Semiquantitative Assessment of 99mTc-MIBI Uptake in Parathyroids of Secondary Hyperparathyroidism Patients from Chronic Renal Failure

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Abstract

Purpose Basing on semiquantitative assessment of ^{99m}Tc-MIBI uptake in parathyroids of secondary hyperparathyroidism (SHPT) patients from chronic renal failure, objective guidance could be given to improve the qualitative diagnosis accuracy of MIBI uptake.

Methods MIBI uptake intensiveness was semiquantitatively calculated with software ImageJ. MIBI uptake intensiveness and clinical indices were compared in 3-level grouping method consisting of slight (group 1), medium (group 2) and high (group 3) MIBI uptake groups and 2-level grouping method consisting of insignificant and significant MIBI uptake groups.

Results Patient age, renal failure course, hemodialysis vintage, glomerular filtration rate (GFR), serum parathyroid hormone (PTH) and alkaline phosphatase (AKP) were positively, but serum uric acid (UA) was negatively, significantly related to MIBI uptake intensiveness; patient age was negatively, but serum phosphorus (P) and calcium (Ca) ´ P were positively, significantly related to MIBI washout; oral administration of calcitriol and calcium would significantly reduce MIBI uptake and washout. MIBI uptake tendency might alter during specified course. In 3-level grouping method, such 7 indices as the MIBI uptake intensiveness, renal failure course, hemodialysis vintage, serum AKP, Ca, cysteine proteinase inhibitor C and PTH were comparable between group 1 and 2, but were significantly different between group 1 and 3, and between group 2 and 3. In 2-level grouping method, above 7 indices plus blood urine nitrogen (BUN)/Creatinine were all significantly different between insignificant and significant group with these indices except BUN/Creatinine being greater in significant group than in insignificant group. All above significant relations or differences were with $p < 0.05$.

Conclusions Patient age, renal failure course, hemodialysis vintage, GFR, serum PTH, AKP, UA, phosphorus and Ca ´ P, oral administration of calcitriol and calcium, and parathyroids themselves could significantly influence MIBI uptake in parathyroids of SHPT patients. 2-level grouping method should be adopted to qualitatively diagnosis MIBI uptake.

Introduction

Secondary hyperparathyroidism (SHPT) is a common complication in patients suffering from chronic renal failure (CRF). SHPT can be managed conservatively if the patient's condition is mild or in short disease course, but parathyroidectomy (PTx), being suggested by the National Kidney Foundation Kidney Disease Outcomes Quality Initiative (KDOQI) to treat severe SHPT when drug regime failed [1], is the preferred treatment [2] and the only cure [3] for severe drug-resistant SHPT. The need for surgical treatment [4] or radiofrequency ablation [5] of SHPT increases with chronic kidney disease progress and the increasing course the patient is dialyzed [6].

Precise identification of the diseased parathyroid lobe(s) is the prerequisite for surgical operation [7]. There are multiple imaging methods such as ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI), ^{99m}Tc-methoxyisobutylisonitrile (MIBI) scintigraphy for facilitating locating diseased parathyroid(s). ^{99m}Tc-MIBI scintigraphy has many advantages [4, 8] in diagnosis or differentiation of parathyroid disease. Different from primary hyperparathyroidism in which patients generally have only one lesion [9], patients with SHPT usually have several lesions including ectopic glands [4] and multi-glandular disease [8, 10], even some patients with parathyroid hyperplasia or adenoma show false negativity [8], which increase the accuracy limitation of ^{99m}Tc-MIBI scintigraphy in positioning the parathyroid(s) relative to SHPT [3, 6, 8, 11].

In diseased parathyroids, significant ^{99m}Tc-MIBI accumulation foci can evidently demonstrate the location of being planned surgical resection, how should those insignificant ^{99m}Tc-MIBI accumulation foci be dealt with? If they are considered negative foci, in fact their serum parathyroid hormone (PTH) are higher than normal range; if they are considered positive foci, the location and numbers of diseased parathyroid(s) can't be confirmed because of low spatial resolution of planar imaging and indistinct boundary from surrounding tissues.

Herein semiquantitative assessment of ^{99m}Tc-MIBI accumulation level in parathyroid lobes with respect to background functioning tissue of SHPT patients was utilized to analyze the functional status of all parathyroid lobes and the relation of ^{99m}Tc-MIBI accumulation to several factors [12], which may help to understand the characters of insignificant ^{99m}Tc-MIBI accumulation foci which often brought confused misinterpretation idea to physicians because of high degree of variability in confidence.

Materials And Methods

Patients

From December 2015 to January 2021, 156 SHPT patients (77 women, 79 men) with CRF course 47.42 (0-223) months, age 47.71 (14-78) years, and hemodialysis vintage 26.29 (0-223) months, were retrospectively investigated. All of them had high serum PTH levels (normal range 15-68.3 pg/ml) and parathyroid MIBI scintigraphy. Most of them had measured serum ionized calcium (Ca), inorganic phosphate (P), alkaline phosphatase (AKP), urine nitrogen (BUN), uric acid (UA), creatinine (Cre), cysteine proteinase inhibitor C (CPI), calcitonine, ferritin (Fer), vitamin B12 (VitB12), folate, erythropoietin (EPO), hemoglobin (Hb) on an empty stomach. All above biochemical tests were completed before hemodialysis if so. Several patients underwent US, CT, MRI, ^{99m}Tc-MIBI single-photon emission computed tomography/computed tomography (SPECT/CT) imaging of bilateral neck and upper thorax, and parathyroid gland surgery. Patients were excluded from the analysis based on the following criteria: history of previous parathyroid or thyroid surgery; abnormal MIBI accumulation beyond thyroid contour; primary hyperparathyroidism. The patients inclusion criteria were as follows: elevated serum PTH; disease history of being confirmed CRF; dual-phase MIBI scintigraphy with the time difference less than 5 days between laboratory biochemical tests and MIBI imaging.

Imaging study protocol

All patients received an intravenous injection of 740 MBq ^{99m}Tc-MIBI. Early and delayed scans of lower part of head, neck and the upper thorax were obtained 20 min and 2 h post injection, respectively, in the supine and neck-extended positions with a planar gamma camera in anterior-posterior view with low energy, parallelhole, general purpose collimator, matrix 128 x 128, and zoom 2.19. Each frame acquisition counted 500 K. The energy window was maintained at 20%, with the photopeak centered at 140 KeV. The imaging acquisition was using Philips precedence SPECT/CT 6 (Philips Medical Systems, Netherlands). SPECT/CT integrated imaging was performed immediately after the delayed planar imaging. A total of 64 frames (20 s/frame, matrix 128 x 128, zoom 1.0) were acquired over 360° for SPECT imaging. Imaging data were reconstructed with a three-dimensional iterative algorithm. Images were smoothed using a Sharp(C) filter. CT acquisition and reconstruction conditions included tube voltage 120 kV, tube current 300 mA, matrix 512 ´512, layer thickness 3 mm, increment 2 mm and pitch 1. Both SPECT and CT 3-mm slices were generated using an Astonish bone application package (Philips) and were transferred to a picture archiving and communication system after generation of DICOM files. SPECT/CT images were fused with the Syntegra software V2.3.1 from Philips. Ultrasonography was performed using the Aixplorer SuperLinear™ SL15-4 scanner (SuperSonic Imagine, France) with a 4-15 MHz linear-array transducer. Whole body scans were simultaneously performed anteriorly and posteriorly 3 hours after intravenous injection of 740 MBq ^{99m}Tc-methyldiphosphate (MDP) for bone scan. Histological changes in parathyroid tissue from PTx were diagnosed basing on frozen slices by haematoxylin and eosin (H&E) staining.

