Imaging of Parathyroid Glands

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KEYWORDS

- Parathyroid
- Sestamibi
- Scintigraphy
- Nuclear medicine
- PET
- Imaging

Parathyroidectomy is the treatment of choice for patients with primary hyperparathyroidism and may be indicated in patients with secondary or tertiary hyperparathyroidism if they do not respond to medical therapy. Preoperative imaging studies have an important role in facilitating successful localization of adenomas for surgeons. Their use has increased and parallels the recent growth of minimally invasive parathyroidectomy.

A variety of anatomic and functional imaging techniques can be used to localize parathyroid adenomas, including ultrasound, MRI, CT, and scintigraphy (nuclear medicine). Surgeons may rely on one or a combination of modalities for planning an operation. In many studies, scintigraphy is reported to have the highest accuracy for localization of adenomas when compared with anatomic imaging techniques. This article discusses the current role and limitations of imaging, with a focus on scintigraphy, in the evaluation of patients before surgery for hyperparathyroidism.

SCINTIGRAPHY WITH SINGLE-PHOTON EMITTERS

Parathyroid scintigraphy can be accomplished with several different radiopharmaceuticals and techniques. Selenium-75–methionine, an amino acid analog of methionine, and thallium-201/technetium-99m (99mTc)–pertechnetate subtraction imaging are of historical interest and were abandoned because of poor image quality and technical limitations that led to suboptimal accuracy. 99mTc-sestamibi is the current radiotracer of choice for parathyroid scintigraphy.

99mTc-sestamibi is a lipophilic cation that is ultimately sequestered in mitochondria because of transmembrane electrical gradients in the cell and mitochondria. Accumulation of 99mTc-sestamibi is probably related to increased vascularity and a higher number of mitochondria-rich oxyphil cells in adenomas. Slower release of the tracer

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from adenomas compared with normal surrounding tissues (parathyroid and thyroid) allows for distinction between the two by imaging (Fig. 1). The sensitivity of $^{99m}$Tc-sestamibi parathyroid scintigraphy for detecting and localizing a single adenoma in patients with primary hyperparathyroidism ranges from 54% to 96%. Few of the studies reported specificity with ranges from 83% to 99%. A meta-analysis, including 20,225 patients with primary hyperparathyroidism, reported an overall 88% sensitivity for detecting a solitary adenoma. Sensitivities were lower for detecting double adenomas (30%) or parathyroid hyperplasia (45%). In patients with tertiary hyperparathyroidism, $^{99m}$Tc-sestamibi parathyroid scintigraphy performs well with a sensitivity of approximately 76%.

Various imaging techniques can be used for $^{99m}$Tc-sestamibi parathyroid scintigraphy and this is the likely reason for its wide range of diagnostic performance in the literature. Imaging can be performed at 1 or 2 time points after radiotracer injection (single- vs dual-phase imaging) and using 2-D planar versus 3-D single-photon emission computed tomography (SPECT) imaging techniques. Specific protocols are determined in part by the nuclear medicine cameras available at an imaging center.

A few studies have directly compared planar with SPECT imaging for detection of parathyroid adenomas. These studies have demonstrated a higher sensitivity of SPECT for detecting and localizing parathyroid adenomas compared with planar imaging. The false-negative rate is reported to be lower for SPECT, and SPECT detects small parathyroid adenomas immediately posterior to the thyroid gland better than planar imaging.

Hybrid SPECT/CT imaging has been a recent focus and studies have demonstrated an advantage of this technique over conventional ones for localization of adenomas, especially in patients with ectopic glands. SPECT/CT allows visualization of corresponding anatomy for differentiation of thyroidal from nonthyroidal tissue and the relationship of the adenoma to adjacent structures (Fig. 2). Mediastinal and intrathyroidal adenomas can be precisely localized, all aiding in the surgical approach (Fig. 3). The precise localization is important because ectopic adenomas can be located in the paraesophageal region (28%), mediastinum (26%), intrathymic

Fig. 1. Differential washout of $^{99m}$Tc-sestamibi between normal thyroid gland and parathyroid adenoma. Early images (A) demonstrate physiologic uptake of $^{99m}$Tc-sestamibi throughout the thyroid gland (arrows), which washes out on subsequent delayed images (B). There is a persistent focus of uptake inferior to the right lower pole of the thyroid gland on early and delayed images (arrowheads), which represents a parathyroid adenoma.
region (24%), intrathyroidal region (11%), carotid sheath region (9%), and high cervical positions (2%).\textsuperscript{27} The accuracy of adenoma localization may continue to improve as CT components with higher resolution are incorporated into SPECT/CT cameras.

