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# Evaluation of the Effectiveness, Accuracy, Specificity, and Sensitivity of High-Frequency Ultrasound in Differentiating Benign and Malignant Breast Micronodules

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**Abstract:** *Objective*: To analyze the significance of high-frequency ultrasound in differentiating benign and malignant breast micronodules. *Methods*: Eighty-five patients with breast micronodules admitted for diagnosis between October 2022 and October 2024 were selected for high-frequency ultrasound diagnosis. The diagnostic efficacy of high-frequency ultrasound was evaluated by comparing it with the results of surgical pathology. *Results*: High-frequency ultrasound detected 50 benign nodules, primarily breast fibroadenomas, and 35 malignant nodules, mainly breast ductal carcinoma in situ. Based on surgical pathology results, the diagnostic accuracy of high-frequency ultrasound was 96.47%, specificity was 97.96%, and sensitivity was 94.44%. In high-frequency ultrasound diagnosis, the proportion of grade III and IV blood flow in malignant nodules was higher than that in benign nodules, while the proportion of regular shape and clear margins was lower. The proportion of microcalcifications and posterior echo attenuation was higher in malignant nodules, and the resistance index (RI) and peak blood flow velocity were lower than those in benign nodules ($P < 0.05$). *Conclusion*: High-frequency ultrasound can effectively differentiate benign and malignant breast micronodules, determine specific nodule types, and exhibits high diagnostic accuracy and sensitivity. Additionally, benign and malignant nodules can be differentiated based on the grading of blood flow signals, sonographic features, and blood flow velocity, providing reasonable guidance for subsequent treatment plans.

**Keywords:** High-frequency ultrasound; Breast micronodules; Differentiating benign and malignant; Accuracy; Sensitivity

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## 1. Introduction

Breast nodules are secondary to various breast diseases. Based on their pathological nature, they can be classified into benign and malignant nodules. The former primarily includes diseases such as breast fibroadenoma and breast adenopathy, which can be completely cured through treatment methods like surgical resection, and the prognosis for these diseases is relatively favorable [1]. The latter refers to the malignant hyperplasia of breast epithelial cells, which has a high degree of malignancy, progresses rapidly, and is associated with a high mortality rate. There are numerous methods for differential diagnosis between the two, such as breast palpation and X-ray examination; however, these methods have a relatively high rate of missed or misdiagnosed cases and possess diagnostic limitations. High-frequency ultrasound is the preferred diagnostic method for this condition, offering advantages such as repeatability, no radiation exposure, and non-invasiveness. It enables a comprehensive examination of the superficial layer of the nodule using a high-frequency probe, providing intuitive and three-dimensional imaging that reveals the shape and location of the nodule, accurately determining its nature [2]. Based on this, the present study selected 85 patients with breast micronodules to evaluate the diagnostic efficacy of high-frequency ultrasound.

# 2. Materials and methods

## 2.1. General information

Eighty-five patients with breast micronodules who were diagnosed and admitted between October 2022 and October 2024 were selected. The patients' ages ranged from 26–65 years, with an average age of (41.56 ± 4.84) years; the disease duration ranged from 2–10 months, with an average duration of (5.71 ± 1.58) months; the nodule diameters ranged from 1–9 mm, with an average diameter of (5.75 ± 1.46) mm; 57 cases had unilateral nodules, and 28 cases had bilateral nodules.

### 2.1.1. Inclusion criteria

Nodule diameter < 1 cm; first occurrence of the nodule; complete imaging data; normal cognitive and communication abilities; informed consent and agreement to participate in the study.

### 2.1.2. Exclusion criteria

Concurrent organic diseases; concurrent psychiatric disorders; concurrent other malignant tumors; pregnancy or lactation; withdrawal from the study midway.

## 2.2. Methodology

A color Doppler ultrasound diagnostic system (LOGIQ S8) manufactured by GE was employed, with the ultrasound probe frequency set at 6–15 MHz. Patients were asked to lie in a supine position with both breasts exposed. The breast tissue was scanned continuously, starting from the outer edge of the breast and radiating towards the nipple. The nipple was used as the central point to determine the location of the nodules. A transverse scan was performed from the direction of the ribs, covering the range from the second to the sixth rib. After detecting a nodule, a multi-planar scan was conducted to evaluate the nodule's edge contour, calcifications, blood flow characteristics, and echo pattern. The focus depth was adjusted appropriately, and the scanning position was changed to ensure clear ultrasound images. Two ultrasound specialists were responsible for reviewing the images using a double-blind method. In cases of diagnostic disagreement, a consensus was reached through consultation.

