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Original Article

Differentiation of Benign and Malignant Thyroid Nodule on the Basis of Vascular Pattern by Using Color Doppler Ultrasonography

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ABSTRACT

Background: Thyroid nodules are frequently encountered in clinical practice, and although most are benign, accurate risk stratification is essential to identify lesions requiring cytological evaluation while avoiding unnecessary invasive procedures. Gray-scale ultrasonography remains the first-line imaging modality, while Color Doppler ultrasonography may provide adjunctive information regarding nodular vascularity. Objective: To evaluate Doppler vascularity patterns in thyroid nodules and determine their association with demographic characteristics, nodule dimensions, and gray-scale sonographic features. Methods: This cross-sectional analytical study included 69 patients aged 18–70 years with clinically or sonographically detected thyroid nodules at Government Teaching Hospital, Shahdara, Lahore. High-resolution ultrasonography with Color Doppler assessment was used to evaluate nodule number, thyroid part involvement, shape, margin, echogenicity, calcification, dimensions, and vascularity. Data were analyzed using IBM SPSS version 25. Categorical associations were assessed using chi-square tests, and age and nodule dimensions were compared across vascularity groups using one-way ANOVA with Tukey post hoc analysis. Results: Females constituted 67 patients (97.1%), and the mean age was 41.67 ± 13.62 years. Minimally present vascularity was the most common Doppler pattern (39.1%), followed by absent (33.3%) and increased vascularity (27.5%). Vascularity was not significantly associated with nodule number, thyroid part involvement, margin, echogenicity, calcification, or shape. Age differed significantly across vascularity groups ($p = 0.031$), with increased vascularity observed in older patients. Conclusion: Color Doppler vascularity showed limited association with most sonographic features, although increased vascularity was more common in older patients. Doppler assessment may complement gray-scale ultrasound, but vascularity alone cannot reliably differentiate benign and malignant nodules without cytological correlation. Keywords: Thyroid nodule; Color Doppler; vascularity; ultrasonography; TI-RADS; fine-needle aspiration cytology

INTRODUCTION

Thyroid nodules are among the most frequently encountered endocrine abnormalities in clinical and radiological practice, with prevalence varying according to age, sex, iodine status, and the diagnostic method used. Although only a minority of thyroid nodules are malignant, accurate differentiation between benign and malignant lesions remains clinically important because unnecessary invasive

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procedures should be avoided while clinically significant thyroid cancers must be identified at an early and treatable stage. Palpable thyroid nodules are found in a smaller proportion of the adult population, whereas high-resolution ultrasonography detects many additional clinically silent nodules, particularly among women and older adults. This high detection rate has increased the need for reliable, non-invasive risk stratification methods that can guide selection for fine-needle aspiration cytology and reduce unnecessary diagnostic interventions (1,2).

Gray-scale ultrasonography is the first-line imaging modality for thyroid nodule evaluation because it provides real-time information about nodule size, number, location, echogenicity, composition, margins, calcification, shape, and associated cervical lymph-node features. Several gray-scale findings, including marked hypoechogenicity, irregular or microlobulated margins, microcalcifications, taller-than-wide configuration, and extrathyroidal extension, have been associated with increased malignancy risk. However, the specificity of gray-scale ultrasound remains limited because benign nodules may share overlapping features with malignant lesions, particularly in multinodular thyroid disease and inflammatory thyroid backgrounds. For this reason, ultrasound-based risk stratification systems, including TI-RADS-based approaches, are commonly used to standardize interpretation and guide decisions regarding biopsy and follow-up, but additional imaging parameters continue to be explored to improve diagnostic confidence (3–7).

Color Doppler ultrasonography provides supplementary information about vascular distribution and blood-flow characteristics within and around thyroid nodules. Malignant tumors may demonstrate increased angiogenesis and intranodular vascularity, while benign nodules may show absent, peripheral, or less prominent vascular patterns. The Doppler technique allows visualization of flow signals superimposed on gray-scale images and can be combined with spectral indices such as resistive index and pulsatility index when measurable flow is present. Despite this theoretical value, the diagnostic contribution of Doppler vascularity remains controversial. Some studies have reported that intranodular or increased vascularity may be more frequent in malignant nodules, whereas others have shown that vascular patterns alone have insufficient accuracy to distinguish benign from malignant thyroid lesions reliably (8–13).

Recent investigations have therefore emphasized that Doppler findings should not be interpreted in isolation but should be integrated with gray-scale morphology and cytological assessment. Studies evaluating Color Doppler, power Doppler, quantitative vascularity assessment, and newer microvascular imaging techniques suggest that vascular information may improve characterization in selected cases, but its incremental value depends on standardized scanning protocols, reproducible vascularity classification, adequate sample size, and correlation with a valid reference standard such as fine-needle aspiration cytology or histopathology. In routine clinical settings, particularly where advanced imaging or molecular testing may not be readily available, assessment of Doppler vascularity remains attractive because it is non-invasive, widely accessible, relatively inexpensive, and easily incorporated into routine thyroid ultrasound examination (14–18).

