

Original Article

Effect of Hashimoto's thyroiditis background on the diagnostic performance of deep fusion ultrasound elastography for benign and malignant thyroid nodules

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Received May 15, 2026; Accepted August 4, 2026; Epub September 15, 2026; Published September 30, 2026

Abstract: Objective: To investigate the effect of Hashimoto's thyroiditis (HT) on deep fusion ultrasound elastography in differentiating benign from malignant thyroid nodules, and to evaluate the predictive value of elastographic data and ultrasound features. Methods: A retrospective analysis was conducted on 362 thyroid nodules (from 328 patients, Jan 2021-Jun 2024), which were divided into training (253) and validation (109) cohorts at a 7:3 ratio. The training set comprised 113 nodules from HT patients and 140 nodules from non-HT patients. Conventional ultrasound and deep fusion elastography were performed. Diagnostic performance was compared against pathology, independent risk factors were identified by logistic regression, and a nomogram was constructed and validated using ROC curves. Results: Baseline characteristics were balanced ($P>0.05$). HT nodules exhibited significantly higher rates of abundant blood flow and ill-defined margins, along with higher elasticity scores (ES), strain ratios (SR), and a higher proportion of microcalcifications ($P<0.001$). The specificity, accuracy, and positive predictive values of elastography were significantly lower in the HT group ($P<0.05$), while sensitivity and negative predictive value were similar. $ES \geq 4.5$, $SR \geq 3.635$, abundant intranodular blood flow, and ill-defined margins were independent malignancy predictors. The combined four-indicator model outperformed any single indicator, and the nomogram demonstrated satisfactory diagnostic performance. Conclusion: Concurrent HT reduces the specificity, accuracy, and positive predictive value of deep fusion elastography. Combining ES, SR, blood flow, and margin features effectively improves differential diagnosis of thyroid nodules in HT patients.

Keywords: Hashimoto's thyroiditis, deep fusion ultrasound elastography, thyroid nodules, benign-malignant differentiation, elastic parameters

Introduction

Thyroid nodules are common lesions seen in clinical endocrinology and ultrasound departments, caused by abnormal proliferation of thyroid cells, and they represent a frequent comorbidity in patients with Hashimoto's thyroiditis (HT) [1, 2]. HT is an autoimmune thyroid disease that can lead to hypothyroidism [3]. Due to the varied clinical presentations and complex sonographic features of thyroid nodules in the context of HT, definitive qualitative diagno-

sis of these nodules remains difficult [4]. In clinical screening and diagnosis of thyroid nodules, ultrasound has become the preferred imaging method due to its noninvasive nature, convenience, and repeatability [5]. However, conventional ultrasound can assess only morphologic features of nodules such as shape, size and margin, and has considerable limitations in distinguishing benign from malignant lesions, particularly for atypical nodules [6]. Therefore, identifying diagnostic methods that can achieve early and accurate differentiation

of benign and malignant thyroid nodules has become a major focus of clinical diagnosis and treatment research.

Deep fusion ultrasound elastography is an emerging ultrasound method that has shown promise in differentiating benign from malignant thyroid nodules [7]. This technique overcomes the spatial resolution limitations of conventional elastography. By integrating information from conventional ultrasound and elastography, it enables quantitative assessment of nodule stiffness, effectively compensating for the shortcomings of conventional ultrasound imaging [8]. However, systematic studies on the underlying mechanisms, the effect on diagnostic efficacy, and optimization strategies for this fusion technique in the context of HT remain limited. To date, no consensus has been reached on whether HT-induced abnormal stiffness of the thyroid parenchyma interferes with the quantitative elastographic assessment of nodule stiffness and further impairs diagnostic accuracy.

Against this background, this study retrospectively analyzed clinical and imaging data from patients with thyroid nodules with and without HT, explored the effect of HT background on the diagnostic performance of deep fusion ultrasound elastography in differentiating benign from malignant thyroid nodules, and evaluated the predictive value of relevant elastic data and ultrasonic features for malignant thyroid nodules, to provide a reference for improving diagnostic accuracy in this patient population.

