

Predictive US findings for differentiating between malignant and benign thyroid nodules: Doppler and microvascular imaging according to the TI-RADS and pathologic subtypes of malignancy

ULTRASONOGRAPHY

ORIGINAL ARTICLE

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Purpose: This study investigated whether Doppler and microvascular imaging help distinguish malignant from benign thyroid nodules in relation to the Thyroid Imaging Reporting and Data System (TI-RADS) and the pathologic subtype of thyroid malignancy.

Methods: This study included 113 consecutive thyroid nodules from 103 patients with confirmed final diagnoses from February 2022 to September 2022. Two radiologists conducted a retrospective review of ultrasonographic (US) findings and assigned vascular scores by consensus using color Doppler imaging (CDI) and microflow imaging (MFI) on a 4-point visual scale. Vascular scores were compared between malignant and benign nodules and analyzed by US pattern according to the Korean TI-RADS (K-TIRADS).

Results: Of the 113 nodules, 72 were benign and 41 were malignant. All nodules were categorized using the K-TIRADS lexicon, and each lexicon feature (composition, echogenicity, orientation, margin, and calcification) significantly differentiated malignant from benign lesions ($P \leq 0.008$). The CDI score also differed significantly ($P < 0.001$). In subgroup analysis by K-TIRADS pattern, differences in CDI and MFI scores were not observed for low- and intermediate-suspicion nodules, whereas in high-suspicion nodules benign lesions had higher CDI and MFI scores than malignant ones ($P = 0.018$ and $P = 0.051$, respectively). Classic papillary thyroid carcinoma showed lower vascular scores on both CDI and MFI, while the follicular variant showed higher scores ($P = 0.075$ and $P = 0.007$, respectively).

Conclusion: CDI and MFI may assist in distinguishing between malignant and benign nodules, and evaluation of nodular vascularity may be tailored to the TI-RADS category.

Keywords: Doppler imaging; Microvascular imaging; Thyroid nodule; Ultrasonography

Key points: Vascular scores from color Doppler imaging and microflow imaging can aid differentiation between malignant and benign thyroid nodules, particularly among high-suspicion nodules. Classic papillary thyroid carcinoma tends to demonstrate lower vascularity than the follicular variant, implying that subtype-specific Doppler patterns may improve diagnostic accuracy. Incorporating vascular scores into Thyroid Imaging Reporting and Data System may enhance malignancy risk stratification and guide a more tailored ultrasonographic assessment of thyroid cancer.

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Introduction

Ultrasonography (US) is the main imaging method used to evaluate thyroid nodules, and it plays a central role in detection and characterization. It not only helps distinguish malignant from benign lesions but also guides fine-needle aspiration (FNA) when malignancy is suspected [1,2]. Color Doppler imaging (CDI) has been widely used to assess vascular patterns of thyroid nodules, contributing to diagnostic evaluation. Multiple guidelines emphasize that US features and risk stratification systems (RSSs) are useful for estimating malignancy risk in thyroid nodules [3–7]. Although numerous RSSs list US features suggestive of malignancy, there is no consensus on the diagnostic significance of nodular vascularity. The rationale for assessing vascularity derives from the observation that proliferative activity may increase vascularization, which can resemble aberrant angiogenesis associated with malignant transformation [8,9]. Nevertheless, whether thyroid cancers actually show increased Doppler vascularity remains a matter of debate [10]. Because the proportions of pathological cancer subtypes differ among studies, findings regarding nodular vascularity have been inconsistent. The American Thyroid Association guidelines suggest that variability in study outcomes may depend on the proportion of follicular thyroid carcinomas (FTCs) [3–7], since FTCs are highly vascular and tend to metastasize hematogenously, whereas papillary thyroid carcinomas (PTCs) are rich in lymphatic vessels and typically metastasize to lymph nodes [11].

Recently, several US manufacturers have introduced techniques for visualizing blood flow in microvessels, collectively termed microvascular flow imaging (MVFI) [12]. This technology adaptively filters random motion while preserving the directional flow of blood, enabling more sensitive and higher-resolution assessments than conventional color or power Doppler US [12]. In other malignancies, such as hepatocellular carcinoma, tumor angiogenesis and neovascularization make CDI and microflow imaging (MFI)—a specific MVFI technique developed by Philips Healthcare (Eindhoven, Netherlands)—valuable diagnostic tools [13]. However, debates persist regarding whether color flow signals are helpful in differentiating malignant from benign thyroid nodules. Consequently, vascular findings have not been incorporated as consensus diagnostic criteria in various RSSs.

Therefore, this study aimed to determine whether vascular scores obtained using CDI and MFI are useful in distinguishing malignant from benign thyroid nodules and to evaluate the correlation between these scores and the Thyroid Imaging Reporting and Data System (TI-RADS) classification. Additionally, by examining the relationship between vascular scores and the pathological subtypes of malignancy, this study sought to clarify the potential diagnostic role of vascularity in thyroid cancer.

Materials and Methods

Compliance with Ethical Standards

This retrospective study was approved by the institutional review board of Chung-Ang University Hospital (H-2303-028-19465), and the requirement for informed consent was waived.

Patients and Lesions

From February to September 2022, a total of 208 newly detected thyroid nodules were identified in 184 patients who underwent initial FNA or core needle biopsy (CNB) at the authors' institution. Of these, 95 nodules from 81 patients were excluded due to the absence of final diagnostic confirmation. Consequently, 113 consecutive nodules measuring ≥ 0.5 cm from 103 patients (87 women and 26 men; mean age, 51.0 ± 15.1 years) were included in the analysis. Final diagnoses of malignancy were established based on (1) histopathological confirmation from surgical specimens and (2) malignant results on FNA or CNB. Final benign diagnoses were based on (1) histopathological confirmation from surgical specimens, (2) at least two benign results from FNA or CNB, and (3) an initial benign diagnosis on FNA or CNB with no interval growth or with size reduction on follow-up US after at least 12 months. Medical records were also reviewed to assess the presence of diffuse thyroid disease (DTD).