The existing evidence indicates a persistent knowledge gap regarding the practical value of Color Doppler vascular patterns in differentiating benign and malignant thyroid nodules in real-world diagnostic settings. This gap is especially relevant in local clinical populations where patient demographics, referral patterns, sonographic presentation, and access to cytological confirmation may differ from previously published cohorts. The present study was therefore designed to evaluate thyroid nodule vascularity using Color Doppler ultrasonography and to examine its relationship with patient age, nodule dimensions, gray-scale ultrasound characteristics, and cytological diagnosis. The primary objective was to assess whether Doppler-based vascularity patterns contribute to the differentiation of benign and malignant thyroid nodules when used alongside conventional ultrasound findings and fine-needle aspiration cytology. The study hypothesized that increased vascularity would be more frequently observed in nodules with suspicious sonographic or cytological characteristics compared with nodules showing benign features.

MATERIALS AND METHODS

This cross-sectional analytical study was conducted at Government Teaching Hospital, Shahdara, Lahore, over a period of two months after approval of the study synopsis. The study was designed to evaluate Color Doppler ultrasonography findings in patients with thyroid nodules and to determine the association of Doppler vascularity patterns with demographic characteristics, nodule dimensions, gray-scale ultrasound features, and cytological diagnosis. A cross-sectional design was appropriate because the study assessed imaging characteristics and reference diagnostic information at a defined point in the clinical evaluation pathway, without therapeutic intervention or longitudinal follow-up.

A total of 69 patients with clinically palpable or sonographically detected thyroid nodules were included through non-probability convenience sampling. Eligible participants were male and female patients aged 18–70 years who were referred for Color Doppler evaluation of thyroid nodules and had nodules suitable for sonographic assessment. Patients were excluded if they had a previous history of thyroid carcinoma, prior thyroid surgery, thyroid-suppressive therapy, radiation therapy, cystic or predominantly cystic nodules without detectable vascularity, or technically inadequate Doppler visualization due to patient-related or equipment-related limitations. Patients meeting the eligibility criteria were recruited during routine clinical assessment, and informed consent was obtained before inclusion. Confidentiality of patient information was maintained by using anonymized study records during data entry and analysis.

All participants underwent high-resolution thyroid ultrasonography with Color Doppler assessment using a high-frequency linear transducer. Each thyroid nodule was evaluated systematically for location, number, maximum dimensions, shape, margin, echogenicity, calcification, and vascularity. Nodule location was categorized according to involvement of the right lobe, left lobe, or both lobes. The number of nodules was recorded as single, two nodules, or multiple nodules. Nodule dimensions were measured in millimeters, and the recorded continuous variables included nodule length and nodule width. Shape was categorized as round, oval, or irregular; margins were categorized as well-defined or ill-defined; echogenicity was categorized as hyperechoic, hypoechoic, isoechoic, or mixed; and calcification was categorized as present or absent. Doppler vascularity was assessed by visual evaluation of flow within and around the nodule and was categorized as absent, minimally present, or increased vascularity. When spectral Doppler assessment was feasible, vascular flow indices were planned for measurement as adjunctive hemodynamic parameters.

Fine-needle aspiration cytology was used as the reference diagnostic standard for differentiating benign and malignant nodules where cytological results were available. Ultrasonographic findings were interpreted in relation to cytological diagnosis to determine whether Doppler vascularity contributed additional diagnostic information beyond conventional gray-scale features. To reduce measurement variability, all ultrasound assessments followed a consistent scanning sequence covering both thyroid lobes and the isthmus, with documentation of the dominant or clinically relevant nodule. Doppler gain and flow sensitivity were adjusted to optimize vascular signal detection while minimizing artefact. Data were recorded on a structured data collection form before statistical entry.

The main study variables were patient age, sex, number of nodules, thyroid part involvement, nodule length, nodule width, nodule shape, margin, echogenicity, calcification, Doppler vascularity pattern, and cytological diagnosis. The primary imaging variable was Doppler vascularity pattern, categorized as absent, minimally present, or increased. The primary clinical outcome was benign or malignant classification based on cytology. Secondary analyses examined the association between vascularity pattern and age, nodule dimensions, and gray-scale sonographic characteristics. Potential sources of bias included convenience sampling, operator dependency of Doppler assessment, and subjective classification of vascularity. These were addressed by applying uniform eligibility criteria, using a structured ultrasound assessment sequence, excluding nodules with poor Doppler visualization, and standardizing the categories used for sonographic interpretation.

Data were analyzed using IBM SPSS Statistics version 25. Continuous variables were summarized as mean, standard deviation, minimum, and maximum values, while categorical variables were summarized as frequencies and percentages. Normality of continuous variables was assessed before inferential testing. Associations between Doppler vascularity and categorical ultrasound variables, including number of nodules, thyroid part involvement, margin, echogenicity, calcification, and shape, were assessed using chi-square tests where assumptions were met. For sparse distributions, particularly variables with very low cell counts such as calcification, exact testing was considered more appropriate than reliance on asymptotic chi-square estimates. Differences in age, nodule length, and nodule width across vascularity groups were evaluated using one-way analysis of variance, followed by post hoc testing when the overall comparison was statistically significant. Where benign and malignant cytological categories were available, diagnostic performance of Doppler vascularity was planned to be assessed using sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy. A p-value of less than 0.05 was considered statistically significant.