## 2.3. Observation indicators

### 2.3.1. Criteria for determining benign and malignant nodules

Malignant: The nodule has a serrated border, infiltrates into the surrounding skin or tissue, has an uneven and irregular shape, exhibits granular calcifications, has a blood flow resistance index ≥ 0.7, shows posterior echo attenuation, and has abundant blood flow signals. Benign: The nodule has a regular and clear border, relatively uniform echo, coarse calcifications, a resistance index < 0.7, significantly enhanced posterior echo, and a small amount or absence of blood flow.

### 2.3.2. Diagnostic efficacy

Based on surgical pathology results, diagnostic accuracy = (true malignancy + true benignity) / total number of cases in this group × 100%, specificity = true benignity / (true benignity + false malignancy) × 100%; sensitivity = true malignancy / (true malignancy + false benignity) × 100%.

### 2.3.3. Blood flow signal grading

Referencing the BI-RADS criteria, incomplete assessment is classified as Grade 0; normal blood flow as Grade I; benign lesions as Grade II; suspicious benign lesions as Grade III; and suspicious malignant lesions as Grade IV.

### 2.3.4. Sonographic features

Evaluate sonographic features such as nodule shape (regular, irregular); nodule margin (clear, indistinct); microcalcifications (present, absent); and posterior echo characteristics (attenuation, enhancement).

### 2.3.5. Blood flow velocity

Record indicators such as Resistive Index (RI), peak blood flow velocity, and Pulsatility Index (PI).

## 2.4. Statistical analysis

Data processing was performed using SPSS 28.0 software. Categorical data were presented as [n/%], and comparisons were made using the chi-square ($\chi^2$) test. Continuous data, after being tested for normal distribution using the Kolmogorov-Smirnov (K-S) test, were presented as [mean ± standard deviation (SD)]. Intergroup comparisons were conducted using the independent samples *t*-test, while intragroup comparisons were performed using the paired samples *t*-test. A *p*-value less than 0.05 was considered statistically significant.

# 3. Results

## 3.1. Detection of breast micro-nodules by high-frequency ultrasound

High-frequency ultrasound detected 50 benign nodules, primarily breast fibroadenomas, and 35 malignant nodules, predominantly breast ductal carcinoma in situ. See **Table 1** for details.

**Table 1.** Detection of breast micro-nodules by high-frequency ultrasound

| Nature of nodule | Category | Cases (n) | Percentage (%) |
|---|---|---|---|
| Benign | Mammary duct adenoma | 4 | 4.71 |
| | Breast adenoma with adenosis | 6 | 7.06 |
| | Breast adenosis | 18 | 21.18 |
| | Breast fibroadenoma | 22 | 25.88 |
| | Total | 50 | 58.82 |
| Malignant | Medullary carcinoma of breast | 2 | 2.35 |
| | Lobular carcinoma of breast | 3 | 3.53 |
| | Invasive ductal carcinoma | 14 | 16.47 |
| | Ductal carcinoma in situ | 16 | 18.82 |
| | Total | 35 | 41.18 |

## 3.2. Diagnostic efficacy of high-frequency ultrasound

Based on surgical pathology results, the diagnostic accuracy of high-frequency ultrasound was 96.47% (82/85), with a specificity of 97.96% (48/49) and a sensitivity of 94.44% (34/36). See **Table 2** for details.

**Table 2.** Diagnostic efficacy of high-frequency ultrasound

| Diagnostic method | | Surgical pathology | | |
|---|---|---|---|---|
| | | Benign | Malignant | Total |
| High frequency ultrasound | Benign | 48 | 2 | 50 |
| | Malignant | 1 | 34 | 35 |

## 3.3. Comparison of blood flow signal grading between benign and malignant nodules

The proportion of Grade I and Grade II blood flow signals in malignant nodules was lower than that in benign nodules, while the proportion of Grade III and Grade IV blood flow signals was higher in malignant nodules ($p < 0.05$). See **Table 3** for details.