US Examinations and US-Guided Procedures

Conventional US was performed by one of two radiologists with 10 and 8 years of experience in thyroid imaging, respectively. Following B-mode US, patients for whom US-guided FNA was planned underwent CDI and MFI, which were performed by the radiologist with 8 years of thyroid imaging experience using a high-resolution 18-MHz linear transducer (EPIQ 7, Philips Healthcare). B-mode US images were acquired first, with subsequent color Doppler and MFI in both the axial and sagittal planes without repositioning the patient. For each nodule, color MFI focused on the nodule and its focal zone, with scanning depth and time-gain compensation kept constant for optimal visualization. Color gain, scale, and wall filter settings were individually adjusted for each nodule to ensure optimal image quality. For all nodules, sagittal and transverse still images, as well as approximately 10-second cine images, were obtained.

US-guided FNA was performed using a 5-mL syringe to which a 23-gauge needle was attached. Adequate sampling was achieved through multiple passes in different directions across the nodule. Collected specimens were preserved in 95% ethanol for subsequent liquid-based cytology. In cases where cytological results were non-diagnostic or indeterminate, repeat biopsies were performed. US-guided CNB was carried out with a free-hand technique using an 18-gauge dual-action semiautomatic core biopsy needle with a 22-

mm throw. Cytologic and histologic specimens obtained from FNA and CNB were reviewed by an experienced thyroid pathologist with two decades of expertise. FNA results were categorized according to the Bethesda System for Reporting Thyroid Cytopathology [14], whereas CNB findings were interpreted using a six-tiered histopathologic reporting system [15]. When malignancy was diagnosed by FNA or CNB, the specimens were re-reviewed by the pathologist to refine the final diagnosis and determine the pathological subtype.

Data and Statistical Analysis

Two radiologists with extensive experience, blinded to cytology results, reviewed the cine loops and still images of thyroid nodules obtained during the US examinations, including CDI and MFI. Image analyses were performed by consensus between the two reviewers, who had 12 and 10 years of thyroid imaging experience, respectively. In cases of disagreement, the video clips were re-examined until consensus was achieved. After a washout period exceeding one month, the reviewers independently reassessed the CDI and MFI images to evaluate both inter-observer and intra-observer variability. Thyroid nodules on B-mode US were classified according to the latest Korean Thyroid Imaging Reporting and Data System (K-TIRADS) [7]. Vascularity in thyroid nodules was visually assessed on CDI and MFI using a four-point scale based on the scoring system proposed by Chung et al. [16]. Scores of 1–2 generally indicated lower vascularity, while scores of 3–4 indicated higher vascularity. Specifically, a score of 1 represented absent vascularity (no vascularity); a score of 2 indicated circumferential vascularity at the nodule margin (perinodular vascularity only); a score of 3 denoted mild intranodular vascularity with or without perinodular flow (vascularity < 50%); and a score of 4 represented marked intranodular vascularity with or without perinodular flow (vascularity > 50%) (Fig. 1).

Continuous variables that did not follow a normal distribution were presented as medians with interquartile ranges. Categorical variables were expressed as counts and percentages. The Mann-Whitney U test was used to compare continuous variables between malignant and benign nodules. For categorical variables, including vascular scores, comparisons were made using the chi-square test or Fisher exact test. Vascular scores were further analyzed according to K-TIRADS categories and correlated with the pathological subtypes of malignancy. Differences in median vascular scores across K-TIRADS categories for benign and malignant nodules were also evaluated using the Mann-Whitney U test. Data values agreed upon by consensus between reviewers were used for all analyses, while independently assigned scores from each reviewer were assessed using kappa statistics to determine inter- and intra-observer agreement. Statistical analyses were performed using IBM SPSS Statistics for Windows version 22.0 (IBM Corp., Armonk, NY, USA). A P-value < 0.05 was considered

statistically significant.

Results

Among the 113 thyroid nodules analyzed, 72 were benign and 41 were malignant. The lesion diameters on B-mode US ranged from 0.5 cm to 5.6 cm (median, 1.2 cm). Surgical confirmation was obtained for 33 nodules. Among these, malignant lesions consisted of 20 classic PTCs and eight follicular variants of PTC, while benign lesions included four nodular hyperplasias and one follicular adenoma (Table 1). The incidence of DTD was comparable between malignant and benign groups (6.9% [5/72] vs. 7.3% [3/41], respectively) and showed no significant difference between K-TIRADS categories 3/4 and category 5 nodules (7.3% [6/82] vs. 6.7% [2/30], respectively).

Table 2 and Supplementary Table 1 summarize the ultrasonographic findings of thyroid nodules according to the K-TIRADS lexicon. All lexicon features—including composition, echogenicity, orientation, margin, and calcifications—significantly differentiated malignant from benign lesions ($P \leq 0.008$) (Supplementary Table 1). The nodules were classified by K-TIRADS category as follows: category 2 ($n = 1$, 0.9%), category 3 ($n = 39$, 34.5%), category 4 ($n = 43$, 38.1%), and category 5 ($n = 30$, 26.5%). Regarding vascular scores, the CDI score differed significantly between malignant and benign nodules ($P < 0.001$), whereas the MFI score did not show a significant difference ($P = 0.174$). Benign nodules more frequently exhibit-

Table 1. Demographic data of 113 nodules with final diagnoses

Characteristic	Value
Age (year)	49.0 (39.0–62.5)
Sex (female:male)	87:26
Nodule size (cm)	1.2 (0.7–1.9)
Final diagnosis	
Benign	72 (63.7)
Surgery	5 (6.9)
Nodular hyperplasia	4 (5.5)
Follicular adenoma	1 (1.4)
At least 2 benign diagnoses on FNA or CNB	2 (2.8)
A benign result on FNA or CNB with follow-up US	65 (90.3)
Malignancy	41 (36.3)
Surgery	28 (68.3)
Classic PTC	20 (48.8)
Follicular variant PTC	8 (19.5)
Malignant result on FNA or CNB	13 (31.7)
Classic PTC	12 (29.3)
Lymphoma	1 (2.4)

Values are presented as median (IQR) or number (%).