The analysis methods of ^{99m}Tc-MIBI uptake image

To reduce misclassification errors in case ascertainment, visual analysis of MIBI uptake were re-evaluated by two experienced nuclear medicine physicians who were blinded to the laboratory, radiological, surgical and pathological results. On visual analysis, basing on accumulation intensiveness, all ^{99m}Tc-MIBI uptake in regions of interest (ROIs) of parathyroids was qualitatively graded to 3 levels [8] illustrated in **figure 1** including slight uptake (no foci could be differentiated, **Fig. 1 A** & **D**), medium uptake (mild foci could be differentiated carefully but sometimes equivocally, **Fig. 1 B** & **E**) and high uptake (significant foci could be confirmed, **Fig. 1 C** & **F**). In the parathyroid lobes images with medium or high MIBI uptake, ROIs covered most spheres with visually increased MIBI uptake. In the MIBI scintigraph with slight MIBI uptake, ROIs covered most of the upper or lower one thirds of thyroid background image [3], because the majority of parathyroid glands distributed among the four usual anatomical positions [4, 13] and located immediately posterior to the thyroid gland [14, 15]. In the MIBI scintigraph loaded into ImageJ 1.46r (National Institute of Health, USA), the average value of the gray value mean of bilateral neck ROIs was utilized as background, and the calculation of target (the gray value mean of specified parathyroid ROI) to background ratio (TBR) for dual phases was used as the indicator for semiquantitatively [16] manifesting the MIBI uptake strength. So the bigger the TBR, the less MIBI uptake level; if some indices were negatively related to the gray value of MIBI uptake, these indices were positively related to MIBI uptake intensiveness; and vice versa. MIBI washout rate = [(early TBR-delayed TBR) ´100]/ delayed TBR.

Statistical analysis

Data are shown as mean ± standard deviation (SD) for continuous variables. P (2-tailed) < 0.05 was considered significant in this study. One way analysis of variance (ANOVA), independent samples t-test, correlation analysis with Pearson's correlation coefficient and multiple linear regression analysis was performed with the statistical software of Statistical Package for Social Sciences (SPSS, version 24, IBM, Armonk, USA). Receiver-operating characteristic (ROC) analysis was performed with software MedCalc (version 19.0.4, MedCalc Software bvba, Ostend, Belgium). In one-way ANOVA, post hoc test of Student-Newman-Keuls (SNK) or Welch was used for homogeneous variances or heterogeneous variances, respectively.

Results

^{99m}Tc-MIBI uptake intensiveness category in individual parathyroid

All parathyroid lobes individually were visually categorized into one of 3 levels MIBI uptake illustrated in **Figure 1** as examples of MIBI uptake levels and the corresponding ROI determination methods.

Although patient A had high serum PTH level 739 pg/ml, there was no or slight MIBI accumulation foci in thyroid contour during early and delayed phases (**Fig. 1 A**), so the ROIs of 4 parathyroid lobes were determined basing on normal parathyroid anatomy [17] (**Fig. 1 D**).

In patient B, there was moderate MIBI uptake in bilateral upper and right lower parathyroid lobes during delayed phase (**Fig. 1 B**). Behind the envelope of right thyroid (**Fig. 1 H**) and left thyroid (**Fig. 1 I**) there were two and one low echo intensity US images, respectively, suggesting enlarged parathyroid lobes. Together with high serum PTH (377 pg/ml), CRF course 102 months, and that in bilateral lungs there were high ^{99m}Tc-MDP uptake (**Fig. 1 G**) and high density images (**Fig. 1 J**) suggesting ectopic calcinosis, all above evidences should be enough to diagnosis SHPT and localize the diseased parathyroids (**Fig. 1 E**).

Patient C had significant MIBI uptake in bilateral upper and right lower parathyroid lobes in planar (**Fig. 1 C**) and SPECT/CT images with the low density images behind thyroid tissue and the fused high MIBI uptake and low density images (**Fig. 1 M**). Combining high serum PTH (2606 pg/ml) with CRF course 108 months, all above evidences were enough to diagnosis SHPT and localize diseased parathyroids (**Fig. 1 F**). The pathological results from PTx confirmed the high MIBI uptake foci to be parathyroid adenoma (**Fig. 1 K & L**).

The relativity of some indices to ^{99m}Tc-MIBI uptake intensiveness

CRF will lead to many abnormal biochemical indices. In CRF patients, the retention of phosphorus and the reductions in calcium and vitamin D levels stimulate the synthesis and secretion of PTH as well as the proliferation or nodularization rate of parathyroid cells [18]. So it's essential to explore the relativity of some factors inclusive of biochemical indices to MIBI uptake in parathyroids to find some relevant factors for improving the diagnostic accuracy of MIBI uptake in SHPT patients.

For expression convenience, in a patient such 6 scintigraphic indicators as AvgE, MinMeanE, AvgD, MinMeanD, MinWash, MaxWash derived from TBR were defined in **table 1**.

From the relativity of clinical variables and biochemical markers with continuous variables to gray value of MIBI uptake in parathyroids (**table 1**), and the difference of gray value of MIBI uptake between categorical variables such as different sex (female and male), thyroid function (low and normal), or oral calcitriol and calcium (whether oral administration of calcitriol and calcium or not) (**table 2**), the specified correlations were listed as the followings (if there was significant relations, $p < 0.05$):

AvgE [19] was only significantly related to patient age. MinMeanE was significantly related to patient age, renal failure course, hemodialysis vintage, AKP and oral calcitriol and calcium. AvgD [19] was significantly related to patient age, renal failure course, hemodialysis vintage, GFR and UA. MinMeanD was significantly related to patient age, renal failure course, hemodialysis vintage, AKP, UA and PTH. MinWash was significantly related to P, Ca ´ P and oral calcitriol and calcium. MaxWash was significantly related to patient age, P and oral calcitriol and calcium. MinMeanE and MinMeanD had the most influential factors, so these 2 indicators should be most valuable in routine interpretation of the MIBI images especially for predicting biochemical state and disease severity.

Patient age was significantly related to AvgE, MinMeanE, AvgD, MinMeanD and MaxWash. Both renal failure course and hemodialysis vintage were significantly related to MinMeanE, AvgD and MinMeanD. Oral calcitriol and calcium was significantly related to MinMeanE, MinWash and MaxWash. AKP was significantly related to MinMeanE and MinMeanD. P was significantly related to MinWash and MaxWash. UA was significantly related to AvgD and MinMeanD. GFR, Ca ´ P, PTH was only significantly related to AvgD, MinWash, MinMeanD (which was different from Li's findings [8]), respectively ($p < 0.05$). BUN, BUN/Cre, Cre, CPI, Ca, calcitonine, Fer, VitB12, folate, EPO, Hb, sex or thyroid function was irrelative to above 6 indicators ($p > 0.05$). So patient age influenced most of above 6 indictors. Ca is one of important factors influencing serum PTH concentration [18], but Ca was irrelative to MIBI uptake, which maybe relative to oral administration of calcitriol and calcium.

Thus with the increment of patient age, renal failure course, hemodialysis vintage, GFR, serum PTH and AKP, MIBI uptake was possibly increased; with the increment of serum UA and oral calcitriol and calcium [15], MIBI uptake was possibly decreased; with the increment of patient age, serum phosphorus, Ca ´ P and oral calcitriol and calcium, MIBI washout was possibly increased.