**Table 3.** Comparison of blood flow signal grading between benign and malignant nodules [n/%]

| Nodule Nature | Cases | Grade I | Grade II | Grade III | Grade IV |
|---|---|---|---|---|---|
| Benign | 50 | 15 (30.00) | 22 (44.00) | 11 (22.00) | 2 (4.00) |
| Malignant | 35 | 2 (5.71) | 3 (8.57) | 16 (45.71) | 14 (40.00) |
| $\chi^2$ | | 7.589 | 12.447 | 5.342 | 17.462 |
| *p*-value | | 0.006 | < 0.001 | 0.021 | < 0.001 |

## 3.4. Comparison of ultrasonographic features between benign and malignant nodules

The proportion of malignant nodules with regular shapes and clear margins was lower than that of benign nodules, while the proportion of malignant nodules with microcalcifications and posterior echo attenuation was higher than that of benign nodules ($p < 0.05$). See **Table 4** for details.

**Table 4.** Comparison of ultrasonographic features between benign and malignant nodules [n/%]

| Nodule nature | Case | Shape | | Margin | | Microcalcifications | | Posterior acoustic features | |
|---|---|---|---|---|---|---|---|---|---|
| | | Regular | Irregular | Well-defined | Ill-defined | Present | Absent | Attenuation | Enhancement |
| Benign | 50 | 44 (88.00) | 6 (12.00) | 47 (94.00) | 3 (6.00) | 15 (30.00) | 35 (70.00) | 6 (12.00) | 44 (88.00) |
| Malignant | 35 | 8 (22.86) | 27 (77.14) | 6 (17.14) | 29 (82.86) | 26 (74.29) | 9 (25.71) | 22 (62.86) | 13 (37.14) |
| $\chi^2$ | | 36.785 | | 51.808 | | 16.171 | | 24.106 | |
| $p$-value | | < 0.001 | | < 0.001 | | < 0.001 | | < 0.001 | |

## 3.5. Comparison of blood flow velocities in benign and malignant nodules

The RI and peak blood flow velocity in malignant nodules were lower than those in benign nodules ($p < 0.05$), while no significant difference in PI was observed between benign and malignant nodules ($p > 0.05$). See **Table 5**.

**Table 5.** Comparison of blood flow velocities in benign and malignant nodules [mean ± SD]

| Nodule Nature | Cases | RI (Resistive Index) | Peak Systolic Velocity (cm/s) | PI (Pulsatility Index) |
|---|---|---|---|---|
| Benign | 50 | 0.51 ± 0.18 | 33.58 ± 3.19 | 1.28 ± 0.57 |
| Malignant | 35 | 0.92 ± 0.26 | 14.74 ± 2.06 | 1.17 ± 0.52 |
| $t$-value | | 8.598 | 30.715 | 0.907 |
| $p$-value | | < 0.001 | < 0.001 | 0.367 |

# 4. Discussion

Breast nodules represent a type of gynecological disease that can occur in women of any age group, predominantly manifesting as breast hyperplasia or breast tumors. The etiology of these conditions is complex and is associated with factors such as environmental changes, endocrine hormone imbalances, genetics, and gene mutations. Benign breast nodules account for a relatively high proportion of cases, with the most common type being fibroadenoma. These nodules typically present as nodular or granular lesions, with their texture and size influenced by the menstrual cycle, exhibiting regular changes. Specifically, the nodules become harder and increase significantly in size before menstruation, then soften and decrease in size after menstruation [3,4].

Benign nodules are characterized by periodic pain, which intensifies before menstruation and gradually diminishes and disappears thereafter. Additionally, benign nodules have a clear boundary with surrounding tissues, cause noticeable pain upon palpation, do not adhere to the skin or deep tissues, and exhibit high mobility. Malignant nodules refer to breast space-occupying lesions with a prolonged disease course. Their symptoms are similar to those of benign nodules but lack the distinct periodic changes. The five-year survival rate for malignant nodules is relatively low. Therefore, it is crucial to adhere to the "three early principles" of tumor diagnosis and treatment for early screening, early diagnosis, and early treatment to achieve a more favorable disease prognosis for affected patients [5].