FNA, fine-needle aspiration; CNB, core needle biopsy; US, ultrasonography; PTC, papillary thyroid carcinoma; IQR, interquartile range.

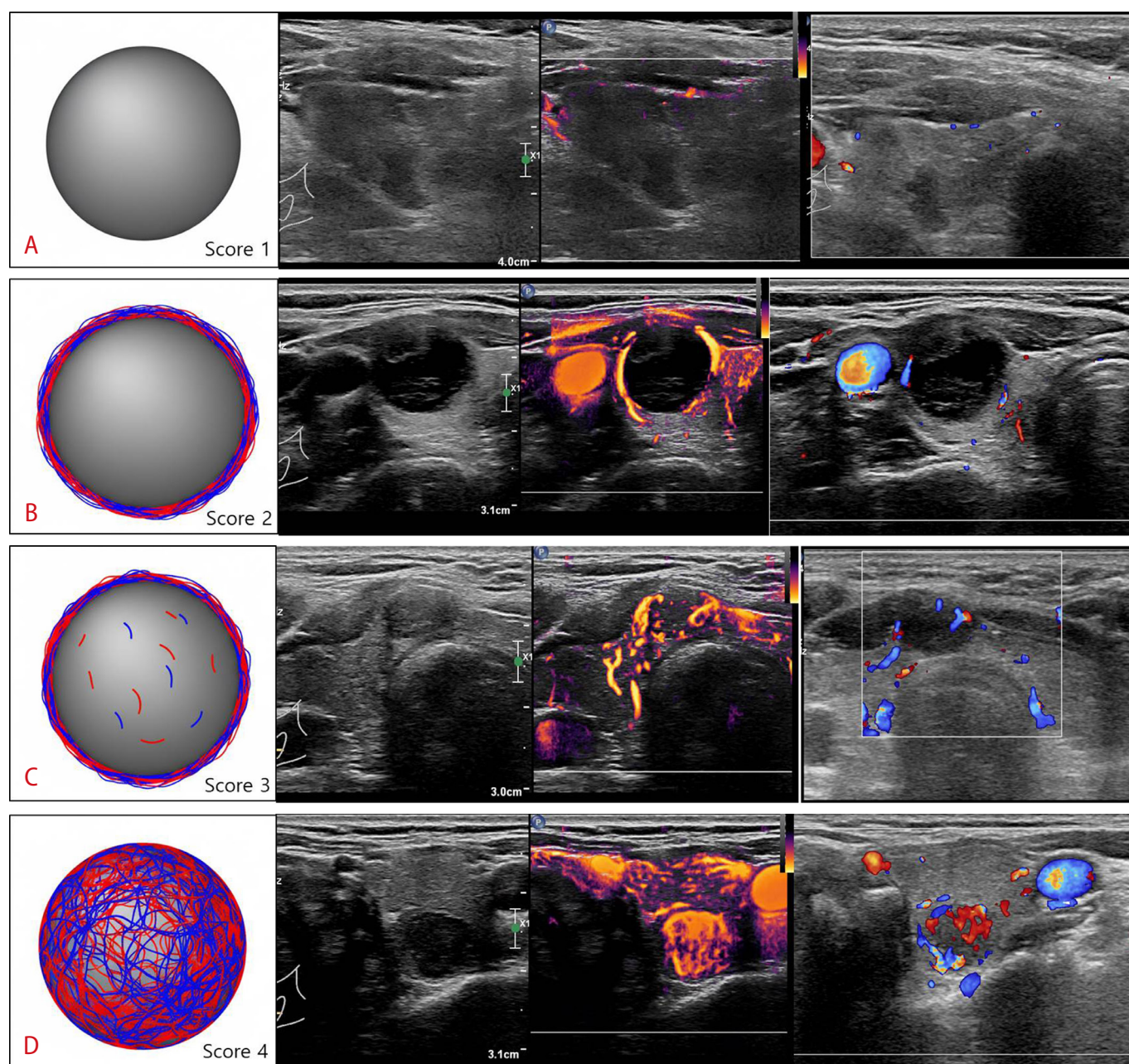


Fig. 1. Representative ultrasonography of thyroid nodules and schematic diagrams corresponding to vascular scores 1 through 4.

A. The nodule demonstrates absence of intranodular vascularity (score 1). **B.** The nodule shows only perinodular vascularity (score 2). **C.** The nodule exhibits mild intranodular vascularity, with or without perinodular flow (score 3). **D.** The nodule exhibits marked intranodular vascularity, with or without perinodular flow (score 4).

ed higher vascular scores (CDI or MFI scores 3–4: 52.8% and 70.8%, respectively) compared with malignant nodules (CDI or MFI scores 3–4: 17.1% and 51.2%, respectively), while malignant nodules more often demonstrated lower vascular scores (Table 2). For the vascular score, both intra-observer and inter-observer variability demonstrated moderate to substantial agreement in CDI and MFI for both reviewers. The intra-observer agreement was $\kappa=0.77$ for re-

viewer 1 and $\kappa=0.79$ for reviewer 2 in CDI, and $\kappa=0.80$ for reviewer 1 and $\kappa=0.79$ for reviewer 2 in MFI. The inter-observer agreement was $\kappa=0.60$ for CDI and $\kappa=0.59$ for MFI.

