11C-Methionine PET/CT Imaging of 99mTc-MIBI-SPECT/CT-Negative Patients With Primary Hyperparathyroidism and Previous Neck Surgery

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Context: 99mTc-Methoxy-isobutyl-isonitrile (MIBI) scintigraphy is a standard preoperative localization imaging modality in patients with primary hyperparathyroidism (pHPT). Its accuracy in localizing a hyperactive parathyroid gland after previous cervical surgery is limited. Recently, 11C-methionine has been introduced as a promising radiotracer for pHPT imaging. Yet, few data exist for this technique in patients with persisting or recurrent pHPT before reoperation.

Objectives: We aimed to investigate the ability of 11C-methionine positron emission tomography (PET)/computed tomography (CT) to localize a parathyroid disorder after cervical surgery and negative postsurgical 99mTc-MIBI single-photon emission CT (SPECT)/CT.

Design, Setting, and Participants: Fifteen patients (6 males, 9 females; age range, 36–85 years) with pHPT and negative 99mTc-MIBI SPECT/CT who had undergone earlier neck surgery because of pHPT and/or thyroid disorder were recruited. Twelve of the 15 patients had thyroidectomy for goiter or differentiated thyroid carcinoma. Ten patients had previous parathyroid surgery for pHPT, and 2 patients had a history of parathyroid carcinoma. Thirteen of 15 patients showed elevated levels of intact PTH at the time of PET/CT imaging, whereas all patients had elevated serum calcium values.

Main Outcome Measurements: Pathological results of contrast-enhanced 11C-methionine PET/CT and surgical results were evaluated.

Results: In 6 of 15 patients 11C-methionine PET/CT showed a hypermetabolic focus in the upper mediastinum in 2 patients, in the thoracic outlet in 1 patient, and in the cervical region in 3 patients. In 9 of the 15 patients, no hyperactive parathyroid gland could be visualized. Reoperation was performed in 5 of 6 patients without surgical complications. One patient refused surgery. In 2 of the 5 patients, a transsternal procedure was performed. Correlating with the 11C-methionine PET/CT results, a single parathyroid adenoma was found in 4 patients and parathyroid carcinoma metastasis in 1 patient.

Conclusion: 11C-Methionine PET/CT is a useful complementary imaging technique to localize parathyroid adenoma or carcinoma in 99mTc-MIBI SPECT/CT-negative patients. (J Clin Endocrinol Metab 99: 4199–4205, 2014)
Primary hyperparathyroidism (pHPT) is an endocrine disorder characterized by autonomous and increased secretion of PTH. It leads to hypercalcemia by stimulating osteoclasts and activating the renal tubular absorption of calcium and by decreasing tubular reabsorption of phosphate. In 80% to 90% of cases, a single adenoma is the underlying disorder of pHPT; in 5% to 10%, a double adenoma or a 4-gland hyperplasia exists (1). Surgical removal of all pathological parathyroid glands is the only approach that provides a definitive and durable cure. The cure rate has been reported in the range of 94% to 100% for bilateral neck as well as for minimally invasive focused explorative surgery. Because of the improvements in the field of preoperative imaging within recent years, a more targeted surgical approach could be established (2–5). $^{99m}$Tc-Methoxy-isobutyl-isonitrile (MIBI) SPECT/CT in combination with sonography of the neck is the imaging modality of choice before parathyroidectomy (6–9). However, after initial surgery, 2% to 7% of patients will have persistent pHPT (10). In this situation, the optimal imaging approach is still controversial. $^{99m}$Tc-MIBI SPECT/CT seems to be limited with a reported sensitivity of 30% to 80% (11–14).

During the last 15 years, imaging techniques have rapidly developed in nuclear medicine. Planar imaging was followed by SPECT and SPECT/CT methods, which allow a better anatomical localization of functional imaging results. This fact has successively changed imaging protocols and patient management. For parathyroid imaging, hybrid SPECT/CT instruments have been implemented in the imaging protocols and have become a routine procedure before target surgery (9). For PET imaging, we have a comparable situation. Emerged as a very important and widely used imaging technique during the last 2 decades, the combination of PET and CT in a single hybrid examination has been established.