The common diagnostic methods for breast nodules include breast palpation and mammography. Palpation allows for the clear detection of nodular lesions in the breast area and provides a preliminary assessment of their size and location, making it a frequently used initial diagnostic tool. Mammography enables the observation of nodule characteristics on molybdenum target films, facilitating effective differentiation of nodule nature based on differences in nodule boundaries and morphology, and offers high diagnostic feasibility [6]. However, the image resolution of X-rays is not optimal, and its diagnostic efficacy for small breast nodules is generally limited, necessitating the combination with other diagnostic methods.

Small breast nodules refer to breast nodules with a diameter of less than 1 cm. They are highly concealed, lack obvious symptoms, and are easily overlooked by patients. Ultrasound technology is the primary diagnostic method for small breast nodules. It offers rapid examination, high safety, and precise results, enabling accurate determination of nodule nature in a short period [7]. High-frequency ultrasound, with a higher probe frequency compared to conventional ultrasound, can clearly distinguish soft tissues and is ideal for diagnosing small breast nodules. It can comprehensively obtain imaging data of the breast area, comprehensively assess the edge regularity and morphological characteristics of breast nodules, and differentiate their nature.

The results showed that high-frequency ultrasound had a detection rate of 58.82% for benign nodules and 41.18% for malignant nodules. Using surgical pathology as the gold standard, the diagnostic accuracy of high-frequency ultrasound was 96.47%, with a specificity of 97.96% and a sensitivity of 94.44%. This is attributed to the high spatial resolution of high-frequency ultrasound. Using a high-frequency probe, it can clearly observe the cystic and solid structures, morphological characteristics, and edge features of small nodules, effectively differentiating benign from malignant nodules based on morphological differences. High-frequency ultrasound has the advantage of microscopic observation, enabling clear detection of millimeter-sized nodules and observation of fine features such as microcystic structures or microcalcifications, thereby improving diagnostic efficacy. Additionally, high-frequency ultrasound allows for real-time imaging. After applying pressure with the probe, it can accurately assess nodule hardness and perform multi-plane and multi-angle scans of the nodule area, preventing tissue overlap and accurately evaluating the anatomical relationship between the nodule lesion and surrounding tissues, reducing the likelihood of missed or misdiagnosed cases [8,9].

The proportion of Grade I and II malignant nodules is lower than that of benign nodules, while the proportion of Grade III and IV blood flow is higher in malignant nodules compared to benign ones. The proportion of regularly shaped and clearly edged malignant nodules is lower than that of benign nodules, while the proportion of microcalcifications and posterior echo attenuation is higher in malignant nodules. The RI and peak blood flow velocity of malignant nodules are lower than those of benign nodules ($p < 0.05$). The reason is that under high-frequency ultrasound, benign nodules exhibit expansive growth, which has a relatively minor impact on the boundaries and specific morphology of the nodules, resulting in clear boundaries and regular shapes.

Malignant nodules, on the other hand, demonstrate infiltrative growth without a complete capsule, significantly altering the morphology of the nodules, leading to excessive stroma and unclear boundaries. Moreover, the higher collagen fiber content in the stroma can cause posterior echo attenuation. The rapid growth rate of malignant nodules, accompanied by excessive tissue proliferation, leads to significant calcium salt deposition, forming microcalcifications. Additionally, malignant nodules are highly dependent on neovascularization during their growth, increasing the number of blood vessels and causing tortuous vascular pathways and thinned vessel walls, which in turn increases blood flow, resulting in Grade III and IV signals [10].

Under these circumstances, the neovascularization in malignant nodules lacks elastic fibers and has a low smooth muscle content, rendering the vessels non-contractile, reducing vascular bed resistance, and lowering the RI value. Furthermore, the tortuous vascular pathways in malignant nodules require greater energy expenditure, leading to a decrease in peak velocity in the nodule area.

## 5. Conclusion

In summary, high-frequency ultrasound demonstrates high efficacy in differentiating between benign and malignant breast micro-nodules, with high accuracy and sensitivity. It can clearly display differences in blood flow signals and sonographic features between benign and malignant nodules, offering high diagnostic performance.

## Disclosure statement

The authors declare no conflict of interest.

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