To further evaluate vascularity, a subgroup analysis was performed according to K-TIRADS categories (Table 3). The vascular scores did not differ significantly between malignant and benign nodules in K-TIRADS categories 3 and 4 ($P>0.05$). However, in K-TIRADS 5

Table 2. Nodule size, vascular scores and K-TIRADS scores of the thyroid nodules (n=113)

Characteristic	Benign (n=72)	Malignancy (n=41)	P-value
Nodule size (cm)	1.5 (0.9–2.4)	0.8 (0.6–1.2)	< 0.001
< 1.0	18 (25.0)	27 (65.9)	
≥ 1.0	54 (75.0)	14 (34.1)	
Color Doppler imaging			< 0.001
Score 1	5 (6.9)	8 (19.5)	
Score 2	29 (40.3)	26 (63.4)	
Score 3	38 (52.8)	7 (17.1)	
Score 4	0	0	
Microflow imaging			0.174
Score 1	2 (2.8)	3 (7.3)	
Score 2	19 (26.4)	17 (41.5)	
Score 3	47 (65.3)	20 (48.8)	
Score 4	4 (5.5)	1 (2.4)	
K-TIRADS			< 0.001
Category 2	1 (1.4)	0	
Category 3	35 (48.6)	4 (9.8)	
Category 4	32 (44.4)	11 (26.8)	
Category 5	4 (5.6)	26 (63.4)	

Values are presented as median (IQR) or number (%).

K-TIRADS, Korean Thyroid Imaging Reporting and Data System; IQR, interquartile range.

nodules, vascular scores differed significantly between malignant and benign lesions ($P=0.018$ for CDI and $P=0.051$ for MFI). The vascular scores were relatively higher in benign nodules than in malignant ones (Fig. 2).

Table 4 presents a comparison of vascular scores according to K-TIRADS categories. K-TIRADS 3 and 4 nodules showed similar vascularity regardless of benign or malignant status. However, malignant nodules classified as K-TIRADS 5 tended to exhibit lower vascularity than benign nodules, in both CDI and MFI ($P=0.012$ and $P=0.070$, respectively) (Fig. 3). In the subgroup analysis of small nodules, K-TIRADS 5 lesions demonstrated similar trends, although the differences did not reach statistical significance ($P=0.091$ for both CDI and MFI) (Supplementary Table 2). In the analysis of vascular scores based on pathologic subtypes of malignancy, classic PTC showed lower vascular scores in both CDI and MFI, whereas the follicular variant of PTC exhibited higher vascular scores ($P=0.075$ and $P=0.007$, respectively). Notably, no vascular score of 1 was observed in the follicular variant of PTC, and no score of 4 was recorded in classic PTC on either CDI or MFI. Despite these trends, the pathologic subtypes of malignancy did not show a significant correlation with K-TIRADS categories ($P=0.406$) (Supplementary Table 3).

Table 3. Vascularity score of thyroid nodules according to the K-TIRADS categories

Characteristics	Benign	Malignancy	P-value
K-TIRADS 3, number	35	4 ^{a)}	
Color Doppler imaging			> 0.999
Score 1	1 (2.9)	0	
Score 2	10 (28.6)	1 (25.0)	
Score 3	24 (68.5)	3 (75.0)	
Score 4	0	0	
Microflow imaging			0.371
Score 1	1 (2.9)	0	
Score 2	6 (17.1)	0	
Score 3	27 (77.1)	3 (75.0)	
Score 4	1 (2.9)	1 (25.0)	
K-TIRADS 4, number	32	11 ^{b)}	
Color Doppler imaging			> 0.999
Score 1	4 (12.5)	1 (9.1)	
Score 2	16 (50.0)	6 (54.5)	
Score 3	12 (37.5)	4 (36.4)	
Score 4	0	0	
Microflow imaging			0.886
Score 1	1 (3.1)	0	
Score 2	11 (34.4)	3 (27.3)	
Score 3	18 (56.3)	8 (72.7)	
Score 4	2 (6.2)	0	
K-TIRADS 5, number	4	26 ^{c)}	
Color Doppler imaging			0.018
Score 1	0	7 (26.9)	
Score 2	2 (50.0)	19 (73.1)	
Score 3	2 (50.0)	0	
Score 4	0	0	
Microflow imaging			0.051
Score 1	0	3	
Score 2	1 (25.0)	14 (53.8)	
Score 3	2 (50.0)	9 (34.6)	
Score 4	1 (25.0)	0	

Values are presented as number (%).

K-TIRADS, Korean Thyroid Imaging Reporting and Data System; PTC, papillary thyroid cancer; FVPTC, follicular variant papillary thyroid cancer.

^{a)}Consists of 2 classic PTC and 2 FVPTC. ^{b)}Consists of 9 classic PTC, 1 FVPTC, and 1 lymphoma. ^{c)}Consists of 21 classic PTC and 5 FVPTC.

Discussion

This study investigated whether vascular scoring could predict thyroid cancer and explored its potential integration into the TI-RADS system to refine malignancy risk assessment. When all nodules were analyzed collectively, benign lesions exhibited higher CDI scores than malignant ones. In contrast, within K-TIRADS categories 3 and 4, there was no meaningful difference in vascularity between malignant and benign nodules. Among K-TIRADS 5 nodules, benign lesions

