value.

Ho Shon et al. (18) investigated pinhole imaging using oblique images and included pertechnetate thyroid imaging as well. Among 86 patients with 90 parathyroid lesions, they found a sensitivity of 89% and a specificity of 92%, which was similar to the 89% sensitivity and 93% specificity we found for anterior pinhole sestamibi imaging alone.

It is tempting to speculate that performing SPECT or SPECT/CT sestamibi parathyroid imaging could render the pinhole-versus-parallel-collimator issue a moot point. Published data, however, suggest otherwise. In one series, using

SPECT/CT read simultaneously with early and late parallel-hole planar images, the test had a sensitivity of 92% (33/36) (19), not significantly different (*P* = 0.92) from the 89% sensitivity we are reporting for planar pinhole imaging. In another series in which SPECT/CT was performed along with parallel-hole planar imaging, the sensitivity of the test was only 65% (20), significantly lower (*P* = 0.005) than the 89% sensitivity for pinhole imaging and comparable (*P* = 0.31) to the 56% sensitivity for parallel-hole imaging in our series.

In patients with single-gland disease, the sensitivity of pinhole imaging (96%) in our series was significantly higher than that of some of the literature reported for SPECT alone (54%, *P* < 0.0001), SPECT/CT alone (54%, *P* < 0.0001), and SPECT/CT in various combinations with early or delayed parallel-hole planar imaging and early or delayed SPECT/CT (57.5%–73%, *P* < 0.0001 to *P* = 0.0047) (21). Previously, we reported that parallel-hole SPECT is less sensitive and less accurate than pinhole planar imaging (22). Consequently, it seems unlikely that, at the present time, SPECT alone or SPECT/CT can replace planar imaging for the detection of parathyroid disease in the neck.



**FIGURE 4.** Multigland disease. Parallel-hole imaging (top) has negative findings. A 170-mg left superior lesion and 170-mg right inferior parathyroid lesion (arrows) are identified on pinhole imaging, but 90-mg left inferior parathyroid lesion is not. (Early images are on left; late images are on right.)

## CONCLUSION

Our data indicate that, in patients with primary hyperparathyroidism, the sensitivity and accuracy of sestamibi parathyroid imaging of the neck are significantly improved when imaging is performed with a pinhole collimator instead of a parallel-hole collimator. We conclude that, for maximum accuracy, sestamibi parathyroid imaging of the neck should be performed with a pinhole collimator.

## ACKNOWLEDGMENT

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