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Preoperative localisation of adenomas in primary hyperparathyroidism: the value of ^{11}C-choline PET/CT in patients with negative or discordant ultrasonography and ^{99m}Tc-Sesta-MIBI-SPECT/CT

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ABSTRACT:

Purpose: We aimed to assess the value of ^{11}C-choline positron emission tomography (PET) in patients with primary hyperparathyroidism (pHPT) with negative or discordant results in methoxyisobutylisonitrile (MIBI) imaging and neck ultrasound.

Methods: Eighty-seven patients with pHPT and negative or discordant neck ultrasound and MIBI single photon emission computed tomography/computed tomography (SPECT/CT) were assessed using ^{11}C-choline PET/CT and subsequently received a parathyroidectomy. PET/CT image data were analysed semi-quantitatively using maximum standardised uptake value (SUV_{max}) and ratios (target to contralateral thyroid gland and carotid artery). A positive PET/CT was defined as a focal uptake significantly higher than regular thyroid tissue. Ectopic foci were also considered to be positive. Inconclusive PET/CT cases were defined as a lesion with uptake equal to normal thyroid tissue. If no prominent or ectopic uptake was detectable, the PET/CT was considered be negative.

Results: When dichotomizing the ^{11}C-choline PET/CT imaging results by defining lesions with both positive and inconclusive uptake as positive, 84 of 92 lesions (91.3%) were found to have true-positive uptake versus 8 lesions (8.7%) with false-positive uptake. One lesion showed a false-negative uptake; sensitivity was 98.8%. The corresponding lesioned positive predictive value was 91.3%. The mean SUV_{max} was 6.15±4.92 in 72 lesions with positive uptake (70 patients); and mean SUV_{max} was 2.96±2.32 ±±in 20 lesions with inconclusive uptake (18 patients).

Conclusion: These results in a large group of patients indicate that^{11}C-choline PET/CT is a promising tool for parathyroid adenomas (PTA) localisation, in cases in which ultrasound and MIBI imaging yield negative or discordant results.

Keywords: ^{11}C-choline, PET/CT, primary hyperparathyroidism

INTRODUCTION

In primary hyperparathyroidism (pHPT), preoperative localisation of hyper-functioning parathyroid adenoma(s) is necessary for planning surgery. Neck ultrasound and ^{99m}Tc-Sesta-methoxyisobutylisonitrile (MIBI) parathyroid scintigraphy with and without (single photon emission computed tomography/computed tomography (SPECT/CT) are currently the most commonly used imaging tools (*1,2*). Neck ultrasound has the advantages of being non-invasive, low cost, and widely available. It is also not associated with any radiation exposure and can be used to assess coexisting thyroid nodules (*2*). Sensitivities of ultrasound for the detection of parathyroid adenomas (PTAs), however, are highly variable and reported between 57% and 76% (*3-5*). Ectopic PTAs or PTAs deep in the tissue pose a problem for this imaging method (*6,7*).

Parathyroid imaging using ^{99m}Tc-Sesta-MIBI, preferably including hybrid imaging with SPECT/CT, is also non-invasive and available in most centres, but it is associated with radiation exposure. Sensitivities reported, mainly in retrospective studies using SPECT/CT, are mostly superior to those of neck ultrasound alone and range from 53% to 92% (*4,7-9*). MIBI imaging has the advantage over ultrasound in that it is able to also detect ectopic PTAs or PTAs located deeper within the neck. However, thyroid nodules may also show increased MIBI uptake and an association between thyroid , i.e. (multi)-nodular goiter or toxic (multi)-nodular goiter, and parathyroid disease is quite common (*10*) This can result in difficulties in identifying PTAs. Many institutions combine neck ultrasound and parathyroid scintigraphy, which results in an increased sensitivity of 80% to 90% (*11-13*). If the adenoma(s) can be found preoperatively by imaging, minimally invasive surgery may be performed in many cases. If the adenoma cannot be clearly localised before surgery, the surgeon usually has to find and inspect all parathyroid glands, which requires a significantly more extensive surgery, and, thus, the patient is more prone to morbidity. Also, ectopic PTAs cannot be detected this way. Therefore, it is problematic if both imaging modalities cannot locate the PTA or if the results obtained by imaging are inconclusive or discordant. ^{11}C-methionine-PET/CT has been successfully applied in this setting (*14-18*). During the last years radiolabelled choline has been increasingly used to localise PTAs with very high sensitivities reported (*19-22*). However, many studies were conducted in small patient cohorts. Our aim was to evaluate the utility of ^{11}C-choline in a large cohort of patients with

negative, inconclusive, or discordant neck ultrasound and MIBI scintigraphy including SPECT/CT. The imaging results were correlated with histopathologic results.