Materials and methods

Study subjects

Patients with thyroid nodules treated in Lanzhou City No.2 People's Hospital from January 2021 to June 2024 were enrolled as study subjects. The difference in diagnostic specificity between the two groups was used as the primary outcome measure, and the sample size calculation formula for comparison of two independent sample proportions was adopted:

$$n = \frac{[Z_{1-\alpha/2} \sqrt{2\bar{p}(1-\bar{p})} + Z_{1-\beta} \sqrt{p_1(1-p_1) + p_2(1-p_2)}]^2}{(p_1 - p_2)^2}$$

The significance level was set at $\alpha=0.05$ (two-sided), with the corresponding standard normal quantile $Z_{1-\alpha/2}=1.96$; the statistical power was set at $1-\beta=0.80$, with the corresponding

$Z_{1-\beta}=0.84$. Referring to previous similar studies on ultrasound elastography for differentiating thyroid nodules under HT background, the diagnostic specificity was preset as $P_1=0.92$ in the non-HT group and $P_2=0.70$ in the HT group, with a between-group rate difference of 0.22; the pooled proportion $\bar{p}=(P_1+P_2)/2=0.81$. Substitution into the formula showed that at least 46 nodules were required for each group, with a total of 92 nodules for both groups. After accounting for an estimated 10% rate of case exclusion or missing data, the minimum required total sample size was 102 nodules. In this study, 328 patients with 362 thyroid nodules were finally included.

The final sample size substantially exceeded the minimum requirement, indicating sufficient statistical power to stably detect the prespecified between-group effect difference. Stratified random sampling was adopted in this study. A random allocation sequence was generated using SPSS 26.0 software, and all cases were divided into a training set (230 patients with 253 thyroid nodules) and a validation set (98 patients with 109 thyroid nodules) at a ratio of 7:3. The training set was further divided into an HT group and a non-HT group according to the presence of concurrent HT. There were 102 patients with 113 nodules in the HT group and 128 patients with 140 nodules in the non-HT group. The validation set contained 44 patients with 51 nodules in the HT subgroup and 54 patients with 58 nodules in the non-HT subgroup. This study was approved by the Lanzhou City No.2 People's Hospital Ethics Committee.

Inclusion criteria: (1) All patients underwent conventional ultrasound and deep fusion ultrasound elastography before intervention, with complete imaging records; (2) Age ≥ 18 years; (3) All nodules were pathologically confirmed as benign or malignant by surgical resection or fine-needle aspiration cytology (FNAC); for nodules diagnosed as benign by FNAC alone, occult malignancy was ruled out by ≥ 12 months of sonographic follow-up; (4) Complete thyroid autoantibody assays and baseline ultrasound data were available; (5) Intact clinical and follow-up records.

Exclusion criteria: (1) Previous thyroid surgery or neck radiotherapy; (2) Severe comorbidities such as hyperthyroid crisis or distant metastatic thyroid cancer; (3) Prior local intrathyroidal

Hashimoto background affects thyroid elastography diagnosis

drug injection or ablation therapy before examination; (4) Suboptimal image quality precluding reliable elasticity measurement; (5) Concurrent autoimmune disorders including systemic lupus erythematosus or rheumatoid arthritis; (6) Uncontrolled hyperthyroidism or hypothyroidism; (7) Long-term use of medications known to alter thyroid tissue stiffness (e.g., glucocorticoids, amiodarone).

Diagnostic criteria for Hashimoto's thyroiditis

HT diagnosis was established based on the following criteria: Clinical diagnosis (primary reference): Fulfillment of both serological and imaging criteria: Elevated serum anti-thyroid peroxidase antibody (TPOAb) and/or anti-thyroglobulin antibody (TgAb) above the upper laboratory reference limit; Typical diffuse sonographic features of HT, including diffusely reduced and heterogeneous parenchymal echogenicity with or without reticular hyperechoic striations, with or without glandular enlargement.

Pathologic diagnosis (supplementary reference): Histopathologic confirmation of classic HT features in surgical specimens, including dense lymphocytic infiltration, follicular architecture destruction, and interstitial fibrosis.

Two sonographers with ≥ 5 years of experience in thyroid imaging independently reviewed all ultrasound scans in a blinded manner, and one endocrinologist verified serum antibody results. Cases meeting both serological and sonographic criteria were assigned to the HT group; those meeting only one or neither criterion were allocated to the non-HT group. Discrepancies between readers were resolved by a senior radiologist at the associate chief physician level or above to ensure grouping consistency.

Outcome measures

(1) General clinical data: Baseline characteristics of all patients were collected, including age, sex, maximum nodule diameter (MND), thyroid antibody levels, and other relevant indicators.

