Application of Thyroid Nodule Calcification in the Ultrasonic Diagnosis of Thyroid Cancer

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Abstract: Objective: To explore the application of thyroid nodule calcification in the ultrasonic diagnosis of thyroid cancer. Methods: A single-center study was conducted, enrolling 112 patients with thyroid nodules who were pathologically confirmed at our hospital from January 2022 to January 2026. Using pathological results as the reference standard, ultrasound-determined benign or malignant status and key ultrasound features (including margin clarity, blood flow signal, and calcification patterns) were recorded. A descriptive analysis of feature distribution was performed. Results: Ultrasound assessment classified 96 nodules as benign and 16 as malignant. Feature comparison revealed that benign nodules exhibited a higher proportion of well-defined margins, whereas malignant nodules more frequently presented with abundant blood flow signals. Conclusion: The implementation of ultrasound diagnosis for thyroid nodule calcification demonstrates significant clinical application value and is worthy of promotion.

***Keywords*:** thyroid cancer; thyroid nodule calcification; ultrasonic diagnosis; pathological diagnosis

1. Introduction

Thyroid nodules are one of the common conditions encountered in clinical endocrinology, with benign lesions constituting the vast majority. In recent years, the detection rate of thyroid nodules has shown a continuous upward trend, driven by increased public health awareness and the widespread adoption of health check-ups [1]. Epidemiological data indicate that the age of onset for this condition is trending younger, posing a significant impact on patients' quality of life and overall public health [2]. Accurate differentiation between benign and malignant thyroid nodules is a critical step in clinical diagnosis and management. Ultrasonography reveals that calcification within thyroid nodules is one of the most common radiological characteristics and is closely associated with the occurrence of thyroid cancer. Nodular calcification refers to the deposition of calcium salts within the nodule, a process with a complex pathogenesis potentially involving factors such as tissue degeneration, abnormal nodule metabolism, and aberrant proliferation of tumor cells. Studies have shown that nodules of different pathological natures exhibit significant differences in their distribution, size, and morphological features on ultrasound imaging, providing an important basis for distinguishing between benign and malignant lesions [3]. Early-stage thyroid cancer often presents with subtle or no apparent clinical symptoms in most patients. Therefore, early radiological screening is of great significance for timely diagnosis, formulation of individualized treatment plans, and improvement of patient prognosis. Due to its advantages of being radiation-free, easy to perform, non-invasive, and highly reproducible, ultrasonography has become the primary imaging screening method for thyroid nodules. This technique can clearly display key information such as the nodule's morphology, size, margin, internal echogenicity, and calcification characteristics [4]. Based on this, the present study aims to systematically evaluate the clinical application value of ultrasound diagnosis in differentiating between benign and malignant calcified thyroid nodules by screening a cohort of patients with thyroid nodule calcification, with the goal of providing a reference for clinical decision-making.

2. Subjects and Methods

2.1 Subjects

This single-center study was conducted following approval by the Ethics Committee. A total of 112 patients with thyroid nodules who were pathologically confirmed at our hospital from January 2022 to January 2026 were included. There were 56 male and 56 female patients, aged 29-76 years, with a average age of 53.69 ± 6.98 years. Inclusion criteria: (1) patients were informed of the study content and voluntarily participated; (2) patients had complete general clinical data. Exclusion criteria: (1) patients with cognitive impairment who were unable to cooperate with the study procedures; (2) patients who had recently participated in other research projects.

2.2 Ultrasonography

Prior to the examination, patients were provided with health guidance and instructed to maintain a correct position, generally in the supine position. The shoulder probe frequency was adjusted to 5-12 MHz. During the procedure, patients were also instructed to keep their shoulders elevated and head lowered. The examining physician closely observed the thyroid condition of the patients, identified the location, number, and size of any masses, and analyzed and observed the calcification status of the lesions.

2.3 Primary clinical outcomes

(1) Observation of benign or malignant status by ultrasound examination; (2) Observation of ultrasound characteristics of thyroid nodules.