After multiple linear regression analysis, MinMeanE and MinMeanD maybe predicted as:

MinMeanE = 0.803 - 0.324 ´ age years - 0.253 ´ AKP (u/L), $R^2 = 0.146$, $F = 12.552$, $p = 0.000$;

MinMeanD = 0.863 - 0.278 ´ age years - 0.209 ´ AKP (u/L) + 0.203 ´ UA (mmol/L) -0.209 ´ P (nmol/L), $R^2 = 0.143$, $F = 7.220$, $p = 0.000$.

MIBI uptake discrepancy in different CRF course

The discrepancy of MIBI uptake intensiveness often emerged (**Fig. 2**). The general tendency was that with CRF course increasing, MIBI uptake intensiveness were gradually increased (the gray value was gradually decreased). However, in some cases in anyone of 4 parathyroid lobes the tendency was changed, even fluctuating, whatever during early or delayed phase, which indicated that in specified analysis of MIBI uptake in parathyroids, above relative indices to MIBI uptake sometimes didn't directly contribute to the diagnosis in general rules, which were similar to Mario's findings [20].

The difference of ^{99m}Tc-MIBI uptake intensiveness and some indices among 3 qualitative groups

For expression convenience, parathyroid groups with slight, medium and high MIBI uptake intensiveness were named as group 1, 2 and 3, respectively. For group 1 and 3, the visual classification of MIBI uptake intensiveness was not controversial between 2 nuclear medicine physicians. But in group 2, physicians were absent of diagnostic confidence for the confirmation and localization of abnormal parathyroid lobe only depending on MIBI uptake with inexplicit outline, so was the retention of the group 2 necessary for clinical practice? Because in group 2 all patients had high serum PTH, and just like that patient B had enlarged parathyroids and ectopic calcinosis in both lungs but ambiguous MIBI foci boundary (**Fig. 1**), physicians were afraid of missing this kind of diagnosis of possible positive cases, thus the individual parathyroid lobe with medium or equivocal MIBI uptake was classified into group 2 with the consensus of 2 nuclear medicine physicians sometimes with much hesitation. For answering the question of whether keeping group 2, the difference of ^{99m}Tc-MIBI uptake intensiveness and some indices among 3 qualitative groups were analyzed as the followings:

If MIBI uptake was grouped on per-parathyroid lobe basis, during early or delayed phase, in most of 4 parathyroid lobes of all patients the MIBI uptake intensiveness was comparable between group 1 and 2 ($p > 0.05$), but was significantly different between group 1 and 3, and between group 2 and 3 ($p < 0.05$) with there being more intensive MIBI uptake in group 3 than that in group 1 or group 2（**table 3**）.

If MIBI uptake was grouped on per-patient basis, all cases were divided into 3 groups basing on the most intensive MIBI uptake parathyroid lobe in 4 parathyroid lobes of every patient. Renal failure course, hemodialysis vintage, AKP, Ca, CPI and PTH were all comparable in group 1 and 2 ($p > 0.05$), but was significantly different between group 1 and 3, and between group 2 and 3 ($p < 0.05$) during both early phase (**table 4**) and delayed phase (**table 5**) with the indices being greater in group 3 than in group 1 or 2, which showed that MIBI uptake might be indicative of disease state.

It was interesting that although MIBI uptake intensiveness in table 3 were comparable between group 1 and 2, the MIBI uptake mean were all less in group 1 than in group 2, which indicated that nuclear medicine physician had chosen the appropriate cases into corresponding groups even if the determination was hard.

Now that there were the similarity in group 1 to group 2, and the difference between group 1 and 3, and between group 2 and 3 with regard to MIBI uptake and some indices, group 1 and group 2 might be combined into one group named as insignificant group (shorted for insignificant MIBI uptake group); on the contrary, the previous group 3 could be named as significant group (shorted for significant MIBI uptake group). So what clinical value lied on this kind of 2-level grouping methods in MIBI uptake intensiveness?

The difference of ^{99m}Tc-MIBI uptake intensiveness and some indices between 2 qualitative groups basing on 2-level grouping method

The ROC analysis (**table 6**) displayed that all $p < 0.05$ with high sensitivity for diagnosing the significant MIBI uptake if the criteria of MIBI uptake gray value was less than 0.50-0.71 in individual parathyroid lobe during early or delayed phase. The optimal cutoff value of the gray value of MIBI uptake and 95%CI of AUC were shown in **figure 3** for differentiating the insignificant from significant MIBI uptake in parathyroid lobes. The less the MIBI uptake gray value, the higher sensitivity for diagnosing the significant MIBI uptake.

During early or delayed phase, renal failure course, hemodialysis vintage, AKP, BUN/Creatinine, Ca, CPI and PTH were all significantly different between insignificant and significant group ($p < 0.05$) with the indices except BUN/Creatinine being greater in significant group than in insignificant group (**table 7**).

So the 2-level grouping method, displaying the detectability of abnormal parathyroid lobe with obvious MIBI uptake, should be recommended to be adopted in clinical practice for visually differentiating the MIBI uptake intensiveness because between these 2 groups there were significantly different MIBI uptake, biochemical data and time indices related to CRF progression and treatment.

The correlations of both indices

All listed indices relative to CRF (**table 8**) were positively or negatively significantly related to some other indices some of which were similar to document reports [8]. Some indices were significantly different, other indices were comparable, between insignificant and significant group, i.e., some indices could, but other indices couldn't, directly predict MIBI uptake intensiveness. These indicated the complexity, interaction even mutual offset of these indices in influencing MIBI uptake. It's essential to more deeply study the complex interaction network of these indices in the course of CRF for assistance of understanding MIBI imaging value in diagnosing diseased parathyroid(s) in SHPT patients.

Discussion

The average value of gray value means in the ROIs of right necks or left necks was 245.136 ± 6.150 or 244.453 ± 5.676, respectively, with the difference of 0.683 ± 4.093 (cases = 156) during early phase; and was 242.820 ± 8.095 or 241.424 ± 8.198, respectively, with the difference of 1.397 ±5.183 (cases = 156) during delayed phase, which indicated that it was reliable that the average gray value in the ROIs of bilateral necks was treated as background for the calculation of MIBI uptake or washout in parathyroid lobes. The little gray value variance of bilateral necks should be superior to the big gray value variance in thyroids [9].

In this paper, through analyzing the difference of MIBI uptake intensiveness and multiple factors in 3-level and 2-level grouping method, medium group shouldn't be kept even if it was possible that the rate of missing the diagnosis of positive MIBI uptake was elevated, but the possibility was statistically little. By dichotomising patient MIBI uptake level outcomes into insignificant and significant group, 2-level grouping method did not sacrifice analytical rigor; on the contrary, in clinical practice the convenience and efficiency should be improved without loss of confidence and with diagnostic accuracy being preserved. So semiquantitative assessment with the help of software ImageJ was essential to objectively determine the qualitatively grouping methods regarding MIBI uptake intensiveness in parathyroid lobes. It was recommended that in the parathyroids of SHPT patients the conception of insignificant or significant MIBI uptake should be adopted, but the conception of negative or positive MIBI uptake should be inappropriate due to the negativity might be likely false [21]. For localizing the diseased parathyroid(s) for PTx, the insignificant group should resolutely fall back on other possible imaging methods such as US [5], CT, MRI.