(2) Sonographic features: Nodule characteristics were documented for both groups, including size, morphology, echogenicity, margin definition, vascularity, and calcification pattern. Calcifications were categorized as microcalcification, coarse calcification, or absent. Microcalcification was defined as punctate hyper-

echoic foci < 1 mm in diameter without posterior acoustic shadowing; coarse calcification was defined as hyperechoic foci ≥ 1 mm with posterior acoustic shadowing.

(3) Elasticity score and strain ratio: Elasticity score and strain ratio values were recorded for each lesion. ES was graded according to a 5-point scale: 1: uniformly green; 2: predominantly green with minor blue areas; 3: equal green and blue; 4: predominantly blue; 5: uniformly blue.

SR was measured by comparing the stiffness of each nodule with that of adjacent normal thyroid parenchyma. Each measurement was repeated three times, and the mean value was adopted as the final result.

(4) Diagnostic performance indicators: Histopathologic results of surgically resected specimens were used as the gold standard. The sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV) of deep fusion ultrasound elastography in differentiating benign and malignant thyroid nodules were calculated accordingly.

Statistical analysis

SPSS 26.0 statistical software was used for data analysis. The measured data were expressed as mean $\pm$ standard deviation ($\bar{x} \pm s$), and the independent sample t test was used for the comparison between the two groups; The counted data were expressed in rate (%), and χ^2 test was used for comparison between groups. Taking pathologic results as the gold standard, the sensitivity, specificity, accuracy, PPV, and NPV of deep fusion ultrasound elastography in the diagnosis of malignant thyroid nodules in the two groups were calculated. The objective was to explore the independent risk factors of malignant thyroid nodules by multivariate logistic regression analysis, and draw the nomogram and ROC curve to analyze the diagnostic efficiency of each factor for malignant thyroid nodules. A difference was significant if $P < 0.05$.

Results

Baseline characteristics and ultrasound indexes in training and validation sets

No statistically significant differences in baseline characteristics were observed between the

Table 1. Comparison of baseline data between the training and validation sets [n (%), $\bar{x} \pm s$]

	Training set (n=230)	Validation set (n=98)	t/χ^2	P
Age (yr)	42.24 $\pm$ 4.36	42.23 $\pm$ 4.26	0.019	0.985
Sex			0.558	0.455
Male	100 (43.5)	47 (48.0)		
Female	130 (56.5)	51 (52.0)		
BMI (kg/m ²)	23.62 $\pm$ 2.11	23.65 $\pm$ 2.09	0.118	0.906
MND (mm)	15.21 $\pm$ 3.51	15.23 $\pm$ 3.39	0.048	0.962
Hyperlipidemia			0.990	0.804
Isolated TPOAb positivity	74 (32.2)	33 (33.7)		
Isolated TgAb positivity	44 (19.1)	17 (17.3)		
Double positive	97 (42.2)	44 (44.9)		
Double negative	15 (6.5)	4 (4.1)		

Notes: MND, maximum nodule diameter; BMI, body mass index; TPOAb, anti-thyroid peroxidase antibody; TgAb, anti-thyroglobulin antibody.

Table 2. Comparison of ultrasound-related indicators between the training and validation sets [n (%)]

	Training set (n=253)	Validation set (n=109)	χ^2	P
Nodule size			0.005	0.945
≤ 10 mm	78 (30.8)	34 (31.2)		
> 10 mm	175 (69.2)	75 (68.8)		
Nodule morphology			0.003	0.959
Regular	54 (21.3)	23 (21.1)		
Irregular	199 (78.7)	86 (78.9)		
Nodule echogenicity			0.276	0.599
Hypoechoogenicity	112 (44.3)	45 (41.3)		
Hyperechoogenicity	141 (55.7)	64 (59.7)		
Nodule vascularity			1.638	0.201
Poor	184 (72.7)	72 (66.1)		
Abundant	69 (27.3)	37 (33.9)		
Nodule margin			0.603	0.438
Well-defined	182 (71.9)	74 (67.9)		
Ill-defined	71 (28.1)	35 (32.1)		
Calcification pattern			0.155	0.926
Microcalcification	82 (32.4)	37 (33.9)		
Coarse calcification	31 (12.3)	12 (11.0)		
No calcification	140 (55.3)	60 (55.0)		

training and validation sets, including age, sex, MND or thyroid antibody levels ($P > 0.05$, **Table 1**). Similarly, there were no significant inter-group differences in ultrasound-related features of thyroid nodules, such as nodule size, morphology, echogenicity, margin, blood flow signal or calcification pattern ($P > 0.05$, **Table 2**).

fically, of the 113 nodules in the HT group, 53 (46.9%) were malignant and 60 (53.1%) benign; among 140 nodules in the non-HT group, 57 (40.7%) were malignant and 83 (59.3%) benign. The proportion of malignant nodules showed no significant difference between the two groups ($\chi^2 = 0.974$, $P = 0.374$).