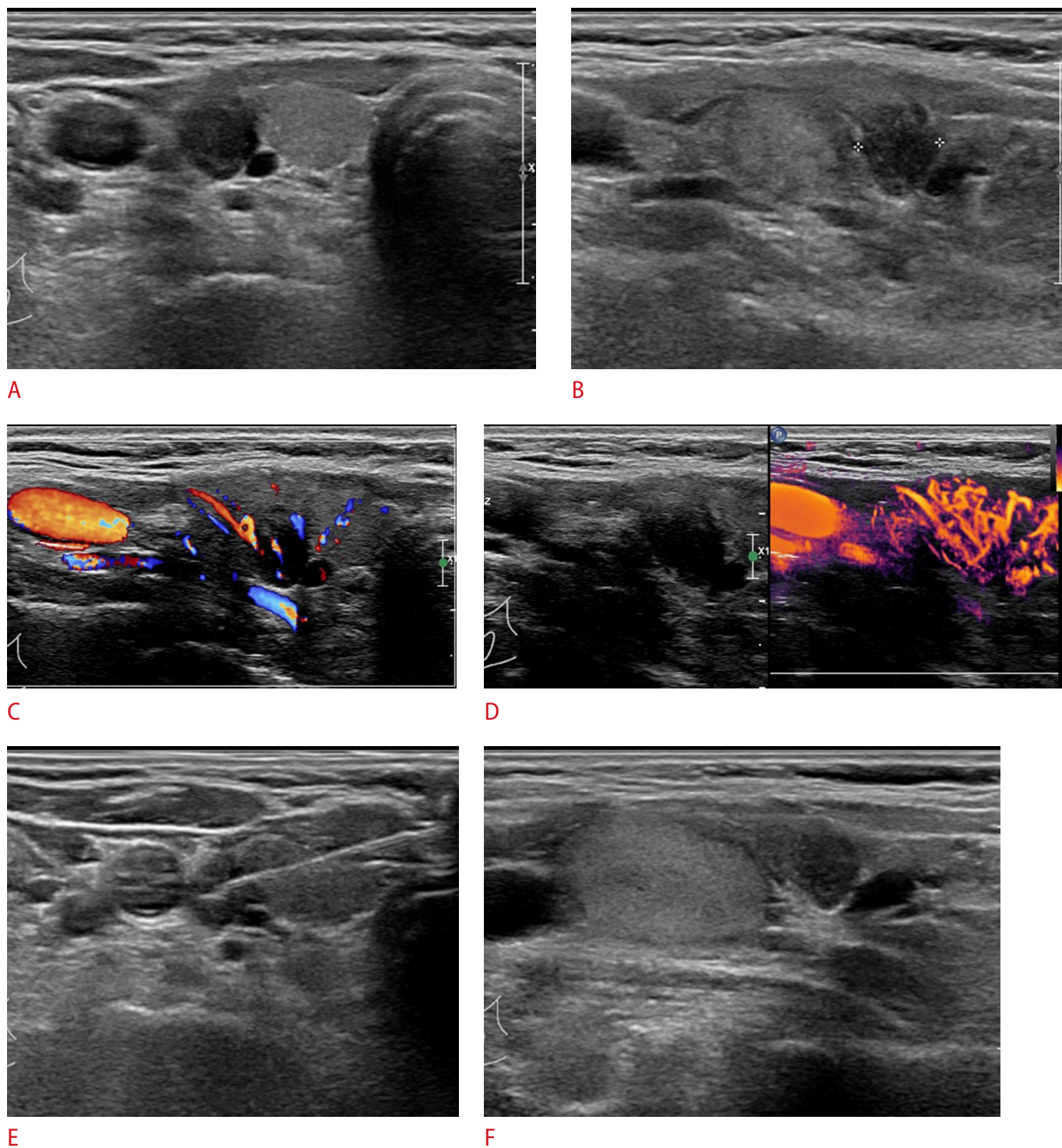


Fig. 2. A 79-year-old female patient with a confirmed benign nodule presenting high-suspicion ultrasonographic features.

A, B. A 0.8-cm nodule with highly suspicious features is identified in the right lower lobe. **C, D.** This nodule is assigned a vascularity score of 3 on color Doppler imaging and 4 on microflow imaging. **E, F.** Fine needle aspiration confirmed the nodule as a benign follicular lesion, with no change observed on follow-up US at 28 months.

