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Original Research Article

DIAGNOSTIC EFFICACY OF DIFFUSION-WEIGHTED MAGNETIC RESONANCE IMAGING IN THYROID LESIONS

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Abstract

Background: Thyroid nodules, prevalent in up to 76% of populations, pose a diagnostic challenge due to the potential for malignancy. Conventional imaging techniques, like ultrasound and computed tomography, often lack accuracy. Diffusion-weighted magnetic resonance imaging (DW-MRI) has emerged as a promising tool for thyroid lesion assessment. By measuring apparent diffusion coefficient (ADC) values, DW-MRI offers insights into tissue microstructure, aiding in distinguishing between benign and malignant nodules. Despite challenges, integrating DW-MRI into clinical practice promises improved diagnostic accuracy and personalized treatment planning.

Methods: This prospective cross-sectional study assessed diffusion-weighted MRI (DW-MRI) in thyroid lesion characterization. Patients with nodules detected on ultrasound underwent DW-MRI and histopathological confirmation. Imaging utilized a 1.5 Tesla MRI scanner with multi-b-value imaging. Two radiologists independently reviewed images, calculating apparent diffusion coefficient (ADC) values. Histopathology involved FNAB or surgical excision. Statistical analysis determined diagnostic metrics and optimal ADC thresholds for malignancy prediction using SPSS version 20.0.

Results: Our study enrolled 69 patients with thyroid nodules, with a mean age of 39.2 ± 15.3 years. DW-MRI exhibited high diagnostic accuracy in distinguishing benign (n=43) from malignant (n=26) thyroid nodules. Sensitivity was 91.30%, specificity 89.13%, positive likelihood ratio 8.40, negative likelihood ratio 0.10, positive predictive value 80.77%, negative predictive value 95.35%, and accuracy 89.86%. ROC analysis revealed an area under the curve of 0.934 ($p<0.0001$), indicating DW-MRI's robust discriminatory capability. Concordance between DW-MRI diagnosis and histopathological results was significant ($p<0.001$).

Conclusion: DW-MRI demonstrates high accuracy in differentiating benign from malignant thyroid nodules. Its robust diagnostic performance, evidenced by sensitivity, specificity, and ROC analysis, underscores its potential as a valuable adjunct to conventional imaging modalities. Implementation of DW-MRI could enhance clinical decision-making and reduce unnecessary invasive procedures for thyroid lesion evaluation.

Keywords: MRI, Ultrasound, Malignant, Benign, Thyroid.

Introduction

Thyroid nodules are a common clinical finding, with a prevalence ranging from 20% to 76% in various populations, predominantly identified through imaging studies or physical examination [1]. While the majority of thyroid nodules are benign, a subset harbor malignant potential, necessitating accurate diagnostic tools for their discrimination. Conventional imaging techniques, such as ultrasound (US) and computed tomography (CT), are routinely employed for thyroid lesion assessment [2].

However, their ability to distinguish between benign and malignant nodules remains limited, often leading to unnecessary invasive procedures and healthcare costs [3,4].

In recent years, diffusion-weighted magnetic resonance imaging (DW-MRI) has emerged as a promising non-invasive imaging modality for the evaluation of thyroid lesions [5]. DW-MRI capitalizes on the Brownian motion of water molecules within tissues, providing insights into tissue microstructure and cellularity [6]. Malignant tumors typically exhibit increased cellularity and restricted diffusion compared to benign lesions, which manifests as higher signal intensity on DW-MRI sequences [7].

Several studies have investigated the utility of DW-MRI in discriminating between benign and malignant thyroid nodules, with promising results [8,9]. By quantifying apparent diffusion coefficient (ADC) values derived from DW-MRI, researchers have demonstrated its potential to aid in lesion characterization and risk stratification. Malignant lesions often exhibit lower ADC values compared to benign nodules due to increased cellularity, reflecting their aggressive nature and potential for metastasis [9].