Baseline clinical data of patients in HT and Non-HT groups

Baseline demographic and clinical characteristics, including age, sex, MND, and thyroid antibody levels, were comparable between the HT group and non-HT group, with no significant differences detected ($P > 0.05$, **Table 3**).

Comparison of ultrasound features between the two groups

Nodule size, morphology and internal echogenicity showed no significant differences between the HT group and non-HT group ($P > 0.05$). However, the proportion of nodules with abundant blood flow and ill-defined margins and calcification pattern was significantly higher in the HT group than in the non-HT group ($P < 0.05$; **Table 4**).

Comparison of elastographic data of thyroid nodules between the two groups

Both the ES and SR were significantly higher in the HT group than in the non-HT group ($P < 0.001$, **Table 5**).

Sensitivity, specificity, accuracy, PPV, and NPV between the two groups

Among the 253 thyroid nodules in the training set, 110 (43.5%) were pathologically confirmed as malignant and 143 (56.5%) as benign. Specifi-

Table 3. Comparison of baseline data between the HT and non-HT groups [n (%), $\bar{x} \pm s$]

	HT group (n=102)	Non-HT group (n=128)	t/χ^2	<i>P</i>
Age (yr)	42.40±4.55	42.11±4.21	0.501	0.617
Sex			0.395	0.530
Male	42 (41.2)	58 (45.3)		
Female	60 (58.8)	70 (54.7)		
BMI (kg/m ²)	23.68±2.03	23.58±2.17	0.393	0.695
MND (mm)	15.26±1.38	15.15±4.55	0.236	0.814
Antibody levels			0.444	0.931
Isolated TPOAb positivity	32 (31.4)	42 (32.8)		
Isolated TgAb positivity	18 (17.6)	26 (20.3)		
Double positive	45 (44.1)	52 (40.6)		
Double negative	7 (6.9)	8 (6.3)		

Notes: HT, Hashimoto's thyroiditis; MND, maximum nodule diameter; BMI, body mass index; TPOAb, anti-thyroid peroxidase antibody; TgAb, anti-thyroglobulin antibody.

Table 4. Comparison of ultrasound-related indicators between the HT and non-HT groups [n (%)]

	HT group (n=113)	Non-HT group (n=140)	χ^2	<i>P</i>
Nodule size			0.145	0.885
≤10 mm	31 (27.4)	47 (33.6)		
>10 mm	82 (72.6)	93 (66.4)		
Nodule morphology			1.435	0.231
Regular	28 (24.8)	26 (18.6)		
Irregular	85 (75.2)	114 (81.4)		
Nodule echogenicity			0.266	0.606
Hypoechoogenicity	48 (42.5)	64 (45.7)		
Hyperechoogenicity	65 (57.5)	70 (54.3)		
Nodule vascularity			55.270	<0.001
Poor	56 (52.0)	128 (91.4)		
Abundant	57 (48.0)	12 (8.6)		
Nodule margin			42.965	<0.001
Well-defined	58 (52.0)	124 (50.0)		
Ill-defined	55 (48.0)	16 (50.0)		
Calcification pattern			35.940	<0.001
Microcalcification	58 (51.3)	24 (17.1)		
Coarse calcification	14 (12.4)	17 (12.1)		
No calcification	41 (36.3)	99 (70.7)		

Note: HT, Hashimoto's thyroiditis.

In the diagnosis of malignant thyroid nodules using deep fusion ultrasound elastography, the specificity, accuracy, and positive predictive value (PPV) of the non-HT group were significantly higher than those of the HT group ($P<0.05$), whereas no significant differences

were found in sensitivity or negative predictive value (NPV) between the two groups ($P>0.05$, **Table 6**).

Univariate analysis for malignant thyroid nodules

Nodule size, morphology, and internal echogenicity did not differ significantly between the malignant group and benign group ($P>0.05$). The malignant group exhibited a higher proportion of nodules with abundant blood flow, and ill-defined margins and calcification pattern accompanied by significantly higher ES and SR values compared with the benign group ($P<0.05$, **Table 7**).