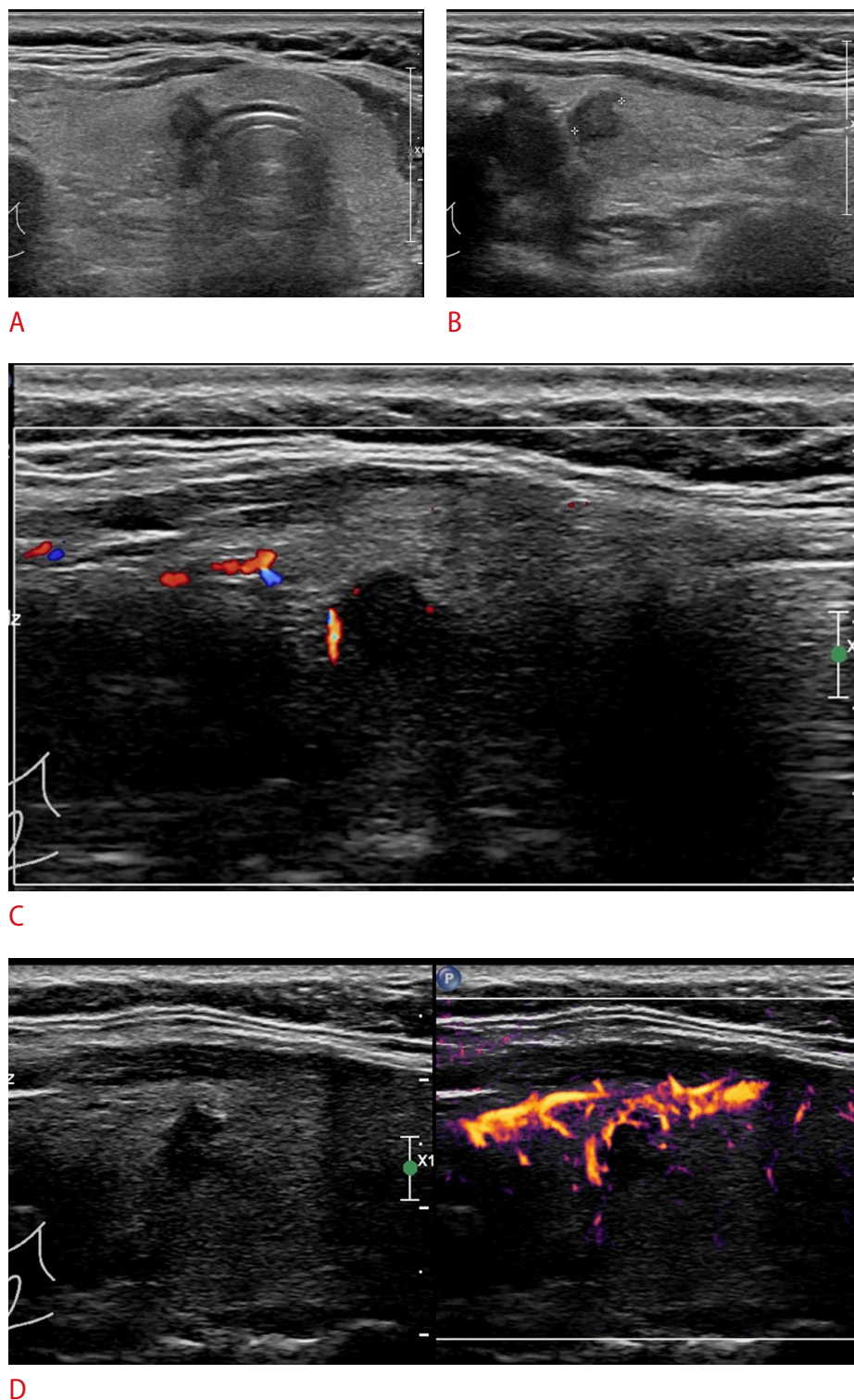


Fig. 3. A 43-year-old female patient with a confirmed malignancy with high-suspicion ultrasonographic features.

A, B. A 0.7-cm nodule with highly suspicious features is observed in the right isthmus. **C, D.** The nodule received a vascularity score of 1 on color Doppler imaging and 2 on microflow imaging. Fine needle aspiration classified the nodule as atypia of undetermined significance with a positive *BRAF* (B-Raf proto-oncogene, serine/threonine kinase) mutation. The patient underwent right lobectomy, and the nodule was confirmed as classic papillary thyroid cancer.

showed higher vascular scores, whereas malignant lesions demonstrated relatively lower values. Within the malignant group, the follicular variant of PTC tended to display higher vascularity than classic PTC. However, the number of nodules in certain subgroups—particularly K-TIRADS 5—was small, limiting statistical power and gener-

alizability. To assess the potential impact of background parenchymal vascularity, we also examined the prevalence of DTD, which can lead to either an increase or a decrease in thyroid gland vascularity, and variations in disease severity may influence the observed vascularity measurements [16]. In this study, the prevalence of DTD did not dif-

Table 4. Comparison of vascular scores according to the K-TIRADS categories

Variable	K-TIRADS 3 or 4 (n = 82)	K-TIRADS 5 (n = 30)
Size (cm)		
Benign (n = 71)	1.5 (0.9–2.4) (n = 67)	1.2 (0.9–1.5) (n = 4)
Malignant (n = 41)	1.2 (0.7–1.7) (n = 15)	0.7 (0.5–0.9) (n = 26)
P-value	0.069	0.058
CDI		
Benign (n = 71)	3.0 (2.0–3.0) (n = 67)	2.5 (2.0–3.0) (n = 4)
Malignant (n = 41)	2.0 (2.0–3.0) (n = 15)	2.0 (1.0–2.0) (n = 26)
P-value	0.676	0.012
MFI		
Benign (n = 71)	3.0 (2.0–3.0) (n = 67)	3.0 (2.25–3.75) (n = 4)
Malignant (n = 41)	3.0 (3.0–3.0) (n = 15)	2.0 (2.0–3.0) (n = 26)
P-value	0.454	0.070

Values are presented as median (IQR).

K-TIRADS, Korean Thyroid Imaging Reporting and Data System; CDI, color Doppler imaging; MFI, microflow imaging; IQR, interquartile range.

fer significantly between malignant and benign nodules or across K-TIRADS categories, suggesting that DTD likely did not substantially affect the observed differences in vascularity between groups.

Representative neoplastic vascular alterations in malignancies include both morphological and hemodynamic changes, typically characterized by hypervascularity and the presence of arteriovenous shunting [9]. However, internal vascularization in thyroid nodules can arise not only from neoplastic vascular proliferation but also from hyperplastic follicular proliferation or granulation tissue in nodules of colloid goiter [17,18]. Therefore, uncertainty persists regarding whether vascularity can reliably differentiate malignant from benign thyroid nodules. Yang et al. suggested that inconsistent findings regarding thyroid nodule vascularity across studies may reflect varying proportions of pathological cancer subtypes, as FTCs and PTCs differ microscopically [10]. PTCs show dense fibrosis in 56%–89% of cases [19–21], whereas FTCs are characterized by abundant blood vessels [11]. The authors also proposed that most hypervascular thyroid nodules correspond to adenomatoid nodules, the encapsulated form of the follicular variant of PTC, or to follicular carcinomas; however, malignant nodules generally lack intranodular vascularity, consistent with the present findings [10]. Moon et al. [22] similarly reported that benign thyroid nodules more frequently exhibit intranodular vascularity, while malignant nodules are more often avascular. Using power Doppler US, they concluded that vascularity was less useful than grayscale US features in predicting thyroid malignancy. Unlike earlier investigations [10,22], the present study assessed nodular vascularity within the structured framework of the TI-RADS system, which uses a lexicon-based approach to stratify malignancy risk. PTC and FTC are known to present distinct ultrasonographic features,

and these differences may aid in predicting histologic subtypes of thyroid cancer [23,24]. A prior study analyzing malignant tumor types across K-TIRADS categories reported that PTC was the predominant malignancy among K-TIRADS category 5 nodules, while FTC predominated in categories 3 and 4 [25]. PTC typically manifests as K-TIRADS 5 nodules and is often associated with dense fibrosis; therefore, vascularity assessment may be more useful in differentiating malignant from benign nodules in K-TIRADS 5 than in K-TIRADS 3 or 4. Taken together, these findings and the prior literature suggest that the diagnostic utility of vascularity in thyroid cancer should be interpreted in the context of the TI-RADS category.

