Comparative Analysis of Ultrasound Imaging and Histopathology in Thyroid Nodule Assessment

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Abstract:

Background: Thyroid nodules are prevalent, some of them being malignant. Good diagnosis is necessary to inform treatment and minimize the needless intervention. Ultrasound (US) has become very popular in the first-time evaluation, but the gold standard is histopathology.

Aim: To test the relationship between ultrasound characteristics and histopathology in thyroid nodules.

Methodology: It was a type of retrospective cross-sectional study involving 90 patients in Department of Radiology, Lord Buddha and Koshi Medical College and Hospital, Gamhariya, Saharsa, Bihar, India, between December 2023 to November 2024. Such ultrasound features as composition, echogenicity, margins, and microcalcifications- were noted. The definitive diagnosis was done by fine-needle aspiration cytology (FNAC) and histopathology. Chi-square tests and logistic regression were used as a part of statistical analysis.

Results: Malignant nodules were strongly related to solid composition, hypo echogenicity, irregular margins, and microcalcifications ($p < 0.05$). Univariate logistic regression demonstrated elevated probability of malignancy: solid lesions (OR 3.2), hypoechoic lesions (OR 4.5), irregular margins (OR 5.0), and microcalcifications (OR 8.2). These characteristics were supported by multivariate analysis as predictors of their own.

Conclusion: Malignancy is highly indicative of ultrasound findings, especially microcalcifications, hypo echogenicity, irregular margins and solid composition. The systematic US assessment can support biopsy choices, reduce redundant interventions, and enhance the management of patients.

Keywords: Ultrasound, Thyroid nodules, Malignancy, Histopathology, Microcalcifications.

Introduction

Thyroid nodules are a frequent clinical observation, whose prevalence is rising with age and is higher in females. Though most thyroid nodules are benign, a minor but considerable portion is an indicator of malignancy, and therefore proper diagnosis is very important to managing the patient. Clinicians use several diagnostic methods to examine these nodules with imaging and histopathological examination taking the central stage [1]. It is vital to know how these modalities are correlated to inform clinical decision-making and eliminate unnecessary surgery procedures.

The ultrasound (US) has become a device of choice in measuring the thyroid nodules because of its affordability, it does not cause any type of invasion, and it is highly resolutory. The characteristics of the nodules such as size, echogenicity, composition (solid or cystic), margins, calcifications and vascularity can be carefully studied using ultrasound. These characteristics can be used to give hints related to the probability of malignancy and so can clinicians categorize patients based on the level of risk and whether subsequent treatment, which may be fine-needle aspiration cytology (FNAC) or surgery, is justified [2].

The use of ultrasound, though useful, is not conclusive in separating benign nodules or malignant nodules. The results of imaging are indicative and not definitive and there are several features that are similar in benign and malignant lesions Therefore, histopathological investigation is best used to make the diagnosis [3]. The histopathology, which is obtained either by surgical excision or core needle biopsy, provides information in detail about the cells and structural changes that can be used in determining

the nature of the nodule, and the further management.

Correlation between the emergence of ultrasound and histopathological findings has also been extensively researched to enhance the predictability of the image. Several scoring systems and criteria have been developed such as the Thyroid Imaging Reporting and Data System (TI-RADS) to standardize the ultrasound examination and categorize the nodules, which are more likely to be malignant. Such systems rely on sonographic features, which have been statistically correlated with histopathological results, including the existence of micro calcifications and irregular margins, hypo echogenicity and taller than wide morphology [4]. Making the US properties and the histopathology findings comparative, the researchers must maximize the data of diagnosis and minimize the instances of invasive procedures required.

In addition, good correlations suggest that there are great implications for managing patients. A high-quality non-invasive assessment program will minimize unwarranted surgeries to cure non-malignant nodules, minimize morbidity in the patient and optimize health care resources. Conversely, high-risk nodules of malignancy are supposed to be identified to work out the intervention and better patient outcomes are obtained in a timely manner [5]. Thus, the awareness of the merits and demerits of ultrasound as a predictor of histopathological outcomes can be considered as one of the most significant research areas of endocrinology and radiology.

The recent technology in ultrasound such as high-frequency transducer, elastography and contrast-enhanced ultrasound have contributed to the ability to characterize thyroid nodules. Such technologies offer additional parameters, which are open to malignancy, such as tissue stiffness or other vascular structures. These progressive approaches with the traditional sonographic norms could be used to improve the diagnostic predictability of ultrasound and the reduction of invasive diagnoses tests [6].

Conclusively, ultrasound and histopathological correlation of thyroid nodules is an essential part of contemporary thyroid examination. Although ultrasound is an accessible and non-invasive technique available to risk stratify, histopathology is the final diagnostic technique. Current research and technological developments are to enhance this relationship and eventually enhance patient care with the balance between accurate diagnosis and less invasive methods.

Methodology

Study Design: This study was a retrospective cross-sectional observational study aimed at evaluating the correlation between ultrasound (US) features and histopathological findings of thyroid nodules.