MATERIALS AND METHODS

Patients

Eighty-seven patients with biologically proven pHPT (elevated PTH levels or normal PTH despite hypercalcaemia) and negative or discordant neck ultrasound and MIBI SPECT/CT assessed using ^{11}C-choline PET/CT and who received parathyroidectomy. All patients gave their written informed consent for the procedure. The exclusion criteria were profound vitamin D deficiency and severe kidney failure (creatinine clearance <30 mL/min). The data were analysed retrospectively. The local ethics committee approved of the data analysis.

Neck ultrasound

The patients were imaged in the supine position with neck extended using a high-frequency linear transducer. The assessment included the area from the mandible to the sternal notch bilaterally. Longitudinal and transverse views were used to locate the parathyroid glands suspected of being abnormal (homogeneous hypoechoic lesions that are oval or bean shaped). Also, the presence or absence of thyroid nodules was documented in all patients. Ultrasonography was performed and reported by two experienced radiologists. The results in terms of PTA detection were categorised into positive, negative, or inconclusive cases.

^{99m}Tc-Sesta-MIBI imaging and analysis MIBI

The patients were injected intravenously with 740 MBq ± 20 MBq of ^{99m}Tc-Sesta-MIBI (Atom Hitech Co., Ltd, Beijing, China). Early and late planar images were acquired at 20 minutes and 2 hours after radiotracer administration, using a conventional gamma camera with a pinhole collimator [200k counts during early and late acquisition] (E.CAM, Siemens Medical Solutions, Erlangen, Germany). In addition, SPECT/CT data were acquired after the second acquisition of planar images [CT: 30mAs, 120 kV, slice thickness 3 mm, SPECT: low energy high-resolution collimator, matrix 128 ×128, zoom 1.0, using a 64-slice SPECT/CT (Philips Precedence, Best, Netherlands)].

The planar images and SPECT/CT data were reviewed for parathyroid visualisation by an experienced nuclear medicine physician, and a negative MIBI scan was defined as the absence of focal uptake on the early and/or delayed images. An inconclusive MIBI SPECT/CT scan was defined as only vague uptake in the soft tissue adjacent to the thyroid, or uptake possibly associated with thyroid nodules.

Evaluation of imaging procedures before PET imaging

Subsequently the results of ultrasound and MIBI imaging were reviewed.

PET/CT was performed, if:

1. Both ultrasound and MIBI imaging were negative.

Or

2. The results of the two modalities were deemed discordant. This was the case if a positive or inconclusive result of one imaging modality could not be confirmed by the other modality (was negative or inconclusive). Also, if there was a discrepancy in the number or location of lesions in the two modalities, the results were rated as being discordant.

^{11}C-choline-PET/CT and analysis

Twenty minutes after intravenous injection of ^{11}C-choline (385±175 MBq), a low-dose CT was performed (30-70 mAs , 120 kV, slice5 mm, pitch 0.8), followed by a 2- to 3-bed position PET acquisition of 6 to 9 minutes covering the neck and upper chest using a three-dimensional (3D) Biograph 64 PET/CT system (Siemens, Erlangen, Germany). The injected activity and the exact time between injection and the start of image acquisition were recorded. The effective dose attributable to the low-dose CT was calculated by multiplying the conversion factor of 0.0059 mSv/mGy/cm with the dose-length product; the effective dose due to the ^{11}C-choline administration was calculated by multiplication of the injected dose in MBq by the conversion factor 0.00435 mSv/MBq.(*23*)