^{99m}Tc-MIBI is a lipophilic, monovalent cationic isonitrile compound that passively diffuses across the cell membrane, firstly suggested for parathyroid imaging by Coakley et al.[22]. The uptake mechanism of MIBI by hyperfunction parathyroid glands has been proposed to occur by increased vascularity, capillary permeability and metabolism. In oxyphillic cells mitochondrial entrapment of ^{99m}Tc-MIBI provides selectively increased and delayed uptake in diseased parathyroid gland(s). The MIBI in cells is treated by transport proteins as a xenobiotic. Depending on protein activity this tracer may be washed out, remain stable or be retained by transport proteins in the cell [23]. MIBI washes out more rapidly from thyroid than from abnormal parathyroid tissue, which is the basic principle for dual-phase imaging of the parathyroid glands [24]. Some parathyroid lesions do not retain MIBI, but some thyroid diseases or lymph nodes accumulate and retain MIBI, leading to false negativity or false positivity.

There were many factors affecting MIBI uptake in parathyroids [3], but several factors in this paper were not significantly associated with MIBI uptake although remained elusive [25]. In this paper 23 items closely relevant to CRF were studied. The destroyed renal function leaded to the retention of metabolite and phosphorus and the reduction of calcium in serum, which induced the proliferation of parathyroids and the increment of PTH. Usually with the CRF progress, the stimulated parathyroid would secret more and more PTH, following which MIBI uptake in parathyroid lobes was strengthened. The treatment for CRF included hemodialysis, PTx, supplement of calcitriol and calcium, levothyroxine, calcitonine, biphosphate, calcimimetic agent cinacalcet, and so on, which would somehow change serum Ca concentration, inhibit the proliferation of parathyroids, and interfere with MIBI uptake in parathyroids. EPO was mainly secreted by kidney, so CRF would induce decreased EPO and the corresponding hematopoietic function. Although EPO was not directly related to MIBI uptake, EPO did be significantly related to several indices relevant to CRF, so the function of EPO in affecting MIBI uptake should be more deeply investigated.

In fact, the property of parathyroid lobe itself including cellularity[3, 20, 25] , the active phase of parathyroid cells[26], p-glycoprotein or multidrug resistance-related protein expression [9, 25], parathyroid lesion weight, single or multiple parathyroid lesions and presence of parathyroid cyst [15] might play vital roles in determining its MIBI uptake. These might be parts of the reasons that in MIBI imaging the diagnostic efficiency in localizing diseased parathyroids changed with big variance [6, 7, 14] although it was sure that until now MIBI imaging was still a very important tool for diagnosing parathyroid diseases [6, 15, 18].

To our knowledge, until now this paper first emphasized on the roles of 23 items associated with CRF, the most intensive MIBI uptake level in 4 parathyroid lobes, and the changed MIBI uptake tendency of individual parathyroid in interpreting MIBI images. The 23 items were widely prescribed in routine clinical practice. The extensive items can widen the views of exploring the correlation of MIBI uptake with clinical practice [8]. The correlation of average MIBI uptake value in 4 parathyroid lobes with some indices might be decreased, however, the correlation of the most intensive MIBI uptake level in 4 parathyroid lobes with some indices might be increased [8]. The tendency of MIBI uptake in individual parathyroid lobes often altered, which brought clinician into troubling in predicting MIBI uptake intensiveness. This aspect wasn't previously discussed, but care about which must be taken to evade empirical error.

The main limitation of this paper lied on that only part of patients had pathological outcome from PTx, and not all patients had undertaken MIBI SPECT/CT imaging, US, CT or MRI imaging for parathyroid location, although they were considered to be not essential [9, 13, 27], and SPECT/CT MIBI imaging didn't increase the detection rate of ectopic parathyroid [6], and 65.9% of ectopic parathyroid gland could not be identified by preoperative examinations including US and planar MIBI imaging[4] inherent to their physical characters. But some literature reported that only planar MIBI imaging decreased the accuracy of localizing parathyroid for ectopic or supernumerary parathyroid lobes [7, 28]. For compensating these shortcomings, the following measurements were taken: all patients had high serum PTH; the patients with ectopic MIBI foci weren't enrolled; in insignificant MIBI uptake group normal anatomical location of parathyroid was referenced to draw parathyroid ROI; the large patient population assessed in this study should mitigate these bias to a certain extent.

Conclusions

Patient age, renal failure course, hemodialysis vintage, GFR, serum PTH, AKP, UA, phosphorus and Ca · P, oral administration of calcitriol and calcium, and parathyroids themselves could significantly influence MIBI uptake in parathyroids of SHPT patients suffering from CRF, but the influential tendency sometimes varied. 2-level grouping method consisting of insignificant and significant MIBI uptake should be suitable for clinically qualitative diagnosis of MIBI uptake, because MIBI uptake intensiveness, some biochemical indices and several other factors were significantly different between the two groups.

Declarations

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Author's contribution

DFY, LZ, YJin and YJ conceptualized the paper; DFY, YJin, DZ and YJ evaluated and reported the imaging findings; DFY, LZ and YJin drafted and edited the manuscript; YJ reviewed the manuscript; and all the authors acquired, analyzed and interpreted data, revised and commented on the paper and approved the final version of the manuscript.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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Tables

Table 1 the relativity of some indices to gray value of ^{99m}Tc-MIBI uptake

indices (unit)	normal range	mean	cases	AvgE		MinMeanE		AvgD		MinMeanD		MinWash		MaxWash	
				r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
age (years)	14 -78	47.71	156	-0.271	0.001	-0.289	0.000	-0.158	0.048	-0.222	0.005	-0.047	0.563	0.161	0.04
Course (months)	0 - 223	47.42	156	-0.148	0.065	-0.235	0.003	-0.178	0.026	-0.237	0.003	-0.095	0.237	0.006	0.93
Hemodialysis months	0 - 223	26.29	156	-0.108	0.181	-0.221	0.006	-0.189	0.018	-0.289	0.000	-0.138	0.086	-0.033	0.68
GFR (ml/min)	> 80	19.49	38	-0.195	0.241	-0.030	0.858	-0.324	0.047	-0.269	0.102	-0.184	0.269	-0.041	0.80
AKP (u/L)	35 -104	182.17	156	-0.118	0.149	-0.208	0.011	-0.101	0.219	-0.184	0.024	-0.001	0.994	0.098	0.23
BUN (mmol/L)	2.0 - 7.1	27.60	155	-0.043	0.596	0.064	0.429	-0.039	0.632	0.024	0.766	-0.092	0.256	-0.066	0.41
Creatinine (umol/L)	45 - 84	871.19	155	-0.043	0.599	0.029	0.718	-0.098	0.226	-0.052	0.517	-0.092	0.255	-0.099	0.22
UA (umol/L)	178 - 416	500.43	155	0.121	0.135	0.112	0.164	0.189	0.018	0.216	0.007	0.067	0.404	0.020	0.80
BUN/Creatinine		34.17	155	0.019	0.819	0.055	0.498	0.085	0.294	0.099	0.222	0.012	0.885	0.029	0.72
Ca (mmol/L)	2.1 - 2.6	2.16	156	-0.080	0.320	-0.128	0.112	0.010	0.905	-0.072	0.373	0.054	0.500	0.066	0.41
P (nmol/L)	0.8 - 1.45	1.94	156	0.120	0.135	0.111	0.166	-0.122	0.128	-0.073	0.364	-0.232	0.004	-0.191	0.01
Ca ´ P		4.18	156	0.017	0.377	0.032	0.688	-0.091	0.260	-0.091	0.261	-0.177	0.027	-0.131	0.10
CPI (mg/L)	0.41 - 0.98	6.68	150	-0.040	0.629	-0.104	0.205	-0.059	0.474	-0.094	0.25	0.008	0.922	-0.022	0.79
calcitonine (pg/mL)	< 2	6.42	156	0.065	0.424	0.017	0.836	-0.003	0.967	0.004	0.957	-0.025	0.755	-0.053	0.51
PTH (pg/mL)	15 - 68.3	1337.8	156	-0.021	0.794	-0.148	0.065	-0.102	0.203	-0.205	0.010	-0.103	0.202	0.009	0.91
Ferritin (ng/mL)	4.63 - 204	397.62	156	-0.089	0.267	-0.132	0.100	-0.014	0.860	-0.024	0.765	0.029	0.722	0.087	0.28
VitB12 (pmol/L)	138 - 652	455.21	156	-0.010	0.901	-0.019	0.817	-0.102	0.205	-0.093	0.247	-0.152	0.059	-0.084	0.29
Folate (nmol/L)	7 - 46.4	22.82	156	-0.005	0.953	-0.005	0.950	-0.111	0.166	-0.104	0.198	-0.066	0.410	-0.099	0.22
EPO (mIU/L)	3.7 - 29.5	36.88	149	0.029	0.729	-0.002	0.983	-0.016	0.848	-0.048	0.559	-0.002	0.979	-0.028	0.73
Hb (g/L)	110 - 150	93.53	156	-0.090	0.261	-0.081	0.316	-0.116	0.150	-0.127	0.115	-0.075	0.355	-0.011	0.88