Independent risk factors for malignant nodules

Variables with significant differences by univariate analysis were assigned coded values as shown in **Table 8**, followed by multivariate logistic regression analysis. As presented in **Table 9**, Elasticity Score ≥ 4.5 , Strain Ratio ≥ 3.635 , abundant intranodular vascularity and ill-defined nodular margin were identified as independent risk factors for malignant thyroid nodules.

Nomogram analysis

The nomogram constructed for the training set (**Figure 1A**) visualized the contribution weights of Elasticity Score, Strain Ratio, intranodular vascularity, and nodular margin for predicting malignant thyroid nodules. The calibration curve for the training set (**Figure 1B**)

showed good agreement between the model-predicted probability of malignancy and the actual observed probability, indicating favorable calibration of the four-indicator model. The nomogram and calibration curve for the validation set (**Figure 1C** and **1D**) yielded consistent

Table 5. Comparison of SR values and nodule elasticity parameters of thyroid nodules between the HT and non-HT groups ($\bar{x} \pm s$)

Group	n	Elasticity Score	Strain Ratio
HT group	113	4.45±0.50	3.64±0.42
Non-HT group	140	3.89±0.39	3.35±0.31
<i>t</i>		10.008	6.313
<i>P</i>		<0.001	<0.001

Note: HT, Hashimoto's thyroiditis.

results, confirming stable calibration performance of the model in the independent cohort.

ROC curve analysis

Results of the ROC curve analysis are presented in **Table 10** and **Figure 2**. In the training set (**Figure 2A**), Elasticity Score, Strain Ratio, intranodular vascularity, and nodular margin all exhibited favorable discriminative ability for malignant thyroid nodules. The four-indicator combined model achieved a significantly higher area under the curve (AUC) than any single measurement, demonstrating superior diagnostic performance. Consistent findings were observed in the validation set (**Figure 2B**): each individual indicator maintained satisfactory diagnostic value, and the combined model still outperformed all single indicators in terms of discriminative efficacy.

Discussion

Accurate differentiation between benign and malignant thyroid nodules is a cornerstone of clinical thyroid disease management [9]. In the setting of Hashimoto's thyroiditis (HT), ongoing destruction of thyroid follicular epithelium, extensive lymphocytic infiltration, interstitial fibrosis, and follicular regeneration lead to diffusely heterogeneous parenchymal echogenicity and increased glandular stiffness, which substantially complicates the differentiation of benign from malignant nodules [10, 11]. Deep fusion ultrasound elastography combines morphologic assessment from conventional ultrasound with quantitative stiffness measurement, providing a comprehensive reflection of nodule biological properties [12, 13]. We retrospectively analyzed patients with thyroid nodules with and without concurrent HT to identify independent risk factors for malignant thyroid lesions. Our findings are discussed below in light of existing evidence.

Our results showed that both ES and SR of nodules were significantly higher in the HT group than in the non-HT group, consistent with findings from Yang et al. [14] and Shingare et al. [15], who investigated the diagnostic performance of ultrasound elastography under HT-related interference and for differentiating thyroid nodules, respectively. These findings support that pathological stiffening of the thyroid parenchyma is a key factor interfering with quantitative elastography assessment. The underlying mechanism may be as follows: Deep fusion ultrasound elastography quantifies nodule stiffness by integrating morphologic information from conventional ultrasound with stiffness data from elastography, and its diagnostic accuracy for benign-malignant differentiation relies on the stiffness contrast between the nodule and adjacent normal thyroid parenchyma [16, 17]. In patients with HT, chronic inflammation induces diffuse fibrosis of the thyroid parenchyma, which globally elevates background tissue stiffness. This narrows the stiffness contrast between benign nodules and the surrounding parenchyma, leading to falsely elevated stiffness readings in some benign nodules and thus increasing the false-positive rate [18, 19]. Accordingly, the diagnostic specificity and accuracy were significantly lower in the HT group than in the non-HT group in this study. Multivariate logistic regression analysis further confirmed that both ES and SR were independent risk factors for predicting malignant thyroid nodules, with SR showing better diagnostic performance than ES. This is because both measurements have a favorable ability to identify malignant nodules in the setting of HT, but the quantitative SR measurement provided by deep fusion ultrasound elastography reduces subjective interpretation bias and reflects the true stiffness characteristics of nodules more accurately than the qualitative ES scale [20, 21]. For clinical diagnosis of patients with HT, prioritizing quantitative SR values over simple qualitative scoring may help reduce diagnostic errors caused by background stiffness interference.