The raw PET data were iteratively reconstructed with two iterations, eight subsets, point-spread-function (PSF) modelling (TrueX), matrix size 168 × 168, and zoom 1.0. Scatter and attenuation corrections were applied. PET/CT imaging data were reviewed by two experienced nuclear physicians (Liu Y and Huo L) blinded to other imaging data and reports. A semi-quantitative assessment based on a visual interpretation was performed. A positive ^{11}C-choline PET/CT scan was defined as a clear focal uptake, which, on visual

interpretation, is significantly higher than that of regular thyroid tissue. Ectopic focal uptake, distant of the thyroid/thyroid bed, was also considered as a positive PET result. Inconclusive PET/CT cases were defined as a soft-tissue lesion with an uptake in the same range as that of normal thyroid tissue. If no prominent or ectopic uptake was detectable, the PET/CT was considered to be negative.

The maximal standardised uptake value (SUV_{max}) of the PTAs was measured by assigning a spherical volume of interest (VOI) with a diameter of 10 mm to the area of suspicious uptake using the PET Edge tool (Siemens, Erlangen, Germany). The SUV_{mean} of the background was measured by placing a spherical VOI with same diameter inside the contralateral thyroid lobe as well as on the contralateral carotid artery. The specific uptake value ratios (SUVRs) were calculated using the two background regions. Receiver operating characteristic (ROC) analysis was used to determine the optimal cut-off value for SUVR in predicting true PTA lesions. Sensitivity, specificity and accuracy for predicting true PTA lesions were also calculated.

Surgery and PTH-level examination

Surgery was performed between 1 week and 20 weeks after ^{11}C-choline PET/CT. The surgeons were aware of the outcome of the imaging results. If the PTA could not be localised intraoperatively by minimally invasive surgery, the surgeons proceeded to bilateral neck exploration. The intraoperative location of the PTA(s) was recorded and correlated with the results of PET/CT. Patients received additional thyroidectomy when a goiter or a large dominant thyroid nodule was present. All patients were discharged from the hospital within 1 to 2 days. PTH levels and serum calcium were determined during hospitalisation. Successful parathyroidectomy was defined as a greater than 50% decrease in intraoperative PTH level 10 minutes after parathyroidectomy, or normalisation of PTH level postoperatively at first follow-up along with the presence of abnormal parathyroid tissue at pathological examination.

Histology

Histological analysis was performed on sections taken from paraffin-embedded tissue stained with haematoxylin and eosin. Immunohistochemistry with anti-PTH antibody was performed. Parathyroid adenoma and parathyroid hyperplasia were considered as a true-positive result.

Statistical analysis

Quantitative variables are described as mean ± standard deviation (SD), whereas qualitative variables are described as numbers and percentages. For group comparisons, unpaired Student t tests were used for parametric variables, and the Mann-Whitney U test was used for the non-parametric variables.

Sensitivity, specificity, and accuracy were calculated by chi-square testing. All statistical analyses were performed using SPSS v. 23 (SPSS Inc., Chicago, IL). P-values <0.05 were considered statistically significant.

RESULTS

Patient characteristics

A total of 87 patients with pHPT could be included in the analysis. Patient characteristics, including laboratory values (Table 1) and results of ultrasound and MIBI imaging (Table 2) are provided.

^{11}C-choline imaging

The mean delay between injection and image acquisition was 25 ± 5 minutes. Effective doses due to the ^{11}C-choline injection and the low-dose CT were calculated to be 1.7 ± 0.8 mSv and 2.5 ±1.5 mSv, respectively. In 86 patients, ^{11}C-choline PET/CT visualised 92 positive foci including 20 foci with inconclusive uptake; on CT, the lesions had a mean maximum transverse diameter of 13.7 ± 7.0 mm. Three representative examples of a positive (Fig. 1.) and an inconclusive (Fig.2) and a negative (Fig.3) PET/CT scans were shown.

Of 92 lesions with positive and inconclusive uptake, the lesional uptake value (SUV_{max}), background uptake value in carotid and thyroid, as well as the lesion-to-background ratios ($SUVR_{max}$) are listed in Table 3. Assessing 72 PET lesions with positive uptake in 70 patients, the mean SUV_{max} was 6.15±4.92 and the mean SUVR (carotid) and SUVR (thyroid) were 4.49±2.68 and 2.22±1.18, respectively. For 20 lesions with inconclusive uptake in 18 patients, a mean SUV_{max} of 2.96±2.32, mean SUVR(carotid) of 2.68±0.98, and SUVR(thyroid) of 1.37±0.33 were calculated. One patient had one lesion with positive uptake and one lesion with inconclusive uptake (Table 3). A SUVR(carotid) cut-off value of 2.84 and a SUVR(thyroid) cut-off value of 1.67 were determined by ROC analysis.