Study Area: The study was conducted in the Department of Radiology, Lord Buddha and Koshi Medical College and Hospital, Gamhariya, Saharsa, Bihar, India.

Study Duration: The study was carried over a period from December 2023 to November 2024.

Study Participants:

Inclusion Criteria:

- Patients of all age groups presenting with thyroid nodules on ultrasound.
- Patients who underwent fine-needle aspiration (FNA) or surgical excision of the thyroid nodule.
- Patients with complete clinical, radiological, and histopathological records.

Exclusion Criteria:

- Patients with purely cystic thyroid lesions.
- Patients with incomplete medical records or missing ultrasound images.
- Patients with prior thyroid surgery or radioactive iodine treatment.

Sample Size: The study included a total of 90 patients who fit in with the inclusion criteria.

Procedure: Each participant was examined with an elaborate ultrasound scan of the thyroid gland with the use of a high-frequency linear transducer (1015 MHz). The size (maximal diameter), echogenicity (hyperechoic, isoechoic, hypoechoic), composition (solid or mixed), margins (regular and irregular), and microcalcifications were noted as the following characteristics of each thyroid nodule.

The procedure of the cytology of fine-needle aspiration (FNAC) under the ultrasound was conducted with a 25-gauge needle according to the recommendations of the American Thyroid Association (ATA). Cytology results were categorized according to the 2009 Bethesda system. Surgical excision was performed based on cytology results, suspicious ultrasound features, or clinical indications. Histopathological examination of resected nodules was conducted by an experienced pathologist.

Statistical Analysis: Data was entered and analyzed using SPSS version 27. Quantitative variables were expressed as mean ± standard deviation, while categorical variables were expressed as percentages. Comparisons between groups were performed using the student's T-test for continuous variables and Chi-square test for categorical variables. Univariate logistic regression was used to calculate the odds ratios (OR) of malignancy based on ultrasound characteristics. Variables with significant associations in univariate analysis were included in multivariate logistic regression to identify independent predictors of malignancy. Statistical significance was set at $p < 0.05$.

Result

Table 1 gives the demographic features of the 90 study participants. There were 35 male participants (38.9) and 55 female participants (61.1) which means that the proportion of female participants is bigger. The age of the participants was widely spread with an average age of 42.3 years with SD= 12.5. When divided into age brackets, 20 participants (22.2) fell under the age of 30 years, the largest number of 45 participants (50) were between 31 and 50 years, and 25 participants (27.8) were above the age of 50 years. In general, the research sample consisted of mostly women and mostly those in the middle age bracket.

Table 1: Demographic characteristics of study participants (n = 90)		
Variable	**Number (n)**	**Percentage (%)**
Gender		
Male	35	38.9
Female	55	61.1
Age (years)	Mean ± SD	42.3 ± 12.5
Age Groups		
< 30	20	22.2
31–50	45	50
> 50	25	27.8

Table 2 shows the relationship between ultrasound characteristics and histopathological images of different features. In terms of the lesion composition, solid lesions were more common in the malignancy cases (20 out of 25) than in the benign ones (35 out of 65) whereas mixed lesions were more common in the benign cases (30 out of 65) than in the malignancy cases (5 out of 25) with statistically significant association (p = 0.03). Hypoechoic lesions had a high echogenicity was strongly correlated with malignancy (20 malignant vs. 30 benign) whereas iso- and hyperechoic were more frequently seen in benign lesions than in malignant; this relationship was significant (p = 0.01). Margins were also significantly different among benign and malignant lesions (p = 0.02) and regular margins were mostly observed in benign lesions (50 out of 65) and irregular margins in malignant lesions (15 out of 25). Microcalcifications were also most indicative of malignancy, with 18 malign lesions having micro calcifications whereas only 10 benign lesions had micro calcifications, and this parameter demonstrated the highest association with malignancy of all parameters tested (p = 0.001). In general, these results indicate that solid composition, hypo echogenicity, irregular margins, and the existence of micro calcifications in ultrasound have a strong relationship with malignant histopathology.

Table 2: Correlation between ultrasound features and histopathological findings			
Ultrasound Feature	**Benign (n = 65)**	**Malignant (n = 25)**	**p-value**
Composition			
Solid	35	20	0.03
Mixed	30	5	
Echogenicity			
Hypoechoic	30	20	
Isoechoic	25	0	0.01
Hyperechoic	10	5	
Margins			
Regular	50	10	0.02
Irregular	15	15	
Microcalcifications			
Present	10	18	0.001
Absent	55	7	

Table 3 presents the findings of the logistic regression analyses that were conducted to determine the relationship between other ultrasound characteristics and the probability of malignancy. During the univariate analysis, the four features that had statistically significant correlation with malignancy were solid composition, hypoechoic echogenicity, irregular margins, and microcalcifications. Solid lesions were 3.2 times more likely to be malignant than non-solid lesions (95% CI: 1.19954; p = 0.03). Hypoechoic lesions were found to increase the odds of malignancy by 4.5-folds (95% CI: 1.5 to 13.2; p = 0.01) whereas irregular margins increased odds 5 times (95% CI: 1.8 to 14.0; p = 0.002). The most significant predictor was the presence of micro calcifications that raised the likelihood of malignancy

over eightfold (95 percent confidence interval, 3.0-22.5; p =. 0.000).