Our study also demonstrated that abundant intranodular vascularity and ill-defined margins represent additional independent risk factors for malignant thyroid nodules, and the proportions of both features were significantly higher in the HT group than in the non-HT group. These findings are consistent with those of Lai et al.

Table 6. Comparison of sensitivity, specificity, accuracy, PPV, and NPV between the HT and non-HT groups

Group	n	Sensitivity	Specificity	Accuracy	PPV	NPV
HT group	113	90.6 (48/53)	73.3 (44/60)	81.4 (92/113)	75.0 (48/64)	89.8 (44/49)
Non-HT group	140	93.0 (53/57)	94.0 (78/83)	93.6 (131/140)	91.4 (53/58)	95.1 (78/82)
<i>t</i>		0.214	11.844	8.840	5.728	1.360
<i>P</i>		0.644	<0.001	0.002	0.017	0.244

Notes: HT, Hashimoto's thyroiditis; PPV, positive predictive value; NPV, negative predictive value.

Table 7. Univariate analysis of factors affecting the diagnosis of malignant nodules [n (%), $\bar{x} \pm s$]

	Malignant group (n=110)	Benign group (n=143)	<i>t</i> / χ^2	<i>P</i>
Nodule size			0.063	0.802
≤ 10 mm	33 (30.0)	45 (31.5)		
> 10 mm	77 (70.0)	98 (68.5)		
Nodule morphology			0.026	0.872
Regular	24 (21.8)	30 (21.0)		
Irregular	86 (78.2)	113 (79.0)		
Nodule echogenicity			0.187	0.665
Hypoechoogenicity	47 (42.7)	65 (45.5)		
Hyperechoogenicity	63 (57.3)	78 (54.5)		
Nodule vascularity			54.817	<0.001
Poor	54 (49.1)	130 (90.9)		
Abundant	56 (50.9)	13 (9.1)		
Nodule margin			54.400	<0.001
Well-defined	53 (48.2)	129 (90.2)		
Ill-defined	57 (51.8)	14 (9.8)		
Elasticity Score	4.41 $\pm$ 0.51	3.94 $\pm$ 0.43	7.945	<0.001
Strain Ratio	3.69 $\pm$ 0.37	3.32 $\pm$ 0.32	8.515	<0.001
Calcification pattern			31.180	<0.001
Microcalcification	56 (50.9)	26 (18.2)		
Coarse calcification	12 (10.9)	19 (13.3)		
No calcification	42 (38.2)	98 (68.5)		

