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Clinical Evaluation of the Diagnostic Effectiveness of Thyroid Radionuclide Imaging in Differentiating the Causes of Hyperthyroidism

Xiao-Wei Ma*

General Hospital of Ningxia Medical University, Yinchuan, Ningxia, 750000, China

***Correspondence to:** Xiao-Wei Ma, General Hospital of Ningxia Medical University, Yinchuan, Ningxia, 750000, China, E-mail: 2538855140@qq.com

Abstract: Objective: To investigate the clinical value of thyroid radionuclide imaging in the differential diagnosis of the causes of hyperthyroidism and to provide scientific evidence for precise clinical diagnosis and treatment. **Methods:** A retrospective analysis was conducted on the clinical data of 120 patients with hyperthyroidism admitted between January 2022 and December 2023. The diagnostic performance of radionuclide imaging in differentiating the major causes—Graves' disease, toxic multinodular goiter, and autonomously functioning thyroid adenoma—was systematically evaluated. **Results:** Among the 120 patients, 82 had Graves' disease (68.33%), 25 had toxic multinodular goiter (20.83%), 10 had autonomously functioning thyroid adenoma (8.33%), and 3 had other causes (2.50%). The overall diagnostic accuracy of thyroid radionuclide imaging for differentiating the causes of hyperthyroidism reached 93.33% (112/120). The sensitivity and specificity for diagnosing Graves' disease were 96.34% and 90.91%, respectively; for toxic multinodular goiter, 88.00% and 97.62%, respectively; and for autonomously functioning thyroid adenoma, 90.00% and 99.09%, respectively. **Conclusion:** Thyroid radionuclide imaging can accurately reflect the structural morphology and functional status of the thyroid gland and demonstrates excellent accuracy in the differential diagnosis of hyperthyroidism causes.

Keywords: Hyperthyroidism; Radionuclide imaging; Etiological differentiation; Diagnostic accuracy; Clinical application

Introduction

Hyperthyroidism, as a common endocrine and metabolic disorder, has shown a steadily increasing incidence worldwide and significantly affects the quality of life as well as the physical and mental health of patients. The clinical manifestations of this disease are complex and diverse, and significant differences exist in treatment strategies and prognosis among various etiologies of hyperthyroidism. Therefore, accurate etiological diagnosis is crucial for achieving precision medicine[1]. This study systematically analyzes the application value of thyroid radionuclide imaging in differentiating the causes of various types of hyperthyroidism, aiming to provide more reliable diagnostic evidence for clinicians and to promote the standardized diagnosis and treatment of thyroid diseases.

1 Materials and Methods

1.1 General Information

A total of 120 patients diagnosed with hyperthyroidism who visited the Department of Endocrinology of our hospital from January 2022 to December 2023 were selected. Among them, 38 were male (31.67%) and 82 were female (68.33%). The age ranged from 18 to 72 years, with an average age of (45.3±12.7) years. All patients presented with varying degrees of typical symptoms such as palpitations, excessive sweating, weight loss, and irritability.

Inclusion criteria: (1) meeting the clinical diagnostic criteria for hyperthyroidism, i.e., typical symptoms of hypermetabolism accompanied by elevated serum free triiodothyronine (FT3) and free thyroxine (FT4) levels and decreased thyroid-stimulating hormone (TSH) levels; (2) voluntarily undergoing thyroid radionuclide imaging and signing informed consent.

Exclusion criteria: (1) pregnant or lactating women; (2) patients with severe dysfunction of vital organs such as the heart, liver, or kidneys; (3) those who recently received radioactive iodine treatment or antithyroid medication that may affect imaging results; (4) those with a history of thyroid surgery or neck radiotherapy.

1.2 Methods

1.2.1 Instruments and Reagents

A Siemens SPECT/CT imaging system from Germany equipped with a high-resolution collimator was used for examinations. The imaging agent was the radionuclide 99mTcO4-, produced by the China Institute of Atomic Energy, with radiochemical purity ≥ 95% and chemical purity ≥ 98%. All reagents met the requirements of the National Medical Products Administration and were used within their validity period.