This table demonstrated that some indices were, but several indices were not significantly related to gray value of MIBI uptake, so it indicated that some indices were significantly related to parathyroid MIBI uptake and/or washout or not. **AvgE**, **AvgD**: the average value of 4 gray value means in parathyroid lobes ROIs of each patient during early, delayed phase, respectively; **MinMeanE**, **MinMeanD**: the minimum one among 4 gray value means in parathyroid lobes ROIs of each patient during early, delayed phase, respectively; **MinWash**, **MaxWash**: the minimum, maximum one among 4 parathyroid lobes washout ratios, respectively; **GFR**: glomerular filtration rate; **AKP**: alkaline phosphatase; **BUN**: blood urea nitrogen; **Ca**: serum calcium ion; **P**:inorganic phosphorus; **UA**: uric acid; **CPI**: cysteine proteinase inhibitor C; **PTH**: parathyroid hormone; **VitB12**: vitamin B12; **EPO**: erythropoietin; **Hb**: hemoglobin; ***r***, Pearson's relativity; ***p***, 2-tailed *p* value. In this paper, if there were above abbreviations in other places without special instruction, their meanings were same.

Table 2 the difference of gray value of ^{99m}Tc-MIBI uptake between different sex, thyroid function, or oral calcitriol

indices	state	cases	AvgE			MinMeanE			AvgD			MinMeanD			MinWash	
			mean	*t*	*p*	mean	*t*	*p*	mean	*t*	*p*	mean	*t*	*p*	mean	*t*
sex	female	77	0.624	-1.907	0.058	0.542	-1.524	0.130	0.694	-1.251	0.213	0.627	-1.669	0.097	-3.761	-0.8
	male	79	0.670			0.586			0.726			0.678			-7.878	
Thyroid function	low	40	0.651	0.190	0.849	0.572	0.308	0.758	0.704	-0.277	0.782	0.641	0.462	0.645	-8.307	0.5
	normal	115	0.646			0.561			0.712			0.657			-4.894	
Oral calcitriol	no	46	0.624	-1.242	0.216	0.517	-2.101	0.037	0.739	1.469	0.144	0.658	0.229	0.819	2.806	2.2
	yes	110	0.657			0.584			0.698			0.650			-9.464	

The gray value of MIBI uptake and washout were comparable between different sex and thyroid function, but were significantly different whether oral administration of calcitriol and calcium (shorted as oral calcitriol) or not. *t*, independent samples *student*'s *t* test; *p*, 2-tailed p value.

Table 3 the gray value difference of ^{99m}Tc-MIBI uptake among 3 qualitative groups

parathyroid lobe	F	*p*	group 1		group 2		group 3		post-hoc *p*		
			cases	mean	cases	mean	cases	mean	□-□	□-□	□-□
RUE	6.412	0.002	74	0.693	74	0.619	8	0.545	0.128	< 0.05	0.129
RLE	20.806	0.000	75	0.705	61	0.605	20	0.443	0.002	0.000	0.009
LUE	5.512	0.005	60	0.674	89	0.640	7	0.458	0.547	< 0.05	< 0.05
LLE	3.735	0.039	75	0.697	71	0.644	10	0.521	0.101	0.177	0.431
RUD	20.741	0.001	104	0.742	49	0.682	3	0.542	0.051	0.010	0.022
RLD	18.707	0.000	92	0.734	48	0.703	16	0.457	0.468	< 0.05	< 0.05
LUD	9.109	0.000	87	0.738	63	0.708	6	0.461	0.589	< 0.05	< 0.05
LLD	10.628	0.000	83	0.723	68	0.722	5	0.379	0.993	< 0.05	< 0.05

MIBI uptake was significantly different among 3 qualitative groups generally, but comparable between slight and medium MIBI uptake group, and significantly different between slight and high MIBI uptake group, and between medium and high MIBI uptake group. **Group 1**, **2** and **3**: slight, medium and high MIBI uptake group, respectively; □: group 1; □: group 2; □: group 3. ***F***, ANOVA *F* value. In this paper, if there were above abbreviations in other places without special instruction, their meanings were same.

Table 4 the difference of some indices among 3 qualitative groups during early phase

indices	F	*p*	group 1		group 2		group 3		post-hoc *p*		
			cases	mean	cases	mean	cases	mean	□-□	□-□	□-□
age (years)	0.966	0.383	31	47.45	101	46.88	24	51.54	> 0.05	> 0.05	> 0.05
Course (months)	8.902	0.000	31	27.90	101	44.99	24	82.88	0.141	< 0.05	< 0.05
Hemodialysis months	21.395	0.000	31	15.42	101	18.22	24	74.29	0.763	< 0.05	< 0.05
GFR (ml/min)	1.309	0.283	10	25.27	25	17.99	3	12.67	> 0.05	> 0.05	> 0.05
AKP (u/L)	4.552	0.012	30	129.30	98	173.80	22	291.59	0.356	< 0.05	< 0.05
Creatinine (umol/L)	1.347	0.263	31	930.02	101	835.95	23	946.62	> 0.05	> 0.05	> 0.05
BUN (mmol/L)	2.271	0.107	31	30.80	101	27.41	23	24.16	0.217	< 0.05	0.236
UA (umol/L)	1.412	0.247	31	535.19	101	495.64	23	474.57	> 0.05	> 0.05	> 0.05
BUN/Creatinine	2.517	0.084	31	35.49	101	35.18	23	27.97	> 0.05	> 0.05	> 0.05
Ca (mmol/L)	6.746	0.002	31	2.00	101	2.15	24	2.40	0.13	< 0.05	< 0.05
P (nmol/L)	0.139	0.871	31	1.90	101	1.96	24	1.95	> 0.05	> 0.05	> 0.05
Ca ´ P	2.607	0.077	31	3.78	101	4.19	24	4.64	0.216	< 0.05	0.170
CPI (mg/L)	5.276	0.006	31	6.24	97	6.55	22	7.90	0.506	< 0.05	< 0.05
calcitonine (pg/mL)	2.955	0.06	31	3.59	101	6.55	24	9.51	0.201	0.153	0.708
PTH (pg/mL)	9.015	0.000	31	1056.38	101	1286.13	24	1919.15	0.093	0.001	0.017
Ferritin (ng/mL)	0.884	0.421	31	378.57	101	354.15	24	605.18	0.993	0.621	0.477
VitB12 (pmol/L)	0.779	0.460	31	443.55	101	442.57	24	523.42	> 0.05	> 0.05	> 0.05
Folate (nmol/L)	2.688	0.078	31	18.06	101	23.17	24	27.49	0.209	0.109	0.632
EPO (mIU/L)	1.488	0.229	30	20.32	95	35.66	24	62.4	> 0.05	> 0.05	> 0.05
Hb (g/L)	0.720	0.488	31	91.77	101	92.83	24	98.71	> 0.05	> 0.05	> 0.05

Renal failure course, hemodialysis months, AKP, Ca, Ca ´ P, CPI and PTH were significantly different among 3 qualitative groups, comparable between little and medium MIBI uptake group, but significantly different between slight and high MIBI uptake group, and between medium and high MIBI uptake group.