Diagnostic performance

When dichotomizing the ^{11}C-choline PET/CT imaging results by defining lesions with both positive and inconclusive uptake as positive ^{11}C-choline PET lesions, 84 of 92 lesions (91.3%) had true-positive uptake versus 8 lesions (8.7%) with false-positive uptake. One lesion had false-negative uptake, with sensitivity of 98.8 [95% confidence interval (CI): 92.7–99.9] (Table 4). The corresponding per lesion positive predictive value was 91.3% (95%CI: 83.1–95.9). A SUVR(carotid) cut-off value of 2.84 yielded a sensitivity of 58.3%, specificity of 75.0% and accuracy of 61.3%. In comparison, the SUVR(thyroid) cut off value of 1.37 yielded a sensitivity of 56.0%, specificity of 87.5% and accuracy of 65.2%. Detailed histological results can be found in table 4.

PTH level Post-surgery

The PTH levels in the majority of patients with positive choline uptake (67 of 70 patients) and patients with inconclusive uptake (15/16) showed a significant decrease (over 50%) after surgery. The detailed results are listed in Table 5.

DISCUSSION

To the best of our knowledge, this is the largest cohort of patients examined with ^{11}C-choline thus far. All patients had, according to the laboratory parameters obtained, a primary hyperparathyroidism, and negative or inconclusive ultrasound and MIBI imaging (including SPECT/CT); a correlation with histology was performed in all patients. Our retrospective analysis shows that ^{11}C-choline PET/CT can help identify the location of PTAs in the aforementioned group of patients due to its high sensitivity and PPV for the location of PTAs.

In previous studies, ^{11}C-methionine has been shown to be of great value, especially, but not only in the setting of negative MIBI-imaging (*14-17*). The pooled sensitivity in a meta-analysis of nine studies with a total of 137 patients was found to be 86%(*24*). When comparing the SUVR(thyroid) to the data published by Otto et al. (*25*) , the value reported, 1.8 40 min after injection, is slightly lower than the value we observed. The background ratio in this study, up to 2.8, is smaller than the SUVR(carotid) in our study; however the group used soft tissue as a reference. All in all, according to our data, ^{11}C-choline imaging seems to perform at least as well as ^{11}C-methionine in the detection of parathyroid adenomas. However, a head-to-head-comparison is needed to assess, if the method is indeed superior.

The data we obtained are in keeping with the published data using ^{18}F-fluorocholine PET/CT and the only larger study published thus far using ^{11}C-choline PET/CT.

In 2014, Orevi et al. published a study using ^{11}C-choline PET/CT in 40 patients. The results were correlated with other imaging modalities, in particular also MIBI imaging. In 93% of cases, a PTA could be visualised. The results of PET and MIBI imaging were concordant in 29 cases; PET clearly outperformed MIBI imaging. In our study, a correlation with MIBI could not be performed, since only cases with negative or inconclusive MIBI imaging and ultrasound were included. Nevertheless, the detection rate for ^{11}C-choline PET/CT in our study was even higher (99%); however, a selection bias cannot be excluded.

Michaud et al. used ^{18}F-fluorocholine PET/CT in a small patient collective, which is more comparable to ours with equivocal or discordant ultrasound and MIBI imaging; however, patients who also had secondary hyperparathyroidism were included. On a per-patient basis, a sensitivity of 88% for open reading and 94% for blinded reading were observed; these values are slightly lower than the ones in our study. Also, in terms

of quantitation, a mean SUV_{max} of 3.9 and a SUVR(thyroid) of 1.5 were determined in that trial. Using ^{11}C-choline, we found significantly higher values with a mean SUV_{max} of 6.1 and a SUVR (thyroid) of 2.2 in the positive cases.