Table 3: Logistic Regression Analysis of Ultrasound Features Predicting Malignancy				
Ultrasound Feature	Univariate OR (95% CI)	p-value	Multivariate OR (95% CI)	p-value
Solid composition	3.2 (1.1–9.4)	0.03	2.8 (1.0–8.2)	0.04
Hypoechoic echogenicity	4.5 (1.5–13.2)	0.01	4.0 (1.3–12.0)	0.01
Irregular margins	5.0 (1.8–14.0)	0.002	4.5 (1.5–13.5)	0.005
Microcalcifications	8.2 (3.0–22.5)	<0.001	7.5 (2.7–20.8)	<0.001

Discussion

The demographic data of the research sample shows that it comprises mostly of female participants (61.1%), with the individuals in the middle-age bracket (3150 years, 50%). Such a gender and age composition is in line with the prior literature, which claims that some conditions that are measured through ultrasound, e.g., thyroid and breast lesions are more prevalent among females and middle-aged adults. The wide age group (mean 42.3 ± 12.5 years) also makes the findings to be applicable to a wide range of adult population, though comparatively, younger and older age groups were underrepresented. Shin et al., (2015) [7] noted that the nodule size affects the risks of malignancy varied about the US pattern; a nodule size of 3 cm enhanced the risk of malignancy but did not do so in the highly suspicious nodules.

Comparison of the ultrasound characteristics as compared to histopathology showed that there were remarkable differences between the benign and malignant lesions. The presence of solid lesions was more often related to malignancy, but mixed lesions were more in the benign cases. Hypoechoic echogenicity and irregular margins were more typical of the malignant lesions, and iso- and hyperechoic pattern and regular margins were primarily found in benign cases. One of these properties, microcalcifications, portended the highest association with malignancy, and this characteristic is likely to make it an excellent predictor of lesions of interest. Microcalcifications have been a known risk factor of malignancy in thyroid nodules, an OR of 6.7 being reported in a large meta-analysis by Campanella et al., (2014) [8] which studies malignancy in thyroid nodules.

These findings are also supported by the logistic regression analysis which quantifies the risk of each feature of ultrasound. The odds ratio of a solid lesion was 3.2 higher in the incidence of malignancy, and the odds ratio of the hypoechoic echogenicity was 4.5. Abnormal margins were associated with a five times increased risk of malignancy and micro calcifications turned out to be the most significant predictor, with over 8 times increased chances. These findings support the clinical importance of sonographic combination of several features in determining the likelihood of malignancy. Diaz et al., (2016) [9] identified inadequate samples and similar percentage (4%) in a single-center HR-TNC study.

These ultrasound characteristics when used jointly in multivariate analysis were still significant in predicting their value. The independent variables like solid composition, hypoechoic echogenicity, irregular margins, and macrocalcifications increased the risk of malignancy and thereby their assessment provided complementary information and not duplicate information. It substantiates the need to include the systematic ultrasound examination with the incorporation of multiple characteristics as a way of guiding clinical decisions and reducing the number of diagnostic uncertainties. Wang et al., (2006) [10] found that microcalcification was observed in 38.2% (26 out of 68) of the nodules of the malignant type with calcification.

The results of this paper have clinical implications for those clinicians who carry out imaging-based tests. The detection of solid, hypoechoic lesions with irregular margins and macrocalcifications can be used to prioritize lesions before having to undergo a biopsy and hasten the detection of malignancy. Moreover, such ultrasound advantages could help in counseling patients, since the results will show a more precise risk stratification, and eventually help in undertaking the right and timely clinical management. Taki et al., (2004) [11] suggested that the percentage of micro calcification in malignant nodules with calcium was 29.0%

To conclude, this paper shows that certain ultrasound characteristics are highly linked to malignant lesions in particular micro calcifications, hypo echogenicity, irregular margins and solid structure. The incorporation of these features into the daily imaging evaluation may lead to higher accuracy of diagnosing a patient and better patient outcomes. The findings can be further confirmed by future research involving larger and more heterogeneous populations and can generate more accurate predictive models to use in clinical practice.

Conclusion

Summing up, this paper indicates that certain ultrasound characteristics are closely and statistically

significantly related to histopathological results in thyroid nodules. Hypoechoic echogenicity, solid composition, irregular margins and microcalcifications were found to have an independent predictive value on increased risk of malignancy with the strongest predictive value of microcalcifications. The findings suggest that the systematic ultrasound examination is clinically useful in risk stratification and biopsy or surgical intervention decision-making. Through the integration of various sonographic characteristics, clinicians can be able to better detect nodules that have higher malignant potential, reduce the number of unnecessary invasive procedures on benign lesions, and better manage their patients in general. This confirms the complementary nature of ultrasound and histopathology in thyroid nodule evaluation today.

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