2.4 Statistical analysis

Data was analyzed using SPSS version 24.0. Measurement data are presented as mean ± standard deviation (SD). Count data are presented as percentages (%) and analyzed using the chi-square (χ^2) test. $P < 0.05$ was considered statistically significant.

3. Results

3.1 Examination results

Following ultrasonography, 96 cases were diagnosed as benign and 16 cases as malignant. Details are presented in Table 1.

Table 1. Examination results

Ultrasonic diagnosis	Pathological diagnosis		Total
	Positive	Negative	
Positive	94	2	96
Negative	4	12	16
Total	98	14	112

3.2 Ultrasonographic features

Among the ultrasonographic features, a higher proportion of benign cases exhibited well-defined margins, while a higher proportion of malignant cases showed rich blood flow signals. Details are presented in Table 2.

Table 2. Ultrasonographic features (n,%)

Items	Cases	Boundary definition (%)	Abundant blood flow signals (%)	Hypoechoic (%)
Malignant	14	1(7.14)	11(78.57)	2(14.29)
Benign	98	91(92.86)	1(1.02)	6(6.12)
c2	-	61.356	77.013	1.230
P	-	0.000	0.000	0.267

4. Discussion

With significant changes in the lifestyle structure and dietary habits of residents in China, the detection rate and occurrence rate of thyroid nodules have shown a continuous upward trend, becoming one of the increasingly prominent public health concerns in clinical practice. Thyroid nodules can be classified into two major categories based on their pathological nature: benign and malignant. Among these, benign nodules constitute the larger proportion, primarily including nodular goiter, inflammatory nodules, and thyroid adenomas, which generally have a favorable prognosis. However, thyroid cancer, as one of the common malignant tumors in clinical practice, has also exhibited a year-by-year increase in its occurrence rate in recent years, with a trend toward younger age of onset [5]. Therefore, accurately distinguishing between benign and malignant thyroid nodules holds profound clinical significance. Early diagnosis facilitates the formulation of individualized treatment strategies, thereby reducing the risk of complications and improving patient prognosis [6].

Thyroid nodule calcification is one of the most common imaging findings in ultrasonography, representing the deposition of calcium salts within the nodule. Although the mechanism of calcification formation is complex, multiple studies have suggested that it is closely associated with abnormal proliferation and metabolism of tumor cells [7]. Thyroid nodules of different pathological natures often exhibit distinct characteristic features on ultrasound images, providing crucial imaging evidence for the clinical differentiation between benign and malignant nodules [7]. Due to its advantages of being radiation-free and highly reproducible, ultrasonography has been widely used for the screening and diagnosis of various diseases. Through ultrasonographic evaluation, features such as lesion boundaries, size, internal echogenicity, and blood flow signals can be clearly observed, playing an indispensable role in the clinical diagnosis and management of thyroid nodules [8].

A total of 85 patients with thyroid nodules were included in this study. All patients underwent ultrasonography, and the results were compared and validated against pathological findings as the gold standard. Pathological diagnosis identified 98 benign nodules and 14 malignant nodules, whereas ultrasonographic diagnosis identified 96 benign nodules and 16 malignant nodules. Statistical analysis revealed no significant difference in the detection outcomes for distinguishing between benign and malignant nodules between the two diagnostic methods ($P > 0.05$). This finding indicates that ultrasonography holds substantial diagnostic value in differentiating benign from malignant thyroid nodules and can provide reliable imaging evidence for clinical decision-making. Further analysis of its technical advantages revealed that the diagnostic accuracy of ultrasonography in this study primarily benefited from the optimized probe frequency setting (5-12 MHz). This high-frequency setting enabled clear visualization of the fine structures of thyroid nodules, allowing for precise assessment of lesion boundaries, morphology, size, internal echogenicity, and calcification. Particularly in the detection of calcifications, high-frequency ultrasonography demonstrated high sensitivity for identifying microcalcifications, providing crucial imaging information for the differentiation between benign and malignant lesions [9]. Furthermore, ultrasonography allows for real-time dynamic observation of the morphological characteristics of nodules and their internal hemodynamic changes, thereby further enhancing diagnostic accuracy. Given its additional clinical advantages for widespread adoption, such as rapid results, absence of radiation exposure, and relatively low examination cost, ultrasonography is generally well accepted by patients in clinical practice [10].