Table 8. Assignment of influence factors

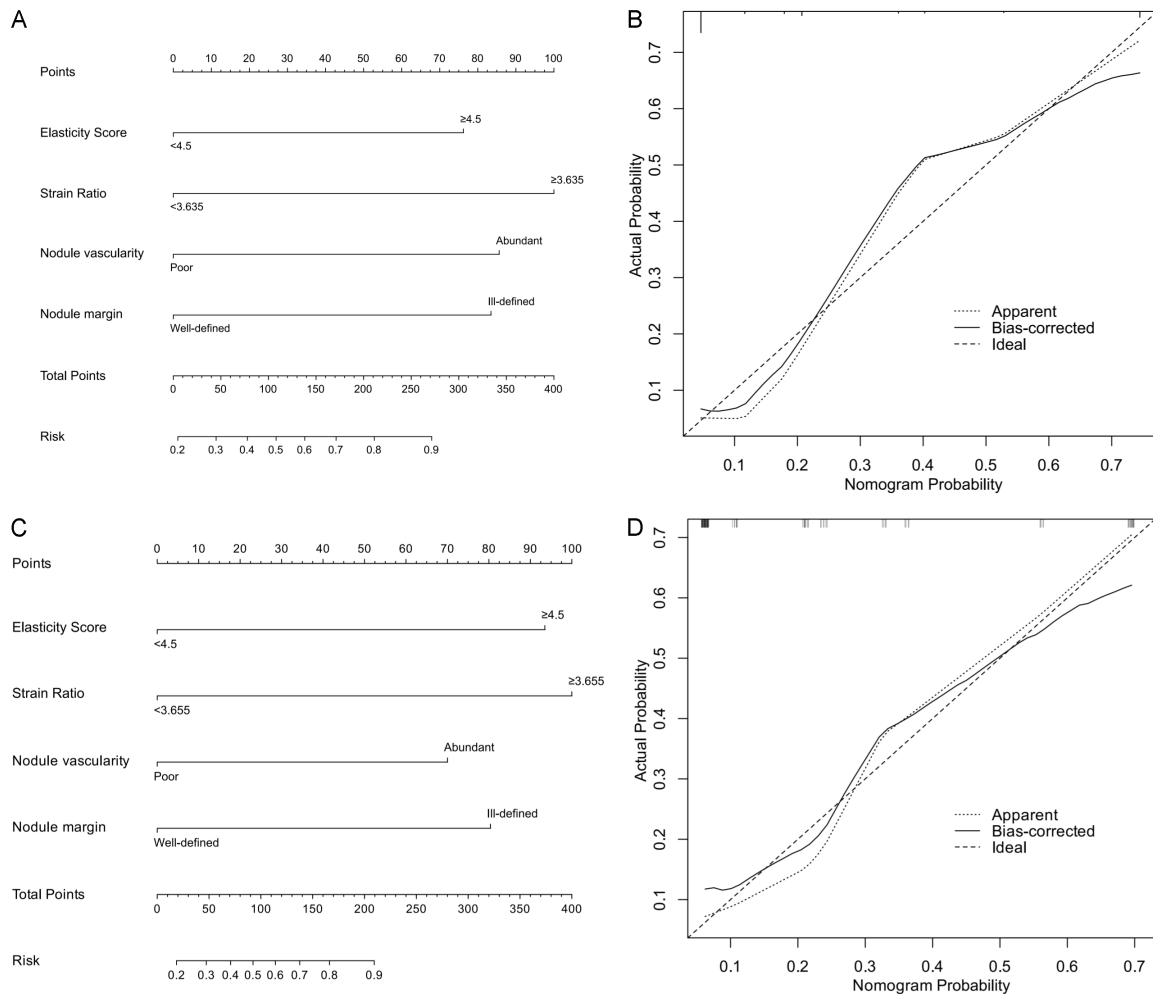
Influencing Factor	Assignment
Elasticity Score	0: <4.5 1: ≥ 4.5
Strain Ratio	0: <3.635 1: ≥ 3.635
Nodule vascularity	0: Poor 1: Abundant
Nodule margin	0: Well-defined 1: Ill-defined
Calcification pattern	0: Coarse calcification & No calcification 1: Microcalcification

[22], who investigated the effect of Hashimoto's thyroiditis on ultrasound-guided radiofrequency ablation for papillary thyroid microcarcinoma, and with the results reported by Chen et al. [23]. From a pathologic perspective, two distinct mechanisms account for ill-defined margins. True margin blurring arises from invasive malignant growth, where tumor cells infiltrate the surrounding thyroid parenchyma, typically appearing as spiculated or irregular borders on ultrasound. In contrast, inflammatory infiltration produces benign pseudoblurring, caused by perinodular lymphocytic infiltration, interstitial edema and fibrosis that obscure the echogenic interface. This pattern usually presents as diffuse, halo-like ill-defined margins, accompanied by globally coarse, reticular parenchymal echogenicity and without evident spiculation [24, 25]. On conventional ultrasound, these two patterns show substantial imaging overlap, particularly in patients with moderate to severe HT. Furthermore, chronic inflammation in HT stimulates glandular vascular proliferation, leading to increased overall perfusion and rich vascular signals even in benign nodules, which contributes to the misclassification of benign lesions as malignant.

Table 9. Multivariate logistic regression analysis of factors affecting the diagnosis of malignant nodules

Factor	β	Std Error	Wald χ^2	P	OR	95% CI	
						Lower	Upper
Elasticity Score ≥ 4.5	1.024	0.481	4.525	0.033	2.784	1.084	7.153
Strain Ratio ≥ 3.635	1.344	0.369	13.279	<0.001	3.833	1.861	7.895
Nodule vascularity: Abundant	1.150	0.427	7.268	0.007	3.159	1.369	7.290
Nodule margin: Ill-defined	1.121	0.415	7.292	0.007	3.069	1.360	6.927
Calcification pattern: Microcalcification	0.412	0.358	1.324	0.250	1.510	0.748	3.047

Notes: β , regression coefficient; Std Error, standard error; Wald χ^2 , Wald chi-square statistic; OR, odds ratio; 95% CI, 95% confidence interval. Variables with $P < 0.10$ in univariate analysis were entered into the stepwise Logistic regression model.

**Figure 1.** Construction and diagnostic performance of the nomogram model. A. Nomogram for training set; B. Calibration curve for validating the nomogram in the training set; C. Nomogram for validation set; D. Calibration curve for validating the nomogram in the validation set.