Moreover, DW-MRI offers advantages over conventional imaging modalities, including lack of ionizing radiation, superior soft tissue contrast, and multiplanar imaging capabilities. These features enhance its utility in challenging clinical scenarios, such as lesions adjacent to critical structures or in patients with iodine contrast allergies [10].

Despite its potential, the role of DW-MRI in thyroid lesion evaluation is still evolving, and several challenges remain. Variability in imaging protocols, interpretation criteria, and ADC threshold values across studies necessitate standardization for widespread clinical adoption. Furthermore, the influence of factors such as lesion size, location, and histological subtype on DW-MRI findings requires further investigation [8,9,10]. In this context, our research aimed to contribute to the growing body of evidence regarding the role of DW-MRI in differentiating benign from malignant thyroid lesions. By systematically evaluating DW-MRI findings alongside histopathological outcomes, we aimed to evaluate its diagnostic accuracy, sensitivity, and specificity. Ultimately, the integration of DW-MRI into routine clinical practice has the potential to improve patient management by enabling accurate risk stratification and personalized treatment planning for thyroid nodules.

Materials and Methods

Study Design

This cross-sectional prospective study was conducted among patients who underwent diffusion-weighted magnetic resonance imaging (DW-MRI) for the evaluation of thyroid nodules in the department of Radiodiagnosis at Tertiary care center for a period of 2 years between July 2019 and June 2021. The study protocol was approved by the Institutional Review Board, and informed consent was obtained from all participants.

Patient Selection

The study included patients with presence of a thyroid nodule(s) detected on ultrasound imaging and underwent DW-MRI examination for further characterization of thyroid nodules and underwent histopathological confirmation through fine-needle aspiration biopsy (FNAB) or surgical excision. Patients with inadequate imaging quality or inconclusive histopathological results were excluded from the study.

Imaging Protocol

Diffusion-weighted magnetic resonance imaging (DW-MRI) examinations were conducted using a state-of-the-art 1.5 Tesla MRI scanner, (Siemens Magnetom Avanto model), renowned for its advanced imaging capabilities and widespread usage in clinical settings. The imaging protocol employed a multi-b-value approach, encompassing b-values of 0, 500, and 1000 s/mm², to comprehensively capture the diffusion characteristics of water molecules within thyroid tissues. This approach facilitated robust estimation of the apparent diffusion coefficient (ADC) values crucial for tissue characterization. For optimization of image quality, echo time (TE) parameters typically ranged between 50 and 80 milliseconds, while repetition time (TR) parameters ranged between 2000 and 3000 milliseconds.

These TE and TR ranges were selected based on previous optimization studies and scanner specifications to ensure optimal signal-to-noise ratio and contrast-to-noise ratio. Images were acquired in axial planes to ensure comprehensive coverage of the thyroid gland and associated nodules, thereby facilitating accurate lesion localization and characterization. Additionally, fat suppression techniques such as spectral fat saturation or inversion recovery were employed to mitigate chemical shift artifacts and enhance tissue contrast.

Two experienced radiologists independently reviewed the DW-MRI images blinded to the histopathological results. Regions of interest (ROIs) were manually drawn around the thyroid nodules on the ADC maps to calculate the apparent diffusion coefficient (ADC) values. Discrepancies between the two readers were resolved through consensus.

Histopathological diagnosis

Tissue samples were obtained through FNAB or surgical excision procedures, depending on the clinical indication and lesion characteristics. FNAB was typically performed under ultrasound guidance, with multiple passes made into the thyroid nodule to collect cellular material for cytological evaluation. Surgical excision, such as lobectomy or total thyroidectomy, was indicated for larger nodules or when FNAB results were inconclusive or suspicious for malignancy. For FNAB samples, cytological evaluation was conducted to assess cellular morphology, nuclear features, and architectural patterns indicative of benign or malignant thyroid nodules. The Bethesda System for Reporting Thyroid Cytopathology was often used to standardize reporting and guide clinical management based on the risk of malignancy associated with each cytological category. Surgical excision specimens underwent thorough gross and microscopic examination to assess tumor size, location, and macroscopic features. Histological sections were prepared from formalin-fixed, paraffin-embedded tissue blocks and stained with hematoxylin and eosin (H&E) for microscopic analysis. The presence of characteristic histological features, such as papillary architecture, nuclear atypia, and vascular invasion, was evaluated to confirm the diagnosis of malignancy.