Parathyroid imaging with methionine was introduced almost 35 years ago using $^{75}$Se-selenomethionine (15) and was subsequently replaced by more efficacious radiopharmaceuticals such as $^{201}$TI or $^{99m}$Tc-tetrofosmin or $^{99m}$Tc-MIBI (16). The availability of the positron emitting radioisotope $^{11}$C allows performance of PET with $^{11}$C-labeled methionine to identify hyperactive parathyroid tissue. Until now, data on preoperative $^{11}$C-methionine PET and pHPT have been reported with sensitivity rates from as low as 44% to as high as 90% (17–21). For patients after previous neck exploration and/or persistent pHPT, data are even rarer and show sensitivities of 75% to 88% (19, 22–25). Parathyroid PET imaging with $^{11}$C-methionine was first described by Hellman et al (17) in 1994, followed by others describing small cohorts of patients with pHPT in first or recurrent preoperative situations as well as in patients with secondary HPT, using different acquisition protocols and camera systems. Only limited data exist for hybrid $^{11}$C-methionine PET/CT imaging and pHPT before reoperation (25–28).

It was the aim of this study to investigate the sensitivity and accuracy of $^{11}$C-methionine PET/CT in localizing hyperfunctional parathyroid tissue negative in $^{99m}$Tc-MIBI SPECT/CT before reoperation.

**Subjects and Methods**

**Subjects**

We studied 15 patients (6 males, 9 females, age range: 36–85 years) after neck surgery for different reasons with biochemical evidence of pHPT. Elevated serum calcium levels were observed in all 15 patients. Elevated levels of intact PTH were found in 13 patients, intact PTH within the upper normal range in 2 patients at the time of $^{11}$C-methionine PET/CT imaging. However, both patients had a history of biochemically active pHPT. All patients had 1 or more previous neck explorations. Thyroidectomy was performed in 12 of 15 patients due to thyroid carcinoma (n = 6) and to goiter (n = 6). Ten of the 15 patients had previous parathyroid surgery for pHPT, and 2 patients had a history of parathyroid carcinoma (Table 1).

$^{99m}$Tc-MIBI SPECT/CT

All patients had routinely at least 1 $^{99m}$Tc-MIBI SPECT/CT with a negative result before $^{11}$C-methionine PET/CT. The time between $^{99m}$Tc-MIBI SPECT/CT and $^{11}$C-methionine PET/CT ranged between 4 days and 3 months with a median time of 26 days. Using a commercial kit preparation (Cardiolite; Du Pont Pharma), SPECT/CT examinations were done on a dual-head SPECT/CT system (Millenium VG; GE). Anterior planar images (matrix, $128 \times 128$; 500 kilo counts per image) of the neck and the mediastinum were acquired in a 20% energy window set at 140 keV 15 minutes and 2.5 hours after iv injection of 550 MBq $^{99m}$Tc-MIBI. CT imaging was performed immediately after planar imaging 2.5 hours after tracer injection. The parameters included a current of 2.5 mA, a voltage of 140 kV, and 10 minutes slice reconstruction in a $250 \times 250$ matrix. The CT rotated at 2.6 rotations per minute. Immediately after CT, SPECT imaging equipped with a low-energy ultra–high-resolution parallel-hole collimator was started using a step-and-shoot protocol (30 s/6°, 360°) and stored in a $128 \times 128$ matrix. SPECT analysis was done by OSEM reconstruction (2 iteration steps per 10 subsets). Butterworth filtering (cutoff 0.42, order 8) and reorientation into transversal, sagittal, and coronal slices were performed with additional SPECT/CT fusion. All studies were visually interpreted by consent of 2 experienced nuclear medicine physicians and 1 radiologist.