Table 5 the difference of some indices among 3 qualitative groups during delayed phase

indices	F	*p*	group 1		group 2		group 3		post-hoc *p*		
			cases	mean	cases	mean	cases	mean	□-□	□-□	□-□
age (years)	0.785	0.458	43	47.79	93	46.87	20	51.45	> 0.05	> 0.05	> 0.05
Course (months)	5.754	0.004	43	36.19	93	45.37	20	81.15	0.682	0.002	0.010
Hemodialysis months	15.475	0.000	43	15.81	93	21.13	20	72.8	0.846	0.000	0.001
GFR (ml/min)	0.362	0.699	19	20.33	16	19.77	3	12.67	> 0.05	> 0.05	> 0.05
AKP (u/L)	5.419	0.008	42	144.42	90	173.38	18	315.16	0.645	0.013	0.055
Creatinine (umol/L)	1.482	0.231	43	794.40	93	891.28	19	946.59	> 0.05	> 0.05	> 0.05
BUN (mmol/L)	1.428	0.243	43	27.35	93	28.53	19	23.66	> 0.05	> 0.05	> 0.05
UA (umol/L)	2.478	0.087	43	539.60	93	488.14	19	471.89	> 0.05	> 0.05	> 0.05
BUN/Creatinine	3.228	0.042	43	37.59	93	33.93	19	27.62	0.289	< 0.05	0.069
Ca (mmol/L)	7.046	0.001	43	2.09	93	2.12	20	2.47	0.750	< 0.05	< 0.05
P (nmol/L)	1.656	0.194	43	1.82	93	2.00	20	1.94	> 0.05	> 0.05	> 0.05
Ca ´ P	3.363	0.037	43	3.81	93	4.22	20	4.76	0.204	< 0.05	0.105
CPI (mg/L)	7.712	0.001	43	5.94	89	6.77	18	8.04	0.082	< 0.05	< 0.05
calcitonine (pg/mL)	1.383	0.263	43	7.35	93	5.17	20	10.22	0.826	0.878	0.372
PTH (pg/mL)	5.858	0.004	43	1102.54	93	1345.31	20	1809.21	0.181	< 0.05	< 0.05
Ferritin (ng/mL)	0.667	0.519	43	345.81	93	379.09	20	595.18	0.969	0.592	0.678
VitB12 (pmol/L)	0.210	0.811	43	467.09	93	443.46	20	484.25	> 0.05	> 0.05	> 0.05
Folate (nmol/L)	1.287	0.285	43	20.30	93	23.12	20	26.89	0.593	0.404	0.787
EPO (mIU/L)	1.159	0.317	41	26.46	88	35.68	20	63.55	> 0.05	> 0.05	> 0.05
Hb (g/L)	1.317	0.271	43	93.02	93	92.08	20	101.35	> 0.05	> 0.05	> 0.05

Renal failure course, hemodialysis months, AKP, Ca, Ca ´ P, CPI and PTH were significantly different among 3 qualitative groups, and comparable between slight and medium MIBI uptake group. But all of them and most of them were significantly different between slight and high MIBI uptake group, and between medium and high MIBI uptake group, respectively.

Table 6 The ROC characters of MIBI uptake gray value for differentiating insignificant from significant MIBI uptake group

Parathyroid lobe	significant cases	insignificant cases	AUC	Z	*p*	criteria	J	sensitivity (%)	specificity (%)
RUE	8	148	0.718	3.959	0.0001	£ 0.64	0.5743	100.00	57.43
RLE	20	136	0.827	7.899	< 0.0001	£ 0.66	0.5176	90.00	61.76
LUE	7	149	0.849	7.475	< 0.0001	£ 0.62	0.6376	100.00	63.76
LLE	10	146	0.684	2.443	0.0146	£ 0.71	0.4589	100.00	45.89
RUD	3	153	0.859	6.926	< 0.0001	£ 0.59	0.7582	100.00	75.82
RLD	16	140	0.874	8.802	< 0.0001	£ 0.50	0.6500	75.00	90.00
LUD	6	150	0.915	7.464	< 0.0001	£ 0.49	0.7933	83.33	96.00
LLD	5	151	0.957	22.936	< 0.0001	£ 0.51	0.9007	100.00	90.07

If the criteria of MIBI uptake gray value was less than 0.50-0.71 in individual parathyroid lobe during early or delayed phase, the significant MIBI uptake could be diagnosed ($p < 0.05$) with high sensitivity and specificity. **Criteria**: the optimal cutoff of MIBI uptake value for differentiating insignificant from significant

MIBI uptake group. **AUC**: the area under the curve; **ROC**: receiver-operating character. Z: z statistic; J: Youden index.

Table 7 The difference of some indices between insignificant and significant MIBI uptake group

indices	insignificant group-1		significant group-1		*t*-1	*p*-1	insignificant group-2		significant group-2		*t*-2	*p*-2
	Cases-1	Mean-1	Cases-1	mean-1			Cases-2	Mean-2	Cases-2	mean-2		
age (years)	132	47.02	24	51.54	-1.381	0.169	136	47.16	20	51.45	-1.211	0.228
Course (months)	132	40.98	24	82.88	-3.838	0.000	136	42.46	20	81.15	-3.242	0.001
Hemodialysis months	132	17.56	24	74.29	-5.541	0.000	136	19.45	20	72.8	-4.609	0.000
GFR (ml/min)	35	20.07	3	12.67	0.855	0.398	35	20.07	3	12.67	0.855	0.398
AKP (u/L)	128	163.37	22	291.59	-2.815	0.006	132	164.04	18	315.17	-3.062	0.003
BUN (mmol/L)	132	28.20	23	24.16	1.562	0.12	136	28.15	19	23.66	1.599	0.112
Creatinine (umol/L)	132	858.04	23	946.62	-1.065	0.288	136	860.65	19	946.59	-0.953	0.342
UA (umol/L)	132	504.93	23	474.57	0.959	0.339	136	504.41	19	471.89	0.947	0.345
BUN/Creatinine	132	35.25	23	27.97	2.249	0.026	136	35.08	19	27.62	2.123	0.035
Ca (mmol/L)	132	2.11	24	2.40	-3.206	0.002	136	2.11	20	2.47	-3.742	0.000
P (nmol/L)	132	1.94	24	1.95	-0.027	0.978	136	1.95	20	1.94	0.065	0.949
Ca ´ P	132	4.10	24	4.64	-1.775	0.078	136	4.09	20	4.76	-2.000	0.047
CPI (mg/L)	128	6.48	22	7.90	-3.157	0.002	132	6.50	18	8.04	-3.128	0.002
calcitonine (pg/mL)	132	5.86	24	9.51	-1.399	0.164	136	5.86	20	10.22	-1.551	0.123
PTH (pg/mL)	132	1232.17	24	1919.15	-4.133	0.000	136	1268.55	20	1809.20	-2.938	0.004
Ferritin (ng/mL)	132	359.89	24	605.18	-1.307	0.203	136	368.57	20	595.18	-1.090	0.289
VitB12 (pmol/L)	132	442.80	24	523.42	-1.252	0.012	136	450.93	20	484.25	-0.478	0.634
Folate (nmol/L)	132	21.97	24	27.49	-1.421	0.166	136	22.22	20	26.89	-1.080	0.291
EPO (mIU/L)	125	31.98	24	62.43	-1.522	0.130	129	32.75	20	63.55	-1.426	0.156
Hb (g/L)	132	92.58	24	98.71	-1.183	0.239	136	92.38	20	101.35	-1.613	0.109

During early phase or delayed phase, some indices were significantly different between insignificant and significant MIBI uptake group. All items suffixed with -1 or -2 were for early or delayed phase, respectively. *t*, independent samples *student*'s *t* test; *p*, 2-tailed p value.