Using a similar small patient collective, but implementing ^{18}F-fluorocholine PET/MR, Kluijfhout et al. reported a per lesion sensitivity of 90%, remarkably without any false-positive findings. In our study, 8 of 92 lesions were false positive. In this PET/MR study, the mean SUV_{max} was found to be a bit higher (4.2) than in the study using PET/CT.

As in most studies, also in our study image data was visually analysed in order to detect PTAs. Using ROC analysis to determine the optimal cut off value for SUVR(carotid) and SUVR(thyroid) the results for sensitivity, specificity and accuracy for predicting true PTA lesions were clearly inferior to visual analysis.

Of course, several limitations of our study have to be pointed out. The most prominent limitation is the retrospective study design, which could potentially lead to a selection bias. In addition, a selection bias can be expected, because only patients who received surgery were analysed. Also, only one type of PET/CT with a specified reconstruction algorithm was used. On one hand, this results in very homogeneous data, but on the other hand, the results for the SUV and ratios cannot be readily applied in other institutions with different types of PET/CT or other reconstruction algorithms. Since the data, very much like in ^{99m}Tc-Sesta-MIBI imaging, was mainly visually interpreted, this can be rated as a minor limitation.

Another limitation is, that due to the short half-life of ^{11}C, late imaging was not feasible in our study. A combination of early and delayed imaging has been recently shown to detect additional PTAs using ^{18}F-fluorocholine PET/CT in a large collective of 46 patients (Broos et al. JNM 2019). A direct comparison cannot be made due to differences in the patient collective and study setup, however, even when the inconclusive cases are included, the ratio of parathyroid to normal thyroid tissue in our study appears to be at least as high as the ratio in the above mentioned study.

CONCLUSION

These results in a large group of patients indicate that ^{11}C-choline PET/CT is a very promising tool for PTA localisation, in case ultrasound and ^{99m}Tc-Sesta-MIBI imaging including SPECT/CT yield negative or discordant results. However, the reported data on the diagnostic accuracy of ^{11}C-choline PET/CT for parathyroid imaging cannot reflect the true diagnostic accuracy in clinical practice because of the obvious referral bias of the study. Furthermore, it is not possible to compare the imaging accuracy to that of ^{99m}Tc-Sestamibi SPECT imaging, since no head-to-head comparison was performed.

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DISCLOSURURE

There are no potential conflicts of interest relevant to this article.

KEY POINTS

Questions: Data on the utility of 11C-choline positron emission tomography (PET) in the detection of parathyroid adenomas in primary hyperparathyroidism (pHPT) is still sparse.Pertinent Findings: In this retrospective analysis of large cohort of patients with pHPT, and negative or inconclusive ultrasound and/or 99mTc-Sesta-MIBI imaging, 11C-choline PET/CT showed a lesioned positive predictive value of 91.3% with high sensitivity of 98.8%.Implications for Patient Care: 11C-choline PET/CT is suitable for detecting hyperfunctioning parathyroid tissue in patients with primary hyperparathyroidism.

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TABLES

Table 1: Patient characteristics

Patients (n=87)	
Sex: women	60
Age (mean±SD) (years)	56.0±12.6
BMI (mean±SD)	24.6±3.7
Previous thyroidectomy, n (%)	5 (5.7)
Previous parathyroidectomy, n (%)	5 (5.7)
Biochemistry (mean±SD)	
Calcium (mmol/L, normal range: 2.13-2.70)	2.73±0.23
Parathyroid hormone (PTH) (pg/mL, normal range: 12.0-65.0)	254.5±303.1
Albumin (g/L, normal range: 35-51)	43±4
Phosphorus (mmol/L, normal range: 0.81-1.45)	0.85±0.18
25-hydroxyvitamin D (ng/mL, normal range: 8.0-50.0)	14.2±7.0
Creatinine (µmol/L, normal range: 59-104)	72±27
Alkaline phosphatase (U/L, normal range: 30-120)	151±206

Table 2: Results of Ultrasonography and ^{99m}Tc-MIBI imaging (patients n = 87)

Ultrasonography	
Negative, n (%)	15 (17)
Inconclusive, n (%)	36 (41.4)
Thyroid nodules, n (%)	54 (62.1)
^{99m}Tc-MIBI imaging including SPECT/CT	
Negative, n (%)	40 (46.0)
Inconclusive, n (%)	27 (31.0)

Table 3. Uptake values in lesions with positive and inconclusive uptake.