This study also identified a certain proportion of misdiagnoses and underdiagnoses in the differentiation of benign and malignant thyroid nodules by ultrasonography. Analysis of the underlying reasons can be primarily attributed to the following two points: First, some early-stage thyroid carcinomas are small in volume (diameter < 1 cm) and exhibit insignificant calcification features, making it difficult for ultrasound imaging to capture typical malignant signs. Second, some early-stage malignant nodules have relatively regular borders, and their sonographic characteristics overlap with those of benign nodules, thereby increasing the difficulty of differential diagnosis. The aforementioned findings indicate that, although ultrasonography demonstrates high accuracy in the clinical diagnosis of thyroid nodules, certain technical limitations persist. Therefore, in clinical practice, decision-making should not rely solely on ultrasonographic findings. Instead, a comprehensive assessment of thyroid nodules should be achieved by integrating other imaging modalities or laboratory test indicators based on the patient's specific condition, thereby further enhancing diagnostic accuracy and reliability.

The morphological characteristics of thyroid nodule calcification and their correlation with thyroid cancer have consistently been a focal area in clinical research. Studies have indicated that different types of calcification features are differentially associated with the benign or malignant nature of thyroid nodules. In this study, ultrasound examinations of enrolled patients revealed that among patients with benign thyroid nodule calcification, a high proportion (95.89%) exhibited well-defined margins. In contrast, among patients with malignant thyroid nodule calcification, a high proportion (83.33%) were characterized primarily by abundant blood flow signals. The distribution differences in these ultrasound features between the two groups were statistically significant. These findings suggest that the degree of blood flow signal abundance and the clarity of margins are important ultrasonographic indicators for differentiating between benign and malignant thyroid nodule calcification, demonstrating certain clinical diagnostic value.

Ultrasonography reveals that calcification in benign thyroid nodules typically presents with well-defined margins, a feature closely associated with their pathological characteristics. Benign nodules often exhibit expansive, localized growth, usually possess a complete capsule, and are clearly demarcated from the surrounding normal thyroid tissue. Consequently, their intact capsule and smooth borders can be clearly visualized on ultrasound imaging. Furthermore, due to the relatively regular cellular proliferation and slower metabolic rate of benign nodules, their demand for blood supply is lower, resulting in generally sparse internal blood flow signals. In contrast, calcification in malignant thyroid nodules often presents with abundant internal blood flow signals on ultrasound imaging. The pathological basis for this lies in the abnormal proliferative capacity of thyroid cancer cells, whose metabolic activity is significantly increased, requiring a substantial blood supply to sustain their rapid growth. This leads to the abundant blood flow signals observed within the nodules [11]. Color Doppler ultrasound can further reveal abnormal manifestations such as disorganized internal blood flow signals and increased blood flow velocity. Simultaneously, due to the invasive growth pattern of malignant tumors and the absence of a complete capsule, their boundaries with the surrounding normal thyroid tissue are typically ill-defined. This also serves as a crucial imaging basis for differentiating between benign and malignant lesions.