Diagnosis of benign thyroid nodules was based on the absence of malignant features, including cellular atypia, nuclear enlargement, irregular nuclear contours, and architectural disarray. Malignant lesions were characterized by the presence of features consistent with papillary thyroid carcinoma, follicular thyroid carcinoma, medullary thyroid carcinoma, or anaplastic thyroid carcinoma, according to the World Health Organization (WHO) classification of thyroid tumors.

Statistical Analysis

Statistical analysis was performed using appropriate software SPSS version 20.0.

Descriptive statistics were used to summarize patient demographics and imaging findings. The diagnostic performance of DW-MRI in differentiating benign from malignant thyroid lesions was assessed using sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV).

Receiver operating characteristic (ROC) curve analysis was conducted to determine optimal ADC threshold values for malignancy prediction.

Ethical Considerations

This study was conducted in compliance with the principles outlined in the Declaration of Helsinki. Patient confidentiality and privacy were strictly maintained throughout the study period.

Results

Our study enrolled 69 patients with thyroid nodules, with a mean age of 39.2 ± 15.3 years. The age distribution varied across different age groups, with the majority of patients falling within the 20-40 years category (42.0%), followed by the 41-60 years group (29.0%). Patients aged <20 years and those over 60 years accounted for 8.7% and 20.3% of the population, respectively. In terms of gender distribution, the cohort was predominantly female, comprising 75.4% of the participants, while males accounted for 24.6% (Table 1).

Table 1: Baseline characteristics of the study subjects (N=69)

Variables	Frequency	%
Age group		
<20 years	6	8.7
20-40 years	29	42.0
41-60 years	20	29.0
>60 years	14	20.3
Mean age (in years)	39.2 ± 15.3	
Gender		
Male	17	24.6
Female	52	75.4

The histopathological analysis revealed that among the 69 thyroid nodules examined, 46 (66.7%) were diagnosed as benign, while 23 (33.3%) were classified as malignant. Within the benign category, the most common diagnoses were colloidal nodules, comprising 33.3% of the cases, followed by follicular nodules (23.2%) and adenomatous nodules (7.2%). Hurthle cell adenomas were less frequently encountered, representing 2.9% of the benign lesions. Among the malignant nodules, papillary carcinoma was the predominant histological subtype, accounting for 13.0% of cases, followed by follicular carcinoma and medullary carcinoma, each comprising 8.7% of the malignant lesions. Lymphoma was identified in 2.9% of the cases (Table 2).

Table 2: Histo/Cytopathological diagnosis of thyroid nodules among study subjects (N=69)

Diagnosis	Frequency	%
Benign (n=46, 66.7%)		
Colloidal nodule	23	33.3
Follicular nodule	16	23.2
Adenomatous nodule	5	7.2

Hurthle cell adenoma	2	2.9
Malignant (n=23, 33.3%)		
Papillary	9	13.0
Follicular	6	8.7
Medullary	6	8.7
Lymphoma	2	2.9

The mean apparent diffusion coefficient (ADC) values, measured in $\times 10^{-3}mm^2/sec$, were significantly different between benign and malignant thyroid nodules. Among the benign lesions (n=46), the mean ADC value was $1.72 \pm 0.38 \times 10^{-3}mm^2/sec$. In contrast, malignant nodules (n=23) exhibited a markedly lower mean ADC value of $0.79 \pm 0.16 \times 10^{-3}mm^2/sec$. This difference in ADC values between benign and malignant nodules was statistically significant ($P < 0.0001$), indicating a clear distinction in diffusion characteristics between the two groups. Overall, when considering all thyroid nodules analyzed (n=69), the mean ADC value was $1.34 \pm 0.41 \times 10^{-3}mm^2/sec$(Table 3).