Another consideration in protocol design is single-phase versus dual-phase imaging. Higher sensitivities are reported for dual-phase imaging protocols. The advantage of the dual-phase technique is 2-fold: (1) distinction between abnormal parathyroid tissue and normal parathyroid or thyroid tissue by differential washout between early and late images and (2) localization of a focus of uptake in relation to thyroid tissue on early images. Dual-phase images may also help identify adenomas with very fast washout rates that might be missed on delayed imaging alone.

Lavely and colleagues\textsuperscript{12} performed a comprehensive study of $^{99m}$Tc-sestamibi parathyroid scintigraphy in 110 patients with primary hyperparathyroidism and no prior neck surgery. Patients underwent planar and SPECT/CT imaging at 15 minutes and 2 hours after injection of $^{99m}$Tc-sestamibi. Early and delayed planar, SPECT, and SPECT/CT images were evaluated individually for each patient. Paired image sets (eg, early and delayed planar and early planar and delayed SPECT) were also evaluated. A total of 19 different combinations of imaging technique was evaluated for each patient. Early SPECT/CT with any delayed imaging emerged as the best methodology for preoperative parathyroid adenoma localization (sensitivity approximately 73%, specificity approximately 99%, accuracy approximately 86%, positive predictive value 86%–91%, and negative predictive value approximately 98%). In the absence of SPECT/CT, dual-phase studies with planar or SPECT imaging was the second best technique (sensitivity approximately 58%–66%, specificity approximately 98%,
More recent studies have also confirmed the benefit of hybrid SPECT/CT imaging. Neumann and colleagues\textsuperscript{25} compared dual isotope iodine-123 (123I)/99mTc-sestamibi SPECT with SPECT/CT. In the patients with primary hyperparathyroidism, the sensitivity (approximately 70%) for localizing an adenoma was not improved with SPECT/CT; however, anatomic localization significantly improved specificity (96% for SPECT/CT vs 48% for SPECT alone, $P<.006$). In a study of 23 patients,\textsuperscript{24} hybrid SPECT/CT accurately localized an adenoma within 19 mm of its intraoperative location in 95% of cases. In addition, the median time from skin incision to adenoma localization was 14 minutes for single adenomas.\textsuperscript{24}

Other techniques to optimize preoperative localization of parathyroid adenomas continue to be investigated in the absence of SPECT/CT. Pinhole imaging, which provides a magnified image, has better diagnostic performance versus parallel-hole collimator imaging and SPECT.\textsuperscript{28–30} Pinhole SPECT is also being investigated and early results are encouraging.\textsuperscript{20}

Parathyroid scintigraphy with $^{99m}$Tc-tetrofosmin, a tracer similar to $^{99m}$Tc-sestamibi, has been investigated. Comparisons of the diagnostic accuracy of the two $^{99m}$Tc-labeled agents have yielded mixed results. Several studies have shown that $^{99m}$Tc-tetrofosmin performs at least as well as $^{99m}$Tc-sestamibi,\textsuperscript{4,31–34} but others have found discordant results with $^{99m}$Tc-sestamibi performing better.\textsuperscript{35–38} Nearly all studies have shown that the differential washout of $^{99m}$Tc-tetrofosmin from the
thyroid gland is slower than that of $^{99m}$Tc-sestamibi, resulting in lower adenoma to thyroid/background ratios. For this reason, $^{99m}$Tc-sestamibi has remained the radiopharmaceutical of choice in most nuclear medicine imaging centers.