	92 lesions with ^{11}C-choline uptake		
	Positive uptake (n=72)	Inconclusive uptake (n=20)	All (n=92)
Uptake value (SUV) of lesions (mean±SD)			
SUV_{max}	6.15±4.92*	2.96±2.32	5.45±4.67
Background uptake (SUV) (mean±SD)			
SUV_{mean} of contralateral thyroid	2.84±1.91	2.14±1.44	2.69±1.83
SUV_{mean} of contralateral carotid artery	1.39±0.79	1.03±0.39	1.31±0.74
Lesion target to background uptake ratio (SUVR), (mean±SD)			
SUVR(thyroid)	2.22±1.18*	1.37±0.33	2.03±1.11
SUVR(carotid)	4.49±2.68*	2.68±0.98	4.09±2.52

SUV: standardised uptake value, SUVR: standardised uptake value ratio.

*Significance level of p value <0.001 (positive lesions vs. inconclusive lesions)

Table 4: Histopathological results of all lesions (n=93)

^{11}C-choline PET/CT	**Pathological examinations**	
	Parathyroid glands (n=85)	Non-parathyroid lesions (n=8)
Lesions with positive uptake (n=72)	Lesions with true-positive PET uptake (n=67, 93.06%) (Histology: 53 parathyroid adenomas; 14 parathyroid hyperplasia)	Lesions with false-positive PET uptake (n=5, 6.94%) (Histology: 3 nodular goiters; thymoma 1; 1 normal parathyroid tissue)
Lesions with inconclusive uptake (n=20)	Lesions with true-positive PET uptake (n=17, 85%) (Histology: 10 parathyroid adenomas; 7 parathyroid hyperplasia)	Lesions with false-positive PET uptake (n=3, 15%) (Histology: 2 nodular goiters; 1 follicular nodule)
Lesions with negative uptake (n=1)	Lesions with false-negative PET uptake (n=1, 100%) (Histology: 1 cystic parathyroid adenoma)	

Table 5. PTH level post-surgery

	PTH level post-surgery
Lesions with positive choline uptake (n=70)	Group 1 (n=1) (No difference)
	Group 2 (n=2) (Decreasing 30%-50%)
	Group 3 (n=67) (Decreasing > 50%)
Lesions with inconclusive choline uptake (n=16)	Group 1 (n=1) (Decreasing = 42%)
	Group 1 (n=15) (Decreasing> 50%)
Lesions with negative choline uptake (n=1)	Group 4 (n=1) (Decreasing > 50%)