Table 3: ADC values on DWI with Histo/Cytopathological diagnosis of thyroid nodules among study subjects (N=69)

Histo/Cytopathological diagnosis	Mean ADC values ($\times 10^{-3}mm^2/sec$)	P value
Benign (n=46)	1.72 ± 0.38	<0.0001
Malignant (n=23)	0.79 ± 0.16	
Overall	1.34 ± 0.41	

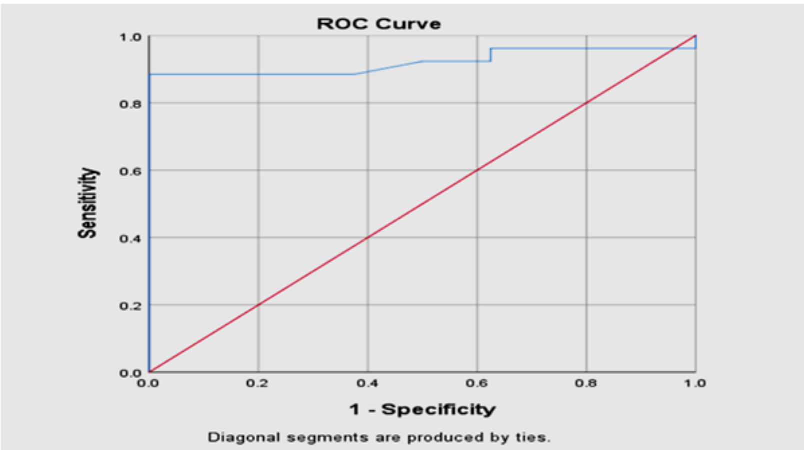

Figure 1: Receiver operating characteristic (ROC) curve analysis to determine optimal ADC threshold values for malignancy prediction

ADC of $1.0 \times 10^{-3}mm^2/sec$ was considered as cut-off value (for Benign lesions ADC > $1.0 \times 10^{-3}mm^2/sec$, and for malignant lesions ADC < $1.0 \times 10^{-3}mm^2/sec$), so among the 69 thyroid nodules evaluated using diffusion-weighted magnetic resonance imaging (DW-MRI), 43 (62.3%) were diagnosed as benign, while 26 (37.7%) were classified as malignant. The Receiver Operating Characteristic (ROC) curve analysis for apparent diffusion coefficient (ADC) values in distinguishing between benign and malignant lesions yielded a highly favorable area under the curve (AUC) value of 0.934, with a statistically significant p-value of less than 0.0001 (Figure 1).

The results of our study underscore the promising role of diffusion-weighted magnetic resonance imaging (DW-MRI) as a valuable diagnostic tool for distinguishing between benign and malignant thyroid lesions.

Our findings reveal that DW-MRI demonstrated high sensitivity (91.30%) and specificity (89.13%) in correctly identifying malignant thyroid nodules, with an overall accuracy of 89.86%. Importantly, DW-MRI exhibited a particularly impressive negative predictive value of 95.35%, indicating its ability to effectively rule out malignancy when the imaging findings are negative (Table 4).

Table 4: Diagnostic performance of DW-MRI in differentiating benign from malignant thyroid lesions

Diagnosis	**Histo/Cytopathological diagnosis**	
DW-MRI diagnosis	Benign (n=46)	Malignant (n=23)
Benign (n=43)	41	2
Malignant (n=26)	5	21
DW-MRI diagnosis evaluation	Value	95% CI
Sensitivity	91.30%	71.96% to 98.93%
Specificity	89.13%	76.43% to 96.38%
Positive Likelihood Ratio	8.40	3.64 to 19.40
Negative Likelihood Ratio	0.10	0.03 to 0.37
Positive Predictive Value	80.77%	64.52% to 90.65%
Negative Predictive Value	95.35%	84.45% to 98.72%
Accuracy	89.86%	80.21% to 95.82%

Discussion

Thyroid nodules represent a common clinical challenge, necessitating accurate differentiation between benign and malignant lesions to guide appropriate management decisions. In our study, we investigated the potential of diffusion-weighted magnetic resonance imaging (DW-MRI) in this regard, aiming to assess its efficacy in distinguishing between benign and malignant thyroid nodules. Our findings, supported by comparisons with existing literature, shed light on the role of DW-MRI as a valuable imaging modality in thyroid nodule evaluation. Our study revealed that DW-MRI exhibited a robust ability to differentiate between benign and malignant thyroid lesions, as evidenced by the significantly lower mean apparent diffusion coefficient (ADC) values observed in malignant nodules compared to benign ones.