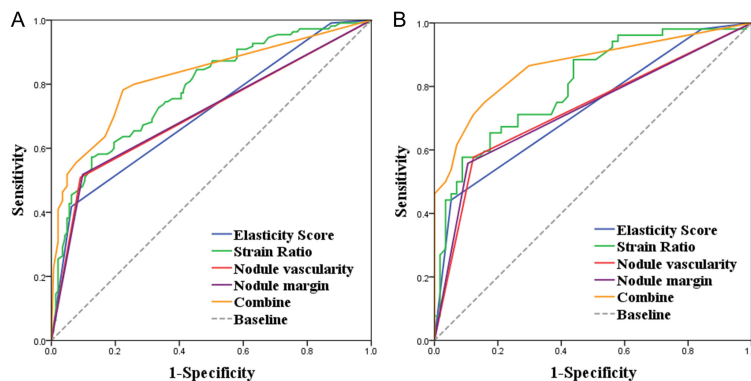
We further constructed a combined diagnostic model incorporating ES, SR, intranodular vascularity, and margin features, and validated its diagnostic value using nomograms and ROC curves. The results showed that the AUC of the

combined model was significantly higher than that of any single indicator. Calibration curves in both the training and validation cohorts indicated good model fit and stable individualized predictive performance. The underlying rea-

Table 10. ROC curve analysis for various risk factors in predicting malignant nodules

	Training set		Validation set	
	AUC	95% CI	AUC	95% CI
Elasticity Score	0.710	0.645-0.775	0.730	0.635-0.824
Strain Ratio	0.783	0.726-0.840	0.806	0.724-0.887
Nodule vascularity	0.709	0.642-0.776	0.727	0.629-0.825
Nodule margin	0.710	0.642-0.776	0.726	0.628-0.824
Combine	0.820	0.766-0.875	0.865	0.794-0.935

Notes: ROC, receiver operating characteristic; AUC, area under the curve; 95% CI, 95% confidence interval. The combined model integrates elasticity score, strain ratio, nodule vascularity and nodule margin.

**Figure 2.** ROC curves for various risk factors in predicting malignant nodules. A. Training set; B. Validation set.

sons are as follows: HT-induced global stiffening of the thyroid parenchyma narrows the stiffness difference between benign and malignant nodules, making single elasticity measurements prone to false-positive results [26]; meanwhile, the imaging overlap of ill-defined margins and rich vascularity between HT-related inflammation and malignant biology increases interpretation errors when relying solely on morphological features. Combining quantitative SR, qualitative ES, and morphologic features can simultaneously counteract background stiffness interference and imaging overlap, achieve multi-dimensional information complementarity, and substantially improve diagnostic performance [27]. These findings address the diagnostic limitations of stand-alone deep fusion ultrasound elastography in the setting of HT. They confirm that multiparametric fusion assessment is an effective strategy to resolve diagnostic challenges in thyroid nodules with concurrent HT, substantially reduce false-positive rates, thereby providing more reliable imaging evidence for clinical decision-making.

Several limitations of this study should be acknowledged. First, this was a single-center retrospective study with a limited sample size, which may have introduced a certain degree of selection bias. Second, elasticity parameters were measured independently by two physicians, and minor subjective measurement bias cannot be completely eliminated. Third, other ultrasound elastography techniques such as shear wave elastography were not compared in this study, thus the diagnostic differences between various elastography modalities in the setting of HT remain unclear. Future multi-center prospective studies with larger sample sizes are warranted to perform stratified analyses incorporating clinical data such as thyroid function and disease duration. If feasible, automated measurement techniques should be adopted to optimize the elasticity parameter measurement workflow,

further refine the diagnostic system for thyroid nodules under a HT background, and enhance the objectivity of research findings.

In conclusion, concurrent HT interferes with the differentiation of benign from malignant thyroid nodules on deep fusion elastography by inducing diffuse parenchymal sclerosis and superimposing inflammation-related sonographic features, which mainly reduces diagnostic specificity and accuracy. ES, SR, intranodular vascularity and ill-defined margins are independent risk factors for malignant nodules. Combined assessment of these four indicators can effectively counteract the interference of HT background, significantly improve diagnostic accuracy, and provide important practical evidence for optimizing the clinical ultrasound diagnostic workflow for thyroid nodules complicated with HT.

Acknowledgements

This work was supported by Natural Science Foundation of Gansu Province (26JRRA855).

Disclosure of conflict of interest

None.

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