FIGURES

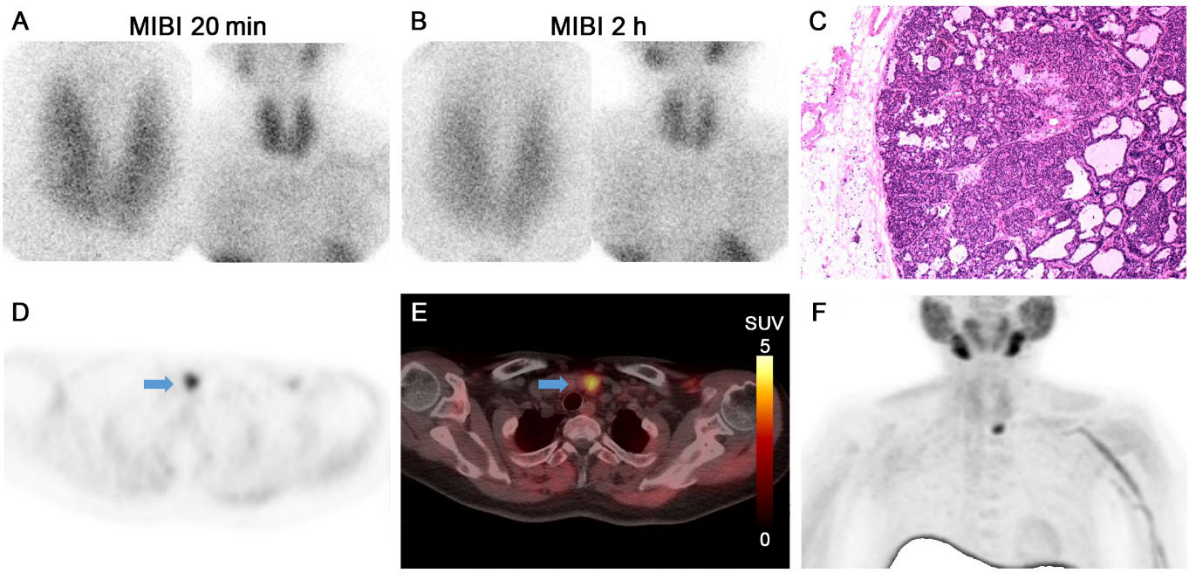

Figure 1. Representative positive PET scan of a 43-year-old man with a parathyroid hormone (PTH) level: 1358pg/mL, Serum-Calcium (Ca): 3.0mmol/L, phosphate (P): 0.78mmol/L, alkaline phosphatase (ALP): 82U/L, creatinine (Cr): 98µmol/L. Neck ultrasound imaging showed a suspicious nodule 1.8×1.5×0.7cm at left thyroid lobe region. A, B. Negative MIBI imaging of the neck at 20 min and 2h post injection. C. Histopathological assessment: Encapsulated parathyroid adenoma, which is composed predominantly of chief cells with pseudoglandular architecture in keeping with a parathyroid adenoma. D, E. Transverse views of the ^{11}C-choline PET/CT; arrow indicates parathyroid adenoma with strong uptake of ^{11}C-choline. Size (CT): 1.1 cm x 1.3 cm x 1.4 cm, SUV_{max}: 6.87, $SUV_{mean}$of contralateral thyroid: 2.03, SUV_{mean} of contralateral carotid artery: 0.67. F, MIP of the ^{11}C-choline PET.

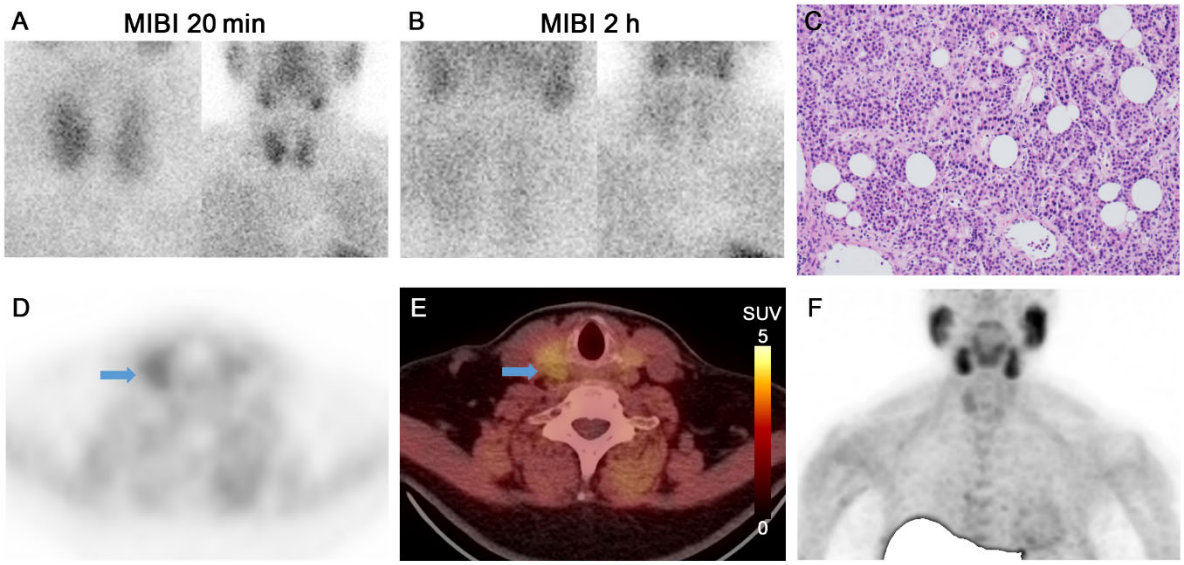

Figure 2. Representative inconclusive PET scan from a 52-year-old woman with PTH level of 138pg/mL, Ca: 2.95mmol/L, P: 0.9mmol/L, ALP: 130U/L, Cr: 61µmol/L. On neck ultrasound: suspicious lesion next to the right thyroid lobe, measuring 2.2 x 1.5 x 0.6 cm. A, B. Negative MIBI scan at 20 min and 2h post injection. C. Histopathological assessment: Parathyroid tissue with hypercellularity, which is composed mainly of chief cells and adipocytes, consistent with parathyroid adenoma. D, E, Transverse views of ^{11}C-choline PET/CT, size (CT) is 0.9 cm x 0.8 cm x 0.8 cm, the arrow indicates an inconclusive focus of ^{11}C-choline uptake suspicious of a parathyroid adenoma. SUV_{max}: 2.16, $SUV_{mean}$of contralateral thyroid: 2.01, SUV_{mean} of contralateral carotid artery: 0.97. F. MIP of the ^{11}C-choline PET.

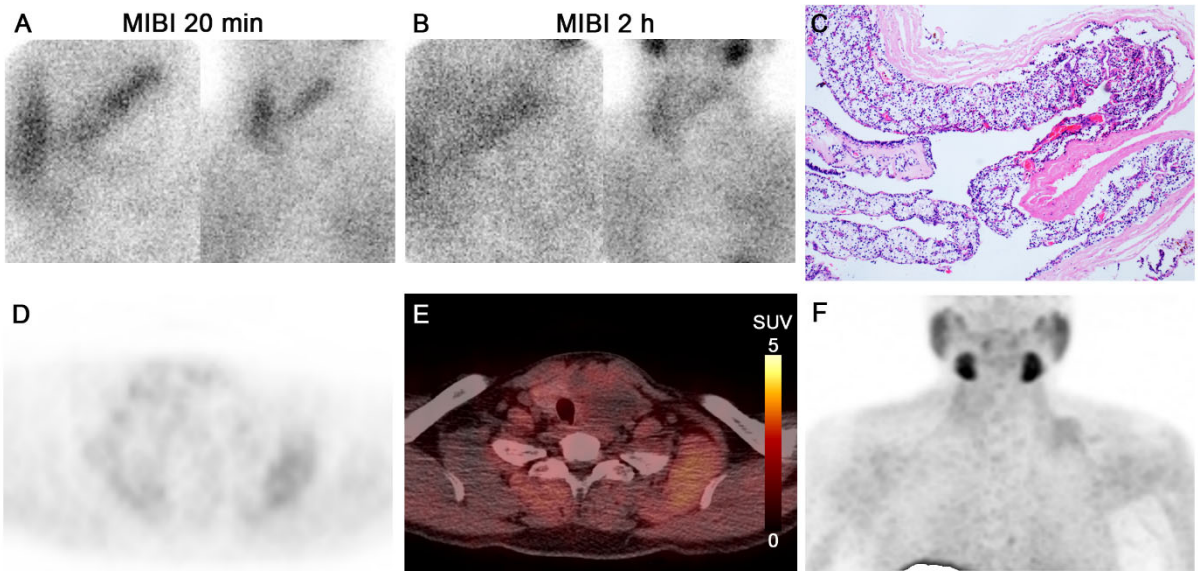

Figure 3. Representative negative PET from a 39-year-old man with PTH level of 140.1pg/mL, Ca: 2.74mmol/L, P: 0.68mmol/L, ALP: 75U/L, Cr: 111μmol/L. Neck ultrasound showed an apparently nodular, cystic, and enlarged left thyroid lobe with 7.7×5.5×3.7 cm. A, B: Negative MIBI scan at 20 min and 2h. C: Pathological examination. Encapsulated hypercellular parathyroid tissue, which is composed of water clear cells. The final diagnosis was parathyroid adenoma with extensive cystic degeneration. E, F, Transverse views of ^{11}C-choline PET/CT: negative, SUV_{mean} of contralateral thyroid: 1.44, SUV_{mean} of contralateral carotid artery 1.86. On CT a cystic lesion was visualised in the left thyroid region. F. MIP of ^{11}C-choline PET.