In this study, 32 cases of classic PTC and eight cases of the follicular variant of PTC were included among the malignant lesions. Classic PTC generally showed lower vascularity than the follicular variant in both CDI and MFI. Although the follicular variant of PTC belongs to the broader PTC group, it is histologically characterized by a predominantly follicular growth pattern [26]. In contrast, classic PTC displays papillary architecture with central fibrovascular cores. Lamellated calcific spherules (psammoma bodies) are observed in approximately 40%–60% of cases, and degenerative changes with cystic formation are frequent. The stroma in classic PTC is often desmoplastic and may be extensive [26]. These histopathologic distinctions between the two PTC subtypes may underlie the vascularity differences observed in the present study. Although no significant difference in K-TIRADS categories was identified between the two PTC variants, further research with larger and more histologically diverse populations is warranted to clarify these associations.

The MVFI technique enables visualization of small vessels and detection of slow blood flow without using contrast agents [12,13]. Its main advantages include the ability to depict low-velocity blood flow clearly, provide high spatial resolution, reduce motion-related artifacts, and maintain high frame rates. Since its clinical introduction, numerous studies have explored the potential applications of MVFI across various organs and disease conditions, including the thyroid gland [12]. Some studies have reported that MVFI outperforms color or power Doppler imaging in evaluating malignant thyroid nodules, with findings such as abundant vascularity and intranodular flow associated with malignancy [27–29]. However, a definitive consensus on the diagnostic utility of MVFI in thyroid nodules has yet to be reached. Therefore, in this study, nodular vascularity assessed by MVFI was applied to the TI-RADS classification system, representing, to the authors' knowledge, the first attempt to integrate MVFI-derived vascular data into TI-RADS. Although the results did not show a statistically significant difference between MVFI and CDI, they support the notion that vascularity should be interpreted differently depending on the K-TIRADS category. Future studies with larger sample sizes and broader malignancy spectra are necessary to further define the clinical

role and diagnostic utility of MVFI in thyroid nodule assessment.

This study has several limitations. First, it was limited by its relatively small sample size and single-center, retrospective design, which may have introduced selection bias, including restricted pathological diversity. The proportion of malignant nodules was relatively high, and these nodules tended to be smaller in size, likely reflecting the tertiary referral setting. Moreover, the sample size was insufficient to robustly evaluate differences in MFI scores across K-TIRADS categories. In particular, the findings for K-TIRADS 5 were based on only four benign nodules, rendering these results preliminary and limiting both their statistical reliability and generalizability. Future multicenter studies with larger cohorts are warranted to validate these findings. Second, US and Doppler imaging are inherently subject to substantial inter-operator and inter-equipment variability. In this study, all CDI and MFI examinations were performed by a single experienced radiologist using the same US system to minimize variability. However, this approach may also limit the generalizability of the results. In addition, vascularity was evaluated using a four-point scale by two reviewers through consensus, which precluded assessment of inter- and intra-observer variability in vascularity scoring. Third, all US examinations were performed using equipment from a single manufacturer, which may limit the applicability of these findings to other US systems. Future validation studies involving multiple operators and diverse equipment are therefore needed. Finally, 13 cases (approximately 32% of malignancies) were diagnosed by FNA or CNB without surgical confirmation, 12 of which were classified as classic PTC. Given the inherent difficulty in differentiating classic PTC from the follicular variant of PTC (FVPTC) using FNA alone, these slides were re-reviewed by an experienced pathologist, confirming consistency with classic PTC. Nonetheless, the possibility of other PTC subtypes, including FVPTC, cannot be completely excluded. Furthermore, the relatively small total sample size ($n=113$) and limited number of FVPTCs ($n=8$) may restrict the generalizability of the findings. Despite these limitations, this study provides important preliminary insights into the potential role of CDI and MFI in distinguishing malignant from benign thyroid nodules. Larger-scale studies are necessary to confirm these results and to further evaluate US vascularity across different pathological subtypes of thyroid cancer.

In conclusion, vascular scores obtained from CDI and MFI appear to be valuable US parameters for differentiating malignant from benign thyroid nodules within the TI-RADS classification framework. The diagnostic application of nodular vascularity in thyroid cancer should be tailored according to the TI-RADS category, which may reflect the underlying pathological subtype of malignancy.

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Conceptualization: Ahn HS. Data acquisition: Yim Y. Data analysis or interpretation: Ahn HS, Hong MJ, Park HJ, Park SB, Yim Y. Drafting of the manuscript: Ahn HS. Critical revision of the manuscript: Ahn HS, Hong MJ, Park HJ, Park SB, Yim Y. Approval of the final version of the manuscript: all authors.

Conflict of Interest

The authors declare that the sponsor had no role in study design, data acquisition, data analysis, or manuscript preparation. The authors retained full control over data acquisition and manuscript preparation.

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Supplementary Material

Supplementary Table 1. Ultrasonographic findings of the thyroid nodules according to the K-TIRADS lexicon ($n=113$) (<https://doi.org/10.14366/usg.25159>).

Supplementary Table 2. Comparison of vascular scores according to the K-TIRADS categories for small nodules (<1.0 cm) (<https://doi.org/10.14366/usg.25159>).

Supplementary Table 3. Correlation between vascular scores and subtypes of malignancy (<https://doi.org/10.14366/usg.25159>).

References

1. Moon WJ, Jung SL, Lee JH, Na DG, Baek JH, Lee YH, et al. Benign and malignant thyroid nodules: US differentiation—multicenter retrospective study. *Radiology* 2008;247:762-770.
2. Frates MC, Benson CB, Charboneau JW, Cibas ES, Clark OH, Coleman BG, et al. Management of thyroid nodules detected at US: Society of Radiologists in Ultrasound consensus conference statement. *Radiology* 2005;237:794-800.
3. Haugen BR, Alexander EK, Bible KC, Doherty GM, Mandel SJ, Nikiforov YE, et al. 2015 American Thyroid Association management guidelines for adult patients with thyroid nodules and differentiated thyroid cancer: the American Thyroid Association guidelines task force on thyroid nodules and differentiated thyroid cancer. *Thyroid* 2016;26:1-133.