Based on the morphology and size of calcifications, ultrasonography typically classifies thyroid nodule calcifications into four types: microcalcifications, coarse calcifications, rim calcifications, and mixed calcifications. Their distribution characteristics and pathological mechanisms differ between benign and malignant nodules. Microcalcifications refer to calcific foci with a diameter less than 1 mm, often appearing as sand-like or pinpoint hyperechoic spots on ultrasound imaging. This type of calcification is closely associated with thyroid carcinoma, especially papillary thyroid carcinoma. Their formation mechanism may involve calcium salt deposition and necrotic areas during abnormal proliferation of tumor cells. These tiny calcifications are mostly distributed within the nodule and appear as characteristic gritty strong echoes on ultrasound [12]. Coarse calcifications typically refer to calcific foci with a diameter greater than 1 mm, often presenting as nodular or patchy distributions. This type of calcification is commonly seen in benign nodules, such as nodular goiter, and its occurrence is related to extensive calcium salt deposition and degenerative changes in nodular tissue. However, coarse calcifications can also be present in a minority of malignant nodules. Therefore, relying solely on the presence of coarse calcifications is insufficient for effectively distinguishing between benign and malignant nodules. Comprehensive judgment requires integration with other radiological characteristics or auxiliary diagnostic methods. Rim calcifications refer to calcifications distributed along the periphery of a nodule, forming a ring-shaped or arc-shaped strong echo, which may be accompanied by posterior acoustic shadowing. This type of calcification is more frequently observed in benign nodules, such as thyroid adenomas, and its formation may be related to calcium salt deposition in the nodule capsule region. Although the detection rate of rim calcifications in malignant nodules is low, their presence still warrants vigilance for potential malignancy. Mixed calcifications refer to the coexistence of two or three of the aforementioned calcification types within a single nodule. Due to the complex composition of mixed calcifications, their value in discriminating between benign and malignant lesions is limited. Individualized comprehensive assessment, incorporating the patient's clinical data and other radiological characteristics, is necessary to clarify the nature of the disease.

In this study, the difference in the hypoechoic ultrasound feature between benign and malignant nodules did not reach statistical significance, which was considered potentially related to the limited sample size. Previous studies have indicated that hypoechogenicity is one of the important radiological characteristics for differentiating benign from malignant thyroid nodules. Some malignant nodules present as hypoechoic, with the pathological basis being the higher density of malignant cells and the propensity for secondary changes such as hemorrhage and necrosis during tumor progression, leading to reduced ultrasound reflection intensity and thus the manifestation of hypoechoic areas [13]. The clinical value of ultrasonography in the assessment of thyroid nodule calcification extends not only to the differentiation between benign and malignant lesions but also to disease evaluation and support for treatment decision-making. Firstly, ultrasound can clearly display the number, size, distribution, and relationship of nodules with surrounding tissues, accurately assessing the extent of infiltration and the degree of impact on adjacent structures, thereby providing key imaging evidence for formulating individualized treatment plans. If malignant signs such as ill-defined borders and rich blood flow signals are detected on ultrasound, malignancy should be highly suspected, and further diagnostic confirmation followed by timely intervention is clinically warranted. For confirmed malignant nodules, minimally invasive procedures such as thyroid lobectomy can be employed for precise excision, thereby maximizing the preservation of normal thyroid function and improving patient prognosis and postoperative quality of life. Furthermore, ultrasonography also holds significant value in postoperative follow-up. Through dynamic observation of cervical lymph nodes and residual thyroid tissue, postoperative recovery can be effectively evaluated, and potential recurrence or metastatic lesions can be detected in a timely manner, providing reliable support for the long-term health management of patients.

5. Conclusion

In conclusion, ultrasonography demonstrates significant clinical application value in differentiating between benign and malignant thyroid nodules with calcification. This technique can clearly display key sonographic features of nodules, including boundary definition, internal blood flow signal richness, and calcification type, thereby providing objective and reliable imaging evidence for clinical differential diagnosis. Furthermore, ultrasonography offers advantages such as strong repeatability, absence of radiation exposure, non-invasiveness, convenience, and relatively low examination cost. It shows high potential for widespread application in the early screening of thyroid cancer, and is generally well accepted by patients. Therefore, ultrasonography can be recommended as a preferred imaging modality for differentiating benign from malignant calcified thyroid nodules and for thyroid cancer screening, and is worthy of broad promotion in clinical practice.

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