**Limitations of Scintigraphy**

The most common cause for a false-positive $^{99m}$Tc-sestamibi study is accumulation of the tracer in thyroid adenomas (Fig. 4). Other causes of false-positive results are thyroid carcinoma, inflammatory thyroid disease (such as chronic lymphocytic thyroiditis [Fig. 5]), and inflammatory or malignant cervical lymphadenopathy. Subtraction imaging with a thyroid imaging agent in combination with $^{99m}$Tc-sestamibi or hybrid SPECT/CT can reduce false-positive results. In the subtraction technique, images with agents that concentrate solely in the thyroid gland (for example, $^{99m}$Tc-pertechnetate and $^{123}$I) are subtracted from those obtained with $^{99m}$Tc-sestamibi (which accumulates in thyroid tissue and parathyroid adenomas). The resulting

![Fig. 4](image)

Fig. 4. A 53-year-old woman was found to have an elevated parathyroid hormone level after presenting with an elevated calcium level on routine laboratory work-up. (A) Early SPECT/CT images demonstrate asymmetrically increased uptake of $^{99m}$Tc-sestamibi in the right thyroid gland versus the left (arrow) and a focus of uptake inferior to the left inferior thyroid gland (arrowhead). (B) The delayed images showed persistent uptake in both locations, although much less on the right (arrow) than the left (arrowhead). (C) The early SPECT/CT images show that the uptake on the right fuses to the thyroid gland. At the time of surgery, a right lower-pole thyroid nodule was found. (D) The early SPECT/CT images show that the focal uptake on the left fuses in the anterior left paratracheal region inferior to the left thyroid gland. At the time of surgery, a 1.7-g left inferior parathyroid adenoma was excised.
subtraction image can then localize the parathyroid adenoma. A major limitation of the subtraction technique is potential artifact generated on the digitally subtracted images due to patient motion during image acquisition.\textsuperscript{40}

Some investigators have tried to identify factors that may affect the sensitivity of scintigraphy for detecting a parathyroid adenoma. Scintigraphy has a better sensitivity for detecting large-sized adenomas and single-gland disease.\textsuperscript{41–43} Higher preoperative parathyroid hormone and calcium levels and decreased vitamin D levels are associated with improved sensitivity in some studies.\textsuperscript{42,44,45} In addition, thyroid suppression has been associated with increased sensitivity for detecting adenomas,\textsuperscript{46} whereas decreased sensitivity has been reported with the use of calcium channel blockers, high P-glycoprotein levels, and multidrug resistance proteins.\textsuperscript{47–50} The cohorts investigated in the various studies, however, were fairly specific and the results cannot be generalized to all patients undergoing $^{99m}$Tc-sestamibi scintigraphy.

Given the various techniques available for performing parathyroid scintigraphy, it is important for referring physicians to be aware of the imaging technique used for their individual patients as it may have impact on the diagnostic performance of the test.

Fig. 5. A 74-year-old woman was found to have primary hyperparathyroidism and her history also included Hashimoto thyroiditis for which she was taking levothyroxine. Early (not shown) and delayed $^{99m}$Tc-sestamibi parathyroid scintigraphy (A) showed diffuse uptake of the tracer throughout the thyroid gland. Transaxial slices through the inferior poles of the thyroid gland (B) demonstrated more focal uptake fusing to lower-pole hypodense nodule in the right inferior lower pole (arrow). The rest of the uptake (C) corresponded to an enlarged thyroid gland and no additional imaging findings were consistent with a parathyroid adenoma. The patient underwent a 4-gland parathyroid exploration. At surgery, there was thyroiditis and the thyroid gland had multiple nodules, including a right exophytic lower-pole thyroid nodule. After further exploration, a 467-mg left superior parathyroid adenoma was resected. This case demonstrates false-positive results from a thyroid adenoma as well as some of the challenges in image interpretation in the setting of background thyroid disease.
Collaboration between surgeons and nuclear medicine physicians/radiologists may also help to improve the accuracy of gland localization.\textsuperscript{51}

**Recurrent Primary Hyperparathyroidism**

A persistently elevated parathyroid hormone level after curative therapy may be due to progression of underlying disease after response to bone mineralization or initial surgery failure. Failure to recognize and adequately resect multigland disease at initial surgery is one of the most common causes for failed initial surgery.\textsuperscript{27,52,53} This remains a challenge because detection of multigland disease is a limitation of \textsuperscript{99m}Tc-sestamibi parathyroid scintigraphy.\textsuperscript{43}

Another significant cause of failed initial surgery is lack of detection of an ectopically located gland (Fig. 6).\textsuperscript{27} The frequency of multiple or ectopic glands, often coexisting, as the cause for recurrence ranges from 44\% to 70\%.\textsuperscript{52,54} In one study, \textsuperscript{99m}Tc-sestamibi parathyroid imaging was reported to have a sensitivity of 65\% for localizing these recurrences.\textsuperscript{54} Jaskowiak and colleagues\textsuperscript{55} reported that the most common site of a missed ectopic adenoma is the tracheoesophageal groove (Fig. 7). Lavely and colleagues\textsuperscript{12} reported that the advantage of combined SPECT/CT seems to be its ability to differentiate ectopic superior glands in the tracheoesophageal groove (located inferior and posterior to the thyroid gland) from true inferior glands (see Fig. 2). Wider use of this technique in the future may prove to decrease recurrence rates due to failed initial surgeries.