1.2.2 Examination Method

Before examination, patients were required to discontinue medications that may affect thyroid function for at least 2 weeks, including iodinated contrast agents, lithium preparations, and amiodarone. Female patients were required to confirm a non-pregnant status. Patients fasted on the morning of the examination and avoided iodine-containing foods and medications. The dosage of 99mTcO4- injection was calculated according to body weight (typically 185–370 MBq for adults) and administered slowly via intravenous injection. Patient reactions were closely monitored during injection to ensure no allergic or adverse responses occurred. Early imaging began 20 minutes after tracer injection, with the patient in a supine position, neck fully extended, and head tilted slightly backward. Planar imaging was performed first, with a collection time of 5–10 minutes and a matrix size of 256×256. This was followed by single-photon emission computed tomography (SPECT), with a 360° rotation, image acquisition every 6°, for a total of 60 frames, each collected for 25 seconds. SPECT/CT fusion imaging was conducted when necessary to improve localization accuracy. Two experienced nuclear medicine physicians independently reviewed the images in a blinded manner.

Main observation indicators included: (1) overall thyroid uptake function; (2) thyroid morphology and size changes; (3) uniformity of radioactive distribution; (4) presence of "hot nodules" or "cold nodules"; (5) contrast between thyroid and surrounding tissues.

1.3 Diagnostic Criteria

1.3.1 Graves' Disease

Typical manifestations include diffuse enlargement of the thyroid gland, uniformly increased radioactive uptake, clearly defined thyroid contours, and absence of obvious nodular shadows. Diagnosis is based on comprehensive assessment of clinical symptoms, physical signs, and laboratory test results.

1.3.2 Toxic Multinodular Goiter

Characteristic imaging features include significant enlargement of the thyroid gland with multiple nodular shadows of varying sizes, heterogeneous radioactive uptake, areas of increased uptake forming "hot nodules," and areas of decreased or absent uptake forming "cold nodules."

1.3.3 Autonomously Functioning Thyroid Adenoma

Imaging typically shows a single round or oval "hot nodule" with well-defined borders within the thyroid gland, with reduced or suppressed uptake in the surrounding thyroid tissue, forming a distinct "halo sign."

1.3.4 Gold Standard Determination

Histopathological examination results were considered the absolute gold standard. For patients without pathological confirmation, long-term clinical follow-up (≥ 12 months) combined with multiple diagnostic methods was used as the relative gold standard. Follow-up included improvement of clinical symptoms, changes in laboratory indicators, treatment response, and occurrence of complications.

1.4 Statistical Methods

Data were processed using SPSS 26.0. Categorical data (expressed as percentages) and continuous data (normally distributed, expressed as mean ± standard deviation) were analyzed using χ^2 test and t-test, respectively. $P < 0.05$ indicated a statistically significant difference. Diagnostic performance indicators included sensitivity, specificity, positive predictive value, negative predictive value, and accuracy. $P < 0.05$ was considered statistically significant.

2 Results

2.1 Final Diagnostic Results

Based on pathological examination or long-term clinical follow-up, the etiological distribution of the 120 patients was as follows: Graves' disease in 82 cases (68.33%), representing the primary cause; toxic multinodular goiter in 25 cases (20.83%); autonomously functioning thyroid adenoma in 10 cases (8.33%); and 3 cases (2.50%) attributed to other rare causes, including 1 case of subacute thyroiditis with thyrotoxicosis, 1 case of iodine-induced hyperthyroidism, and 1 case of pituitary TSH-secreting tumor.

2.2 Diagnostic Results of Thyroid Radionuclide Imaging

Thyroid radionuclide imaging showed that patients with Graves' disease presented with diffuse thyroid enlargement and uniformly increased radioactive uptake, with smooth and well-defined glandular contours. Patients with toxic multinodular goiter exhibited significant thyroid enlargement with multiple nodular radioactive concentration areas, showing heterogeneous distribution. Patients with autonomously functioning thyroid adenoma demonstrated a single round "hot nodule" with well-defined margins, while uptake in the surrounding thyroid tissue was relatively reduced.