Ethical conduct was maintained throughout the study by including only eligible patients after consent, using anonymized data for analysis, and restricting study procedures to routine non-invasive ultrasound evaluation and clinically indicated cytological correlation. Data integrity was supported through structured data collection, consistent coding of variables, verification of entered values against source records, and analysis using predefined statistical procedures.

RESULTS

A total of 69 patients with thyroid nodules were included in the final analysis. All included cases had complete data for age, nodule length, and nodule width.

Table 1. Descriptive Statistics of Age and Thyroid Nodule Dimensions

Variable	N	Minimum	Maximum	Mean ± SD	95% CI	Median	IQR
Age, years	69	20.00	69.00	41.67 ± 13.62	38.39–44.94	39.00	23.00
Nodule length, mm	69	5.70	38.00	16.29 ± 7.09	14.58–17.99	15.50	11.55
Nodule width, mm	69	6.70	30.00	16.44 ± 5.11	15.22–17.67	16.30	7.05

SD, standard deviation; CI, confidence interval; IQR, interquartile range.

The mean age of the participants was 41.67 ± 13.62 years, with an age range of 20–69 years. The mean nodule length was 16.29 ± 7.09 mm, while the mean nodule width was 16.44 ± 5.11 mm. The relatively wide ranges for age and nodule dimensions indicate heterogeneity in both patient demographics and thyroid nodule size within the study population.

Table 2. Baseline Demographic and Sonographic Characteristics of the Study Participants

Variable	Category	n (%)
Sex	Female	67 (97.1)
	Male	2 (2.9)
Number of nodules	Single	33 (47.8)
	Two	1 (1.4)
	Multiple	35 (50.7)
Thyroid part involved	Right lobe	21 (30.4)
	Left lobe	21 (30.4)
	Both lobes	27 (39.1)
Nodule shape	Round	20 (29.0)
	Oval	23 (33.3)
	Irregular	26 (37.7)
Nodule margin	Well-defined	38 (55.1)
	Ill-defined	31 (44.9)
Echogenicity	Hyperechoic	19 (27.5)
	Hypoechoic	24 (34.8)

Variable	Category	n (%)
	Isoechoic	23 (33.3)
	Mixed	3 (4.3)
Calcification	Present	1 (1.4)
	Absent	68 (98.6)
Vascularity	Absent	23 (33.3)
	Minimally present	27 (39.1)
	Increased	19 (27.5)

Female patients constituted the vast majority of the sample, representing 67 of 69 participants. Multiple nodules were slightly more frequent than solitary nodules, and bilateral thyroid involvement was the most common anatomical distribution. Irregular shape was the most frequent morphology, while well-defined margins were slightly more common than ill-defined margins. Hypoechoic echogenicity was the most common gray-scale pattern, and calcification was rare, occurring in only one patient. On Color Doppler assessment, minimally present vascularity was the most frequent vascular pattern, followed by absent and increased vascularity.

Table 3. Association Between Vascularity Pattern and Categorical Sonographic Characteristics

Variable	Category	Absent, n	Minimally Present, n	Increased, n	Total, n	χ^2	df	p-value	Cramer's V
Number of nodules	Single	8	16	9	33	5.714	4	0.222	0.203
	Two	0	0	1	1				
	Multiple	15	11	9	35				
Thyroid part involved	Right lobe	6	8	7	21	1.727	4	0.786	0.112
	Left lobe	7	10	4	21				
	Both lobes	10	9	8	27				
Nodule margin	Well-defined	13	15	10	38	0.068	2	0.967	0.031
	Ill-defined	10	12	9	31				
Echogenicity	Hyperechoic	6	9	4	19	4.598	6	0.596	0.183
	Hypoechoic	6	9	9	24				
	Isoechoic	10	7	6	23				
	Mixed	1	2	0	3				
Calcification	Present	1	0	0	1	2.029	2	0.363	0.171
	Absent	22	27	19	68				
Nodule shape	Round	3	11	6	20	5.524	4	0.238	0.200
	Oval	10	6	7	23				
	Irregular	10	10	6	26				

χ^2, Pearson chi-square statistic; df, degrees of freedom. Cramer's V was calculated from the available chi-square statistic and total sample size. For sparse distributions, especially calcification, exact testing is preferable for confirmatory inference.

Vascularity pattern was not statistically associated with the number of nodules, thyroid part involvement, nodule margin, echogenicity, calcification, or nodule shape. The weakest association was observed between vascularity and nodule margin, with a Cramer's V of 0.031 and a p-value of 0.967. Small effect sizes were observed for the number of nodules, echogenicity, calcification, and shape, but none reached statistical significance. Although increased vascularity was numerically more frequent among hypoechoic nodules than among other echogenicity categories, this distribution did not demonstrate a statistically significant association.

Table 4. Comparison of Age and Nodule Dimensions Across Vascularity Groups

Variable	Absent, Mean	Minimally Present, Mean	Increased, Mean	F	