Patients with a prior history of thyroid or parathyroid surgery were included in several studies evaluating parathyroid scintigraphy and the technique seems equally sensitive for localizing and detecting parathyroid adenomas regardless of the surgical status of the neck. Civelek and colleagues\textsuperscript{10} reported sensitivities of 87\% versus 92\% for delayed \textsuperscript{99m}Tc-sestamibi SPECT imaging in those with (N = 51) versus without (N = 287) a prior history of neck surgery. Similarly, Billotey and colleagues\textsuperscript{8} reported 91\% overall sensitivity for adenoma detection in all patients and 87\% sensitivity for 39 patients undergoing reoperation. In the reoperative setting, \textsuperscript{99m}Tc-sestamibi parathyroid imaging was superior to anatomic imaging modalities.\textsuperscript{5,8,9,54–57}

In 3\% of cases, persistent or recurrent hyperparathyroidism may be due to regrowth of previously resected tumor or remnant tissue.\textsuperscript{27} Additionally, when surgery for secondary or tertiary hyperparathyroidism is performed, one-half of a gland is often reimplemented into a graft site and recurrence can occur due to hyperfunctional activity within the reimplemented parathyroid tissue. In these cases, it is imperative for an imaging physician to know the location of the reimplemented tissue so directed imaging can be performed. When patients with secondary hyperparathyroidism recur, \textsuperscript{99m}Tc-sestamibi imaging is useful to determine if the failure is due to a hyperfunctioning graft or an ectopic fifth gland, necessitating a change in management.\textsuperscript{56} Itoh and Ishizuka\textsuperscript{58} confirmed the high sensitivity (100\% in this study) of \textsuperscript{99m}Tc-sestamibi for the preoperative localization of hyperfunctioning parathyroid glands in patients with persistent or recurrent hyperparathyroidism after 4-gland parathyroidectomy with autoimplantation of parathyroid tissue.

**RADIOGUIDED PARATHYROIDECTOMY**

Radioguided parathyroidectomy is a technique that involves the injection of \textsuperscript{99m}Tc-sestamibi before surgery and intraoperative use of a gamma probe that can help localize the parathyroid adenoma for the surgeon. Several approaches to radioguided parathyroidectomy are reported.\textsuperscript{59–63} Some groups administer the radiotracer, obtain imaging studies, and then perform surgery within a 2- to 3-hour time frame on the
same day whereas others omit the imaging on the day of surgery and inject the tracer before the start of the operation and only use the gamma probe intraoperatively. For both approaches, localization of the adenoma is performed by scintigraphy or other imaging modalities before surgery. A small amount of radioactivity is required when using the gamma probe as compared with imaging studies; therefore, an advantage of not obtaining images on the day of surgery is that the surgical team is exposed to less radiation. Another advantage is that the shorter time interval between tracer

Fig. 6. A 54-year-old man with a history of left hemithyroidectomy and parathyroidectomy for a suspicious thyroid nodule and hypercalcemia presented with persistent hypercalcemia. At the initial surgery, bilateral normal superior parathyroid glands were found, a small right inferior adenoma was removed, but the left inferior parathyroid gland was not identified. The patient presented with persistent hypercalcemia and was referred for parathyroid scintigraphy. Early SPECT/CT images (A) demonstrated \(^{99m}\text{Tc}\)-sestamibi uptake in the remaining right thyroid gland and focal uptake in the right prevascular region (arrows). MRI (B) of the thorax subsequently confirmed a corresponding nodule lateral to the ascending aorta (arrowhead) and the patient underwent a median sternotomy and resection of a 1153-mg parathyroid gland from this location.
injection and surgery may enhance a surgeon’s ability to detect those adenomas that have rapid washout of radiotracer.

The operative technique for using the gamma probe is reviewed by Mariani and colleagues. In general, a parathyroid-to-thyroid count ratio of greater than 1.5 is suggestive of a parathyroid adenoma. Once removed, an ex vivo count rate of at least 20% greater than thyroid background (counted in vivo) confirms the resection of an adenoma. The reported accuracy for distinguishing adenoma from multigland hyperplasia was 100% in the initial studies describing the “greater than 20% rule.”