Table 8 The correlations of both indices

indices	items	course	hemodialysis months	GFR	AKP	BUN	CRE	UA	BUN/CRE	Ca	P	Ca ´ P	CPI	calc
age	*r*	0.306	0.197	-0.204	-0.140	-0.132	-0.215	-0.215	-0.035	-0.130	-0.259	-0.287	-0.041	-0.2
(years)	*p*	0.000	0.014	0.220	0.087	0.102	0.007	0.007	0.664	0.105	0.001	0.000	0.618	0.0
	cases	156	156	38	150	155	155	155	155	156	156	156	150	156
Course	*r*		0.710	-0.265	0.212	-0.078	0.076	-0.157	-0.206	0.198	0.021	0.139	0.449	-0.0
(months)	*p*		0.000	0.108	0.009	0.333	0.345	0.051	0.010	0.013	0.798	0.084	0.000	0.68
	cases		156	38	150	155	155	155	155	156	156	156	150	156
hemodialysis months	*r*			-0.335	0.287	-0.171	0.142	-0.179	-0.346	0.274	-0.015	-0.153	0.565	0.03
	p			0.040	0.000	0.033	0.077	0.026	0.000	0.000	0.852	0.057	0.000	0.7
	cases			38	150	155	155	155	155	156	156	156	150	156
GFR (ml/min)	*r*				-0.307	-0.368	-0.390	-0.022	0.282	0.227	-0.314	-0.085	-0.613	-0.0
	p				0.069	0.023	0.016	0.897	0.086	0.171	0.055	0.612	0.000	0.68
	cases				36	38	38	38	38	38	38	38	37	38
AKP	*r*					-0.084	-0.001	-0.110	-0.117	0.020	-0.039	0.008	0.191	-0.0
(u/L)	*p*					0.305	0.994	0.179	0.154	0.812	0.636	0.926	0.020	0.73
	cases					150	150	150	150	150	150	150	148	150
BUN	*r*						0.548	0.381	0.374	0.298	0.563	0.307	0.055	0.09
(mmol/L)	*p*						0.000	0.000	0.000	0.000	0.000	0.000	0.503	0.22
	cases						155	155	155	155	155	155	150	155
Creatinine (umol/L)	*r*							0.206	-0.456	-0.100	0.633	0.475	0.475	0.24
	p							0.010	0.000	0.216	0.000	0.000	0.000	0.00
	cases							155	155	155	155	155	150	155
UA	*r*								0.304	0.005	0.231	0.191	-0.081	0.05
(umol/L)	*p*								0.000	0.953	0.004	0.017	0.326	0.48
	cases								155	155	155	155	150	155
BUN/Cre	*r*									-0.116	-0.102	-0.152	-0.487	-0.1
	p									0.152	0.205	0.059	0.000	0.15
	cases									155	155	155	150	155
Ca	*r*										-0.080	0.469	0.228	0.16
(mmol/L)	*p*										0.318	0.000	0.005	0.03
	cases										156	156	150	156

Table 8 The correlations of both indices – to be continued

indices	items	course	hemodialysis months	GFR	AKP	BUN	CRE	UA	BUN/CRE	Ca	P	Ca ´ P	CPI	calc
P	*r*											0.829	0.345	0.16
(nmol/L)	*p*											0.000	0.000	0.03
	cases											156	150	156
Ca ´ P	*r*												0.415	0.23
	p												0.000	0.00
	cases												150	156
CPI	*r*													0.18
(mg/L)	*p*													0.02
	cases													150
calcitonine	*r*													

(pg/mL)	*p*	
	cases	
PTH	*r*	
(pg/mL)	*p*	
	cases	
Ferritin	*r*	
(ng/mL)	*p*	
	cases	
VitB12 (pmol/L)	*r*	
	p	
	cases	
Folate	*r*	
(nmol/L)	*p*	
	cases	
EPO	*r*	
(mIU/L)	*p*	
	cases	

All indices were significantly related to parts of other indices. ***r***, Pearson's relativity; ***p***, 2-tailed p value.