$^{11}$C-methionine PET/CT

After giving written informed consent, the PET/CT was performed using a hybrid scanner (Siemens Biograph 64 True Point). Patients fasted for at least 4 hours before undergoing the examination. Both multislice CT and PET covered the neck as well as mediastinum down to the base of the heart. Image acquisition of emission data started 20 minutes after iv injection of
700 to 900 MBq $^{11}$C-methionine with emission scans of 4 minutes and transmission scans of 4 minutes per bed position. A contrast-enhanced CT (venous phase) was performed after iv bolus injection of 100 mL tri-iodinated, nonionic contrast agent (Iomeron 300; Bracco) at a rate of 2 mL/s with the following parameters: 120 kV, 200 to 230 mA, slice thickness 3 mm, increment 2 mm, reconstruction kernel B30 (soft tissue), and a matrix of $512 \times 512$. For matching CT and PET slices, CT was acquired in shallow breathing. Directly after CT, the PET acquisition was started. PET images were reconstructed using the iterative TrueX algorithm, a $168 \times 168$ matrix, a transaxial field-of-view of 605 mm, 4 iterations per 21 subsets, a 5-mm slice thickness, and CT-based attenuation correction. CT and PET images were coregistered and fused into transaxial, coronal, and sagittal images of 5 mm thickness. All studies were interpreted visually by 3 experienced observers (2 nuclear medicine physicists, 1 radiologist). Focal areas of nonphysiological tracer uptake were reported as positive. For quantitative evaluation, maximum standardized uptake values (SUVs) were calculated, whereby the concentration in each pixel was divided by the injection dose per gram body weight (SUV$_{bw}$). Regions of interest (ROI) were drawn manually over the area with suspected focal tracer uptake in axial images. In addition, a background ROI as well as a contralateral ROI was drawn for documentation of the physiological uptake.

### Surgical procedure and histopathological evaluation

A focused surgical approach was used for removal of the suspected lesion guided by preoperative $^{11}$C-methionine PET/CT. In 2 patients, a partial upper sternal splitting was performed to remove the hyperactive tissue. Intraoperative PTH monitoring was used in all patients to predict cure (Vienna criterion) (29). In addition, intact PTH and total calcium was measured 6 months after surgery, confirming cure.

All resected specimens were frozen and subjected to final histopathological examinations.

### Results

$^{11}$C-Methionine PET/CT visualized neither a hypermetabolic focus in the neck or in the mediastinum nor a morphologically suspicious mass suggestive for pHPT in 9 of the 15 patients. In the remaining 6 patients, $^{11}$C-methionine PET/CT showed a focal tracer accumulation in the upper mediastinum in 2 patients with localization of pathological tracer uptake in the thymus region in 1 patient with persistent pHPT indicating a fifth gland (patient 15; Figure 1) and parathyroid carcinoma recurrence in patient 2. In 3 of the 6 patients with positive $^{11}$C-methionine PET/CT, the pathological tracer uptake was found in the cervical region in patients 1 and patient 9, both with a history of thyroid carcinoma, indicating a single parathyroid adenoma after negative cervical exploration, and in 1 patient (patient 12) in the upper thoracic outlet near the brachiocephalic vein, indicating a parathyroid singular adenoma after negative cervical exploration. The maximum SUV$_{bw}$ of the hyperactive parathyroid gland tissue ranged from 5.48 to 1.37 with corresponding physiological maximum SUV$_{bw}$ from 1.64 to 0.50 (Table 2). Guided by the functional $^{11}$C-methionine pathologies, soft-tissue lesions on

**Table 1.** Patient Demographic Data at the Time of $^{11}$C-Methionine PET/CT

<table>
<thead>
<tr>
<th>Patient</th>
<th>Gender</th>
<th>Age, y</th>
<th>History</th>
<th>Serum Calcium (mmol/L)$^a$</th>
<th>Intact PTH (pg/mL)$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>76</td>
<td>pHPT, TE (TC)</td>
<td>2.63</td>
<td>123</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>75</td>
<td>PCA</td>
<td>2.69</td>
<td>209</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>46</td>
<td>ppHPT, TE</td>
<td>2.88</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>70</td>
<td>ppHPT, TE</td>
<td>2.99</td>
<td>214</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>36</td>
<td>PCA</td>
<td>2.68</td>
<td>43</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>62</td>
<td>ppHPT, HTE</td>
<td>2.66</td>
<td>115</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>68</td>
<td>ppHPT, TE (TC)</td>
<td>2.76</td>
<td>134</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>68</td>
<td>ppHPT, TE (TC)</td>
<td>2.76</td>
<td>80</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>54</td>
<td>ppHPT, TE (TC)</td>
<td>2.85</td>
<td>83</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>60</td>
<td>ppHPT, TE</td>
<td>2.76</td>
<td>115</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>36</td>
<td>ppHPT, TE</td>
<td>2.60</td>
<td>79</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>63</td>
<td>ppHPT, TE (TC)</td>
<td>3.02</td>
<td>172</td>
</tr>
<tr>
<td>13</td>
<td>F</td>
<td>85</td>
<td>ppHPT</td>
<td>2.7</td>
<td>95</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>79</td>
<td>ppHPT</td>
<td>2.88</td>
<td>62</td>
</tr>
<tr>
<td>15</td>
<td>M</td>
<td>49</td>
<td>ppHPT, TE (TC)</td>
<td>2.79</td>
<td>181</td>
</tr>
</tbody>
</table>

**Abbreviations:** F, female; HTE, hemithyroidectomy; M, male; PCA, parathyroid carcinoma; ppHPT, persistent pHPT; TC, thyroid carcinoma; TE, thyroidectomy.

$^a$ The normal range of serum calcium is 2.2 to 2.65 mmol/L, and the normal range of PTH is 15 to 65 pg/mL.
CT with maximal axial diameters from 10 to 20 mm were identified.

Five of the 6 patients with positive 11C-methionine PET/CT underwent surgery. Patient 10 refused the operation. The localization of the hyperactive parathyroid tissue enabled a minimal invasive targeted approach in 3 patients (1, 9, and 12) (see also Figure 1). In 2 patients (2 and 15), a transsternal surgical procedure was performed. A surgical complication was observed neither during the operative procedure nor after surgery. In all 5 patients, intraoperative PTH monitoring showed a decay of more than 50% of the baseline PTH level 10 minutes after resection of the 11C-methionine-positive tissue. Definitive cure was later confirmed by measuring PTH and serum calcium levels within normal ranges 6 months after surgery.

Histopathologically, parathyroid adenomas were diagnosed in 4 patients and soft-tissue metastasis of parathyroid carcinoma in 1 patient corresponding to the regions documented by the hybrid PET/CT device. The histopathological dimension was different compared with the respective lesion size on CT (Table 2). In patient 2, who had a history of parathyroid carcinoma, we found 2 11C-methionine focal tracer accumulations in the upper mediastinum correlating to contrast medium-enhanced nodular structures within a larger lesion with elevated inhomogeneous tracer uptake, histopathologically reported as partially necrotic tumor recurrence. In patient 9 with history of a thyroid carcinoma, an implantation thyroid carcinoma metastasis of 4 mm as well as a lymph node metastasis of few millimeters were resected additionally, which did not show any 11C-methionine tracer uptake.

**Table 2. Histopathologically Verified 11C-Methionine PET/CT-Positive Results in 5 of 6 Investigated Patients**

<table>
<thead>
<tr>
<th>Patient</th>
<th>[11C]Methionine PET Localization in PET/CT</th>
<th>CT Measured Axial Max Diameter, mm</th>
<th>Max Diameter Histopathological, mm</th>
<th>Max SUV (Pathology)</th>
<th>Max SUV (Physiology)</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Positive Neck</td>
<td>10</td>
<td>16</td>
<td>5.61</td>
<td>1.71</td>
<td>Parathyroid adenoma</td>
</tr>
<tr>
<td>2</td>
<td>Positive Upper mediastinum*</td>
<td>20</td>
<td>35</td>
<td>5.48</td>
<td>1.18</td>
<td>Mt of parathyroid carcinoma</td>
</tr>
<tr>
<td>9</td>
<td>Positive Neck</td>
<td>12</td>
<td>17</td>
<td>3.49</td>
<td>0.62</td>
<td>Parathyroid adenoma, additional implantation mt and lymph node mt of a thyroid carcinoma</td>
</tr>
<tr>
<td>12</td>
<td>Positive Upper thoracic outlet (near the brachiocephalic vein)</td>
<td>10</td>
<td>12</td>
<td>4.22</td>
<td>0.9</td>
<td>Parathyroid adenoma</td>
</tr>
<tr>
<td>15</td>
<td>Positive Upper mediastinum*</td>
<td>11</td>
<td>15</td>
<td>4.05</td>
<td>1.64</td>
<td>Parathyroid adenoma</td>
</tr>
</tbody>
</table>

Abbreviation: Mt/mt, metastasis.

a Median sternotomy was performed.

Discussion

Recurrent parathyroid surgery is associated with a higher complication and failure rate than primary surgical intervention (30–32). During the last 2 decades, targeted imaging for lesion localization has markedly improved the workup before surgery (9, 32, 33). In persistent pHPT, preoperative evaluation with 99mTc-MIBI-SPECT/CT and sonography of the neck is mandatory but sometimes of limited value (9, 11–14). Only a few studies on 11C-methionine PET reported somewhat superior sensitivities of 75% to 88% in detecting the persistent hypermetabolic parathyroid gland (19, 22–27).

In the present study, we evaluated 15 patients with a history of cervical operation for various thyroid or parathyroid disorders. All of them suffered from pHPT and had at least 1 negative 99mTc-MIBI SPECT/CT at the time of 11C-methionine PET/CT. Sonography of the neck was negative in 14 of 15 patients. The only patient (patient 9) with a sonographic finding also had a history of thyroid carcinoma with a biochemical recurrence. Thus, the result was not clearly positive for parathyroid adenoma.

Six of these 15 patients showed a hypermetabolic focus, in the mediastinum in 2 patients, in the upper thoracic outlet in 1 patient, and in the cervical region in 3 patients, which enabled successful reoperation in 5 patients. The remaining patient refused surgical intervention. With a sensitivity of 40% for 11C-methionine PET/CT, our results differ from other studies. The varying surgical history of the patients in our series may be an explanation. Weber et al (25) investigated 30 patients with pHPT, but only 3 patients with persisting disease and only 9 of the 30 patients had previous neck surgery. Additionally, in this series, MIBI-positive lesions were also included. This was also the case in other studies on the efficacy of 11C-methionine PET (19, 24). In our study, we focused on a highly preselected group of patients with pHPT and previous neck surgery as well as negative 99mTc-MIBI SPECT/CT, which is in contrast to previous studies. In the patient population with pHPT but negative sonographic and 99mTc-MIBI SPECT/CT results, alternative imaging techniques may be useful and justify more cost-intensive localization techniques before reoperation. However, in...
cases of clear positive results revealed by established imaging methods, further imaging examinations do not seem necessary (34).

No established imaging protocol exists for $^{11}$C-methionine parathyroid PET. Activities between 400 and 1000 MBq of $^{11}$C-methionine had been applied in earlier studies onine parathyroid PET. Activities between 400 and 1000 MBq of $^{11}$C-methionine had been applied in earlier studies followed by emission data acquisition between 10 and 45 minutes after tracer injection (17, 19, 22, 23, 26). Otte et al (19) performed an imaging acquisition procedure at 2 different time-points, observing higher SUV parathyroid to SUV soft-tissue ratios 10 minutes after injection and higher SUV parathyroid to SUV thyroid tissue ratios 40 minutes after injection of 900 to 1000 MBq $^{11}$C-methionine. In only 3 of 30 patients, positive PET results were not achieved before 40 minutes after tracer injection. In another study, whole-body scans were done 10 to 20 minutes after injection with 2 minutes of emission scans and 3 minutes of transmission scans per bed position (18). Neither study focused on patients who had previously undergone cervical surgery for pHPT or other conditions. Cook et al (23) investigated patients with persistent HPT after parathyroid surgery imaged 15 minutes after injection of 370 to 740 MBq of $^{11}$C-methionine with positive results in 5 of 8 patients. Rubello et al (26) investigated patients on chronic dialysis for renal failure without previous cervical operation 10 minutes after tracer injection with encouraging results for mono- but also multiglandular parathyroid hyperplasia in 10 of 18 patients. Therefore, the reported higher parathyroid to soft tissue ratios and the high sensitivity in earlier imaging encouraged us to perform $^{11}$C-methionine PET/CT 20 minutes after injecting 700 to 900 MBq. In addition to injected tracer activities and time points of PET imaging, the acquisition time per bed position might also influence the accuracy of $^{11}$C-methionine PET. Nevertheless, acquisition times of 2 minutes per bed position as performed by some groups (18, 35) or 4 minutes as we used did not seem to influence the success of the PET imaging technique.

The extension of the field of view including the mediastinum is also of importance. One main reason for unsuccessful surgery in patients with consecutive persistent HPT is the presence of an ectopic gland (retro-esophageal, mediastinal, in the sheath of the carotid artery, or undescended) besides multiglandular disease (36). False-negative $^{11}$C-methionine PET results were previously reported due to parathyroid hyperactive glands located outside the scanned region (20). In our study, the mediastinum down to the base of the heart was included in the field of view.

In most previous studies, only $^{11}$C-methionine PET was performed and partly compared later with other imaging modalities such as CT (22, 24). We performed our study with a dedicated hybrid PET/CT equipped with a full-ring dedicated PET system and a 64-slice CT. Few reports also used integrated hybrid PET/CT systems, allowing a higher spatial resolution and an accurate data fusion of both modalities, which enables the best imaging-guided surgery (25–27, 37). Most recently, Weber et al (37) have reported a sensitivity for singular-gland adenomas of 91% and a positive predictive value of 93% in a study population of 97 patients and a sensitivity of 80% for multiglandular disease in 5 patients. A significant correlation has been found between true positive findings and weight of the glands.

However, compared with our study, different HPT patient populations had been analyzed. Schalin-Jäntti et al (27) investigated 21 patients with recurrent primary HPT by a dedicated $^{11}$C-methionine hybrid PET/CT with an accuracy of 65% for localizing a pathological gland. Nevertheless, only 4 of these 21 patients had negative $^{99m}$Tc-MIBI imaging results but positive PET/CT results; thus, in the remaining 17 patients, $^{11}$C-methionine PET/CT confirmed an already localized parathyroid adenoma showing the reliability of the method but not its superiority over $^{99m}$Tc-MIBI SPECT/CT. Another 5 patients showed matching results of planar $^{123}$I-$^{99m}$Tc-sestambi and PET/CT for the definition of the correct cervical site. Other parathyroid imaging studies on pHPT used $^{11}$C-methionine PET technology alone, like Otte et al (19) who investigated $^{11}$C-methionine PET in patients with pHPT. Yet in contrast to our study population, they included only 11 of 30 patients with previous surgery of the neck. Of the 11 patients, 5 had persistent pHPT, 4 had secondary HPT, and 2 suffered from parathyroid cancer. In the cohort without previous operation, 1 false-positive result was observed, revealing thyroid adenoma. In accordance with other previous studies investigating patients with pHPT, no false-positive $^{11}$C-methionine tracer uptake was seen in our study group.

Sundin et al (22) performing dynamic imaging from 15 minutes to 45 minutes after injection $^{11}$C-methionine described true-positive $^{11}$C-methionine PET results in 85% of patients with pHPT with SUVs increasing by parathyroid weight, preoperative PTH, and total serum calcium levels. The highest SUVs were described for parathyroid cancer foci, as observed in our study; patient 2 showed recurrent parathyroid carcinoma tissue with a maximal histopathological diameter of 35 mm and a maximum SUV$_{bw}$ of 5.48. In addition to the size of the hypermetabolic tissue, the biochemical characteristics of HPT seem to be important for positive hybrid imaging. The time course of development and the severity of parathyroid disorder vary from patient to patient (26). Yet, imaging of pHPT by $^{11}$C-methionine PET/CT imaging documents a single snapshot of parathyroid function. Two of our study
patients (patients 5 and 14) with negative imaging results showed PTH levels within the upper normal ranges at the time of the \(^{11}C\)-methionine PET/CT examination, reflecting no extensive parathyroid tissue activity.

Recently, magnetic resonance imaging (MRI) as an alternative imaging technique has shown potential in patients with HPT. MRI offers considerably higher soft-tissue contrast than CT, even without the application of contrast media, and does not involve exposure of patients to ionizing radiation. Two studies suggested that MRI has a moderately lower sensitivity and accuracy than MIBI (38, 39) but may detect lesions missed by MIBI (38). In addition, use of MR angiography has been reported to yield a vastly improved sensitivity over MRI, even surpassing that of MIBI (93.3% vs 80%) (40). In view of these results, and the fact that hybrid PET/CT/RI devices are presently being introduced into clinical practice, it remains to be studied whether \(^{11}C\)-methionine PET/CT will improve the results of \(^{11}C\)-methionine PET/CT.

The main limitations of our study are the small number of patients on the one hand and the diversity of surgical history in our patients on the other hand. Yet, especially patients with a complex history of neck surgery and, sometimes repeatedly, negative \(^{99m}\)Tc-MIBI SPECT/CT and negative sonography with well-documented persistent pHPT, were the focus of our observation, which is in contrast to previous studies. Another limitation is that only patients with a positive \(^{11}C\)-methionine PET/CT result have been operated, which of course is a verification bias. In conclusion, \(^{99m}\)Tc-MIBI scintigraphy together with sonography of the neck is the first choice of localization patients with a positive \(^{11}C\)-methionine PET/CT. However, in \(^{99m}\)Tc-MIBI SPECT/CT-negative cases, \(^{11}C\)-methionine PET/CT seems to be a useful complementary localization imaging technique, allowing a targeted approach even in patients with various causes of previous neck surgery.

Acknowledgments

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