Subsequent studies have shown ex vivo count rates of greater than 20% in thyroid nodules and hyperplasia limiting the application of the initial observation. Rubello and colleagues suggested that an explanation for this might be that the timing between the 99mTc-sestamibi injection and surgery was longer (2–3 hours) in the initial studies, which allowed for additional washout from nonadenomas. The optimal timing to surgery may vary from patient to patient and a patient-specific, optimal time-to-surgery protocol has been described. Surgery is performed based on the timing of peak adenoma-to-background ratio as determined by dynamic imaging.

The usefulness of radioguided parathyroidectomy in patients with negative preoperative 99mTc-sestamibi imaging studies is unclear. In 2005, Rubello and colleagues reported that from a surgeon’s perspective, use of the gamma probe was not helpful in 20 patients with negative scans. Forty percent (8/20) of these patients demonstrated multigland disease. More recently, however, Chen and colleagues found equivalent cure rates and major complication rates using radioguided parathyroidectomy in patients with negative (n = 134) versus positive (n = 635) preoperative 99mTc-sestamibi scans. In the scan-negative group, there was a higher rate of multigland disease

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**Fig. 7.** A 65-year-old man presented with persistent hyperparathyroidism after a left parathyroidectomy. Prior parathyroid scan (uncertain technique) reportedly demonstrated an adenoma on the left and a MRI concurred with this finding. At surgery, a 1.8-g left parathyroid gland was resected. No intraoperative parathyroid hormone level measurements were obtained. Postoperatively, the patient continued to have elevated calcium and parathyroid hormone levels. Early (A) and delayed (B) 99mTc-sestamibi SPECT/CT images demonstrate a persistent focus of uptake in the right tracheoesophageal groove (arrows) consistent with a parathyroid adenoma. At surgery, a 330-mg ectopic right superior parathyroid adenoma was resected. His intraoperative parathyroid hormone level declined from 106 pg/mL at baseline to 22 pg/mL at 20 minutes after resection consistent with biochemical resolution of his hyperparathyroidism.
and the parathyroid gland weight was lower. Both of these are known to cause false-negative results on scintigraphy. The in vivo and ex vivo count rates were also lower in the scan-negative versus scan-positive patients but significantly greater than background counts in both instances.69

Proposed guidelines for radioguided minimally invasive parathyroidectomy include its use for patients with a high probability of a solitary adenoma and a normal thyroid gland.64 Other considerations are optimizing the preoperative scintigraphy protocols based on all available information, minimizing radiation exposure to the surgical team, and determining the completeness of surgical resection based on in vivo and ex vivo gamma counting data as well as a documented decline in intraoperative parathyroid hormone levels.64

**ANATOMIC IMAGING**

**Ultrasound**

Ultrasound offers detailed anatomic imaging of the neck and does not expose patients to radiation. Parathyroid adenomas typically appear as hypoechoic homogenous well-demarcated masses, which contrast with adjacent hyperechoic thyroid glands. Ultrasound can provide excellent images of enlarged inferior and superior parathyroid glands located adjacent to the inferior poles of the thyroid, in the thyrothymic ligament or upper cervical portion of the thymus, and just posterior to the thyroid gland (Fig. 8). Certain locations of the parathyroid adenoma limit ultrasound localization, however, such as lesions within the thyroid that may be confused with a thyroid adenoma and those in the tracheoesophageal groove, retroesophageal region, mediastinum, or other ectopic locations.70,71 Ultrasound only demonstrates enlargement of parathyroid glands but does not provide functional information. In these scenarios, scintigraphic imaging of the parathyroid adenoma may be beneficial.