Figures

Figure 1 MIBI uptake intensiveness category

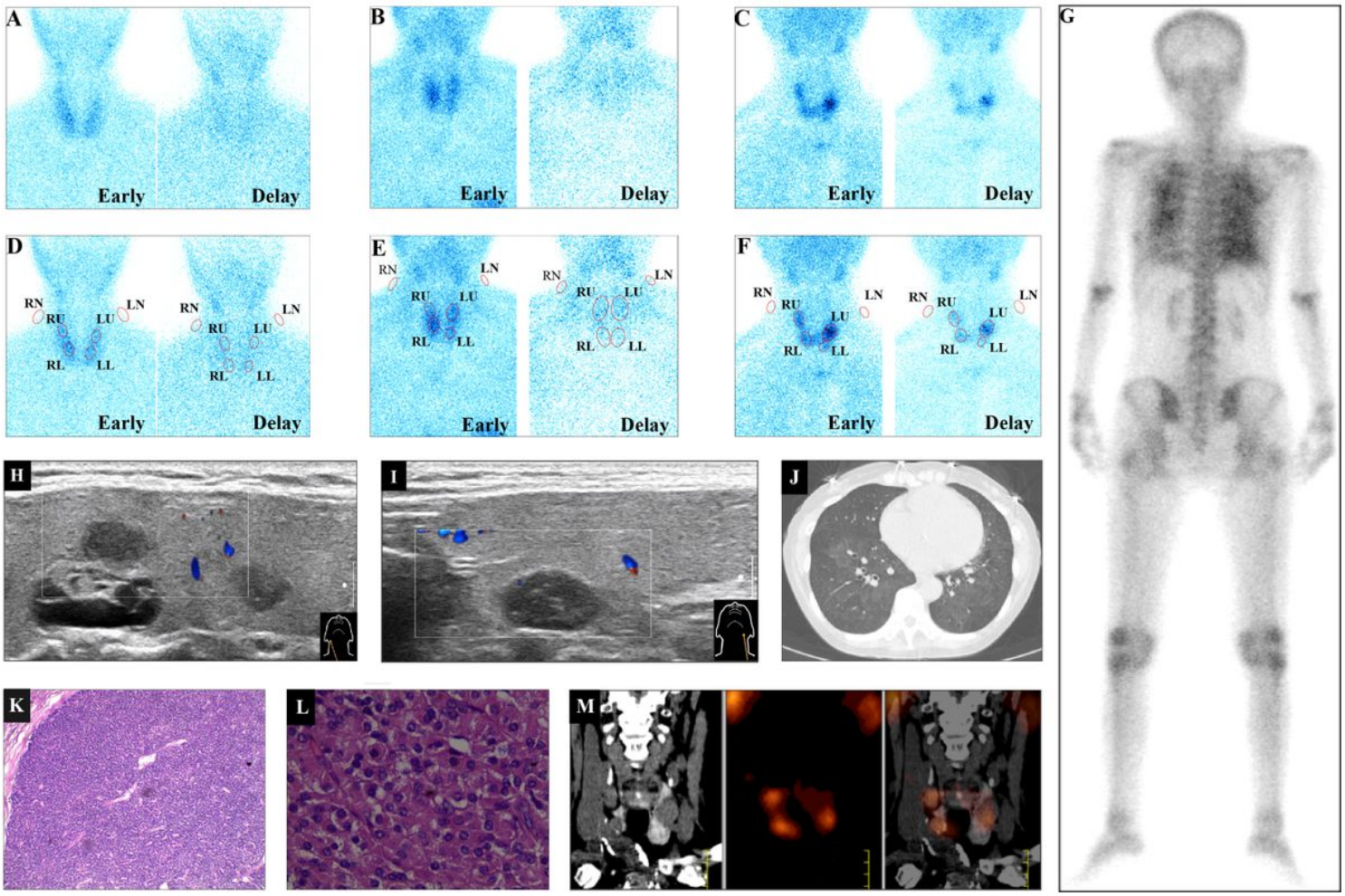

Figure 1

99mTc-MIBI uptake intensiveness category examples Basing on the most intensive degree of 99mTc-MIBI accumulation in 4 parathyroid lobes during delayed phase, slight uptake (all 4 parathyroid lobes in Fig. A), medium uptake (bilateral upper lobes and right lower lobe in Fig. B) and high uptake (bilateral upper lobes and right lower lobe in Fig. C) were demonstrated. Fig. A (MIBI uptake) and Fig. D came from the same Patient A. Fig. B (MIBI uptake), Fig. E, G, H, I & J came from the same Patient B. Fig. C (MIBI uptake), Fig. F, K, L & M came from the same Patient C. Red ellipses in Fig. D, E & F showed the ROIs of MIBI uptake in bilateral neck and 4 parathyroid lobes in Fig. A, B & C, respectively. Fig. G: the posterior 99mTc-MDP bone scan. Fig. H or Fig. I: hypoechoic ultrasound parathyroid images behind right or left thyroid lobe, respectively. Fig. J: CT scan image of thorax. Fig. K (H&E staining, × 40 original magnification) and Fig. L (H&E staining, × 200 original magnification): pathological images of left upper parathyroid adenoma from parathyroidectomy. Fig. M showed sequentially the coronal CT, MIBI uptake SPECT and fused MIBI uptake SPECT/CT image of bilateral parathyroids. MIBI: methoxyisobutylisonitrile; MDP: methyldiphosphate; RN, LN: right, left neck background, respectively; RU, LU, RL, LL: right upper, left upper, right lower, left lower parathyroid lobe, respectively; early, delay: early, delayed phase, respectively；H&E: hematoxylin and eosin.

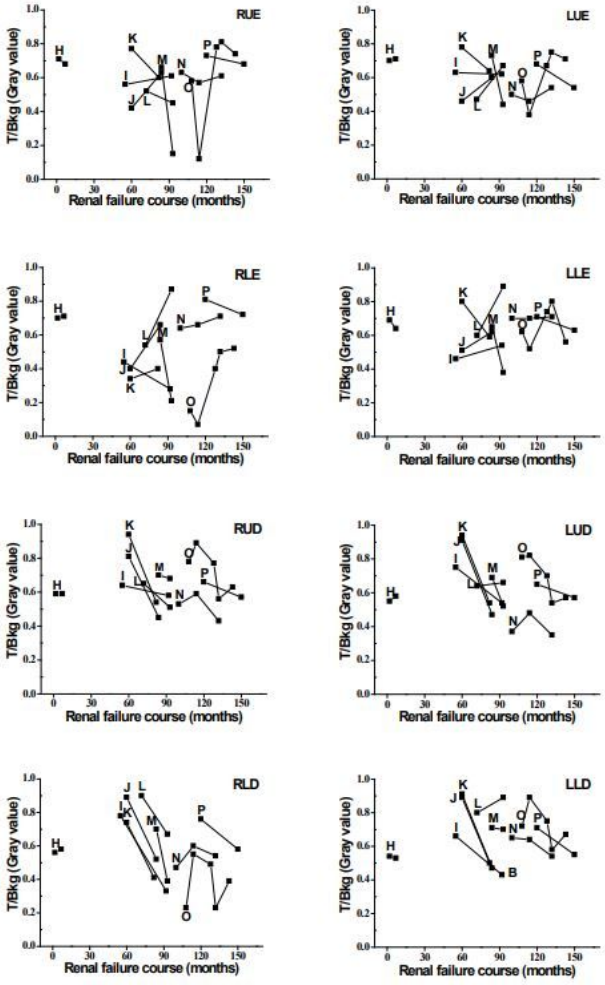

Figure 2

99mTc-MIBI uptake change in different renal failure course In changed CRF courses, MIBI uptake tendency varied. Letter H-P represented 9 patients, and the same letter represented the same patient. RUE, RLE, LUE, LLE: right upper, right lower, left upper, left lower parathyroid lobe during early phase, respectively; RUD, LUD, RLD, LLD: right upper, left upper, right lower, left lower parathyroid lobe during delayed phase, respectively; T: gray value of MIBI uptake in each parathyroid lobe; Bkg: the average gray value of MIBI uptake in the ROIs of bilateral neck. In this paper, if there were above abbreviations in other places without special instruction, their meanings were same.

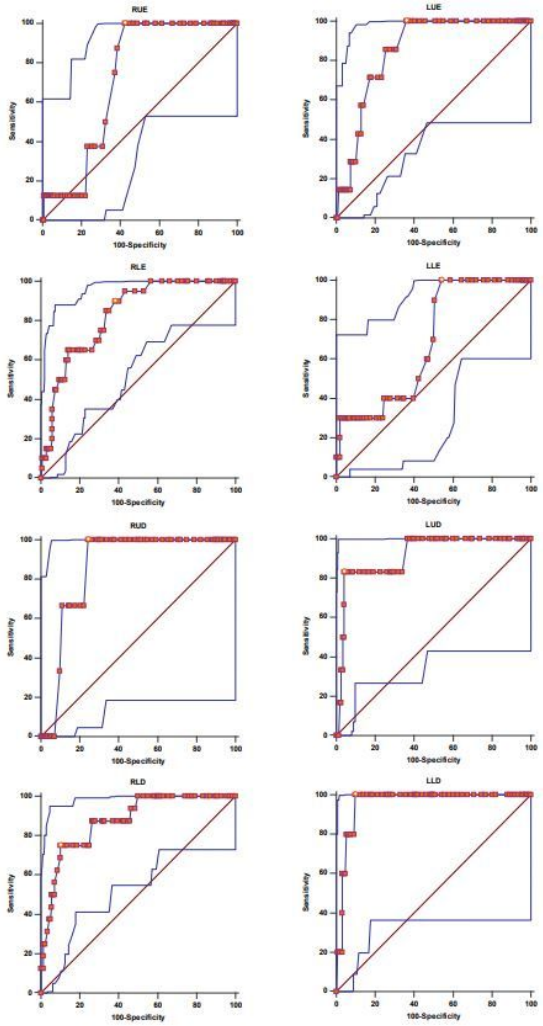

Figure 3

ROC analysis of 99mTc-MIBI uptake The red circles in all figures indicated the optimal cutoff value of the gray value of MIBI uptake for differentiating the insignificant from significant MIBI concentration in parathyroid lobes. The fluctuating dashed lines in ROC graphs indicated 95%CI of AUC. ROC: receiver-operating character; CI: confidence interval; AUC: area under curve.

Supplementary Files

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