This finding aligns with previous studies conducted by El-Hariri et al., Aghaghazvini et al., Razek et al., Abd el Aziz et al., Erdem et al., Khizer et al., Wu et al., and Wang et al., who similarly reported lower ADC values in malignant thyroid lesions, attributed to increased cellularity and restricted diffusion (Table 5) [11-18]. Our study further corroborates these findings, highlighting the consistency of DW-MRI in capturing tissue microstructural changes associated with thyroid malignancy.

Table 5: Comparison of apparent diffusion coefficient (ADC) values observed in malignant nodules compared to benign ones in various studies

Studies	**Mean ADC values ($\times10^{-3}mm^2/sec$)**		**P value**
	Benign nodule	**Malignant nodule**	
El-Hariri et al.	1.85	0.89	<0.05
Aghaghazvini et al.	1.94±0.54	0.89±0.29	<0.05
Razeket al.	1.8	0.73	<0.05

Abd el Azizet al.	-	-	<0.05
Erdem et al.	2.743	0.695	<0.05
Khizar et al.	1.93	0.94	<0.05
Wu et al.	2.37	1.49	<0.05
Wang et al.	1.95	1.26	<0.05

Moreover, our results demonstrated high sensitivity and specificity of DW-MRI in identifying malignant thyroid nodules, with an overall accuracy approaching 90%. These performance metrics are consistent with those reported in recent studies by Linh et al., Mutlu et al., and Nakahira et al., which collectively underscore the diagnostic utility of DW-MRI in thyroid nodule characterization (Table 6) [19,20,21]. The high negative predictive value observed in our study further emphasizes the potential of DW-MRI to effectively rule out malignancy when imaging findings are negative, thereby reducing the need for unnecessary invasive procedures.

Table 6: Comparison of DW-MRI diagnostic accuracy observed in in various studies

Study	AUC (ROC)	ADC Cut off Value ($\times10^{-3}mm^2/sec$)	Sensitivity	Specificity	Accuracy	NPV	PPV
Linh et al.	90%-94%	<1	87.50%	94.29%	93.02%	-	-
Mutlu et al.	-	1	80%	97%	97%	96%	97%
Nakahira et al.	-	1.6	94.73%	82.60%	88.09%	-	-

The strengths of DW-MRI lie in its ability to provide functional information about tissue microstructure and cellularity, complementing the anatomical detail offered by conventional imaging modalities. Additionally, DW-MRI offers several advantages, including lack of ionizing radiation, multiplanar imaging capabilities, and superior soft tissue contrast. These features make DW-MRI particularly well-suited for evaluating thyroid lesions, especially those located in challenging anatomical locations or in patients with iodine contrast allergies.

Limitations

Despite the promising findings, our study has several limitations that warrant consideration. Firstly, the relatively small sample size may impact the statistical power of the analysis and limit the extrapolation of findings to broader patient populations. Furthermore, variability in imaging protocols and interpretation criteria across different centers may affect the reproducibility and standardization of DW-MRI findings.

Conclusion

In conclusion, our study provides valuable insights into the role of DW-MRI in differentiating benign from malignant thyroid lesions. The high diagnostic accuracy, sensitivity, and specificity observed in our findings support the integration of DW-MRI into routine clinical practice as a non-invasive imaging modality for risk stratification and personalized management of thyroid nodules. Future prospective studies with larger sample sizes and standardized imaging protocols are warranted to further validate the findings and optimize the clinical utility of DW-MRI in thyroid nodule evaluation.

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