4. Gharib H, Papini E, Garber JR, Duick DS, Harrell RM, Hegedus L, et al. American Association of Clinical Endocrinologists, American College of Endocrinology, and Associazione Medici Endocrinologi medical guidelines for clinical practice for the diagnosis and management of thyroid nodules: 2016 update. *Endocr Pract* 2016;22:622-639.
5. Russ G, Bonnema SJ, Erdogan MF, Durante C, Ngu R, Leenhardt L. European Thyroid Association guidelines for ultrasound malignancy risk stratification of thyroid nodules in adults: the EU-TIRADS. *Eur Thyroid J* 2017;6:225-237.
6. Tessler FN, Middleton WD, Grant EG, Hoang JK, Berland LL, Teefey SA, et al. ACR thyroid imaging, reporting and data system (TI-RADS): white paper of the ACR TI-RADS committee. *J Am Coll Radiol* 2017;14:587-595.
7. Ha EJ, Chung SR, Na DG, Ahn HS, Chung J, Lee JY, et al. 2021 Korean Thyroid Imaging Reporting and Data System and imaging-based management of thyroid nodules: Korean Society of Thyroid Radiology consensus statement and recommendations. *Korean J Radiol* 2021;22:2094-2123.
8. Lagalla R, Caruso G, Novara V, Cardinale AE. Flowmetric analysis of thyroid diseases: hypothesis on integration with qualitative color-Doppler study. *Radiol Med* 1993;85:606-610.
9. Taylor KJ, Ramos I, Carter D, Morse SS, Snower D, Fortune K. Correlation of Doppler US tumor signals with neovascular morphologic features. *Radiology* 1988;166:57-62.
10. Yang GCH, Fried KO. Most thyroid cancers detected by sonography lack intranodular vascularity on color Doppler imaging: review of the literature and sonographic-pathologic correlations for 698 thyroid neoplasms. *J Ultrasound Med* 2017;36:89-94.
11. Giorgadze TA, Baloch ZW, Pasha T, Zhang PJ, Livolsi VA. Lymphatic and blood vessel density in the follicular patterned lesions of thyroid. *Mod Pathol* 2005;18:1424-1431.
12. Aziz MU, Eisenbrey JR, Deganello A, Zahid M, Sharbidre K, Sidhu P, et al. Microvascular flow imaging: a state-of-the-art review of clinical use and promise. *Radiology* 2022;305:250-264.
13. Bae JS, Lee JM, Jeon SK, Jang S. Comparison of MicroFlow imaging with color and power Doppler imaging for detecting and characterizing blood flow signals in hepatocellular carcinoma. *Ultrasonography* 2020;39:85-93.
14. Cibas ES, Ali SZ. The 2017 Bethesda system for reporting thyroid cytopathology. *Thyroid* 2017;27:1341-1346.
15. Jung CK, Min HS, Park HJ, Song DE, Kim JH, Park SY, et al. Pathology reporting of thyroid core needle biopsy: a proposal of the Korean Endocrine Pathology Thyroid Core Needle Biopsy Study Group. *J Pathol Transl Med* 2015;49:288-299.
16. Chung J, Lee YJ, Choi YJ, Ha EJ, Suh CH, Choi M, et al. Clinical applications of Doppler ultrasonography for thyroid disease: consensus statement by the Korean Society of Thyroid Radiology. *Ultrasonography* 2020;39:315-330.
17. Sabel MS, Haque D, Velasco JM, Staren ED. Use of ultrasound-guided fine needle aspiration biopsy in the management of thyroid disease. *Am Surg* 1998;64:738-741.
18. Foschini MP, Ragazzi M, Parmeggiani AL, Righi A, Flamminio F, Meringolo D, et al. Comparison between echo-color Doppler sonography features and angioarchitecture of thyroid nodules. *Int J Surg Pathol* 2007;15:135-142.
19. Isarangkul W. Dense fibrosis: another diagnostic criterion for papillary thyroid carcinoma. *Arch Pathol Lab Med* 1993;117:645-646.
20. Carcangiu ML, Zampi G, Rosai J. Papillary thyroid carcinoma: a study of its many morphologic expressions and clinical correlates. *Pathol Annu* 1985;20 Pt 1:1-44.
21. Vickery AL. Thyroid papillary carcinoma: pathological and philosophical controversies. *Am J Surg Pathol* 1983;7:797-807.
22. Moon HJ, Kwak JY, Kim MJ, Son EJ, Kim EK. Can vascularity at power Doppler US help predict thyroid malignancy? *Radiology* 2010;255:260-269.
23. Jeh SK, Jung SL, Kim BS, Lee YS. Evaluating the degree of conformity of papillary carcinoma and follicular carcinoma to the reported ultrasonographic findings of malignant thyroid tumor. *Korean J Radiol* 2007;8:192-197.
24. Park JW, Kim DW, Kim D, Baek JW, Lee YJ, Baek HJ. Korean Thyroid Imaging Reporting and Data System features of follicular thyroid adenoma and carcinoma: a single-center study. *Ultrasonography* 2017;36:349-354.
25. Hong MJ, Na DG, Baek JH, Sung JY, Kim JH. Impact of nodule size on malignancy risk differs according to the ultrasonography pattern of thyroid nodules. *Korean J Radiol* 2018;19:534-541.
26. Kini SR. Thyroid cytopathology: an atlas and text. 2nd ed. Philadelphia, PA: Wolters Kluwer, 2015.
27. Cappelli C, Pirola I, Gandossi E, Marini F, Cristiano A, Casella C, et al. Ultrasound microvascular blood flow evaluation: a new tool for the management of thyroid nodule? *Int J Endocrinol* 2019;2019:7874890.
28. Zhu YC, Zhang Y, Deng SH, Jiang Q. A prospective study to compare superb microvascular imaging with grayscale ultrasound and color Doppler flow imaging of vascular distribution and morphology in thyroid nodules. *Med Sci Monit* 2018;24:9223-9231.
29. Kong J, Li JC, Wang HY, Wang YH, Zhao RN, Zhang Y, et al. Role of superb micro-vascular imaging in the preoperative evaluation of thyroid nodules: comparison with power Doppler flow imaging. *J Ultrasound Med* 2017;36:1329-1337.