2.3 Analysis of Diagnostic Performance

Using the final diagnostic results as the gold standard, the diagnostic performance of thyroid radionuclide imaging was systematically evaluated. The results showed that the overall differential diagnostic accuracy of radionuclide imaging for the etiology of hyperthyroidism was 93.33% (112/120), with 8 misdiagnosed cases and 0 missed diagnoses. The diagnostic performance for each etiological type is shown in **Table 1**:

Table 1 Diagnostic Performance of Thyroid Radionuclide Imaging for Different Etiologies of Hyperthyroidism

Etiology Type	Cases	Correct Diagnoses by Radionuclide Imaging	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)
Graves' disease	82	79	96.34	90.91	95.18	93.10
Toxic multinodular goiter	25	22	88.00	97.62	95.65	95.35
Autonomously functioning thyroid adenoma	10	9	90.00	99.09	98.04	97.67
Total	120	112	-	-	-	-

3 Discussion

Hyperthyroidism refers to a clinical syndrome caused by excessive production of thyroid hormones by the thyroid gland itself. Its pathogenesis is complex, involving the interplay of genetic, immunological, and environmental factors [2]. According to etiological classification, the three most common clinical types are Graves' disease, toxic multinodular goiter, and autonomously functioning thyroid adenoma. These three conditions differ significantly in epidemiological characteristics, pathophysiological mechanisms, clinical manifestations, and therapeutic strategies[3]. Since treatment approaches vary fundamentally depending on the underlying cause, accurate etiological diagnosis is particularly important. The main treatments for Graves' disease include antithyroid drugs, radioactive iodine therapy, and surgical intervention; toxic multinodular goiter, which involves multiple functional nodules, usually prefers radioactive iodine therapy as the first-line treatment; while autonomously functioning thyroid adenomas are more suitable for surgical excision [4]. Misdiagnosis may lead to inappropriate treatment choices, affecting therapeutic efficacy and potentially increasing unnecessary risks and complications.

Thyroid radionuclide imaging is a functional imaging technique that uses radiolabeled tracers to reflect the functional status of the thyroid based on their uptake and distribution within the gland. Its fundamental principle relies on the highly specific iodine uptake ability of normal thyroid tissue. After intravenous injection of a radioactive isotope, the thyroid actively absorbs and concentrates the tracer, and γ-cameras or SPECT systems can capture the morphological structure and functional distribution of the thyroid [5]. Compared with conventional imaging methods, thyroid radionuclide imaging has distinct advantages. First, it provides both anatomical and functional information, achieving an integrated view of morphology and physiology; second, the procedure is non-invasive, safe, and well tolerated by patients; third, imaging results are intuitive and easy for clinicians to interpret; finally, for certain special thyroid conditions, such as autonomously functioning nodules, radionuclide imaging provides irreplaceable diagnostic value. In terms of technological advancement, modern thyroid radionuclide imaging has evolved from conventional planar imaging to SPECT, SPECT/CT, and even PET/CT techniques. The application of SPECT/CT fusion imaging, in particular, not only improves spatial resolution and localization accuracy but also provides richer diagnostic information, significantly enhancing overall examination efficacy [6].

The results of this study demonstrate that thyroid radionuclide imaging achieved an overall etiological diagnostic accuracy of 93.33% for hyperthyroidism, fully confirming the clinical value of this technique. Specifically, the sensitivity and specificity for Graves' disease were 96.34% and 90.91%, respectively, indicating excellent diagnostic performance. This high sensitivity is primarily attributed to the characteristic imaging features of Graves' disease, namely diffuse thyroid enlargement and uniformly increased radioactive uptake, which facilitate relatively easy and accurate identification of the condition. For toxic multinodular goiter, the study showed a sensitivity of 88.00% and specificity of 97.62%. The relatively lower sensitivity may be related to the atypical early manifestations of the disease, particularly when the number of nodules is small or their volume is limited, which may lead to confusion with Graves' disease. However, the very high specificity indicates that once typical multinodular changes are observed, the diagnostic reliability is extremely high. The differential diagnosis of autonomously functioning thyroid adenomas exhibited the most outstanding performance, with sensitivity and specificity reaching 90.00% and 99.09%, respectively. This superior performance is attributable to the unique imaging characteristics of the disease, namely a single, well-defined "hot nodule" with suppressed uptake in the surrounding thyroid tissue, forming a highly distinctive diagnostic marker.

In summary, thyroid radionuclide imaging, as a mature imaging modality, demonstrates excellent accuracy and reliability in the etiological differentiation of hyperthyroidism. The systematic evaluation presented in this study further confirms its significant value in clinical practice. With continuous technological development and refinement, thyroid radionuclide imaging is expected to play an increasingly important role in the precise diagnosis and treatment of thyroid disorders, ultimately providing better healthcare experiences for patients.

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