A range of sensitivities (51% to 78%) and specificities (67% to 96%) is reported for the ability of ultrasound to detect and localize parathyroid adenomas.4,20,31,72 Comparisons between ultrasound and scintigraphy also vary in the literature and are highly dependent on the skill of the ultrasonographer and the scintigraphic method used. Studies comparing scintigraphy with ultrasound have generally reported a higher accuracy with scintigraphy. There is a general consensus that the combination of ultrasonography and scintigraphy, however, offers significant superiority in sensitivity and accuracy in the detection and localization of functional parathyroid adenomas.31,72–76 Some clinical practices use the combination of ultrasonography and scintigraphy to maximize the likelihood of success of minimally invasive surgeries and video-assisted parathyroidectomy.77,78 One recent study of 144 patients suggested that scintigraphy may be reserved for those patients with a negative ultrasound performed by a radiologist.72

**MRI**

Normal parathyroid glands are not usually visualized on MRI. Parathyroid adenomas are identified as soft tissue masses that have indeterminate signal intensity on T1-weighted images and high signal intensity on T2-weighted images, and this may depend on histologic composition.79,80 When gadolinium is administered, the signal intensity of parathyroid adenomas significantly increases compared with the adjacent thyroid gland and skeletal muscle on T1-weighted images.81

The sensitivity of planar 99mTc-sestamibi/123I thyroid subtraction parathyroid imaging is higher than MRI and ultrasound in detecting abnormal parathyroid glands, including single adenomas, multiple adenomas, and 4-gland hyperplasia.82 Studies
comparing MRI with 99mTc-sestamibi SPECT parathyroid imaging demonstrate an 86% sensitivity rate in localizing adenomas with SPECT scintigraphy as compared with 71% sensitivity obtained with MRI.83 Ruf and colleagues83 reported added value of software fusing 99mTc-sestamibi SPECT and MRI in 7 of 17 patients with primary hyperparathyroidism. The MRI provided anatomic localization in 5 patients and scintigraphy improved inconclusive MRI findings in 2 patients. Again, no direct comparisons of MRI with hybrid SPECT/CT have yet been performed.

**CT**

CT alone is not commonly used for preoperative localization of parathyroid adenomas. The sensitivity of CT for detecting parathyroid adenomas ranges between 40% and 70% in the unoperated neck and is lower (25%–55%) in the postoperative neck.3,84–86 In combination with SPECT, however, CT is helpful for precise localization of suspected adenomas.12

CT characterization depends on density measurements of the parathyroid adenoma to differentiate it from lymph nodes and normal thyroid tissue and is dependent on the

Fig. 8. A 58-year-old woman presented with primary hyperparathyroidism. Ultrasound (A) showed a hypoechoic nodule (crosshairs) posterior to the right lobe of the thyroid gland (arrow). Sagittal SPECT images (B) demonstrated a focus of 99mTc-sestamibi uptake (crosshairs) posterior to the thyroid gland (arrow). Transaxial SPECT/CT images (C) demonstrated that the focus of uptake fused just posterior (crosshairs) to the right midpole of the thyroid gland (arrows). At surgery, a 760-mg ectopic right superior parathyroid adenoma was resected. Her intraoperative parathyroid hormone level declined from 103 pg/mL at baseline to 30 pg/mL at 10 minutes after resection consistent with biochemical resolution of her hyperparathyroidism.
timing after the injection of contrast material. Typically, the parathyroid adenomas enhance faster and to a greater extent and have faster washout rates compared with lymph nodes.87

SCINTIGRAPHY WITH POSITRON EMITTERS (POSITRON EMISSION TOMOGRAPHY)

The role of 2-[18F]-fluoro-2-deoxy-D-glucose (FDG), a glucose analog, and positron emission tomography (PET) for the detection of parathyroid adenomas or hyperplasia remains uncertain. A few studies over the past 2 decades have yielded sensitivities ranging from 13% to 94%.88,89 Early studies showed promising results, particularly in patients with primary hyperparathyroidism with no prior history of neck surgery. One study demonstrated higher sensitivity of FDG-PET versus dual-phase 99mTc-sestamibi imaging (86% vs 43%)89 probably due to a higher resolution of the PET images and better detection of smaller lesions. These early results have not been reliably reproduced.

PET with 11C-L-methionine has also been evaluated for localizing parathyroid adenomas. 11C-L-methionine uptake reflects amino acid use. Similar to FDG, the range of sensitivities for the detection of parathyroid adenomas is wide with 11C-L-methionine (54%–95%).90-92 The detection rates seem higher for patients with primary hyperparathyroidism and elevated calcium levels.92 Several studies have shown a benefit of using 11C-L-methionine in patients with nonprimary hyperparathyroidism and hypercalcemia when conventional 99mTc-sestamibi imaging is nonlocalizing.93,94 There may be a subgroup of patients in whom PET is useful for localizing a parathyroid adenoma, but further studies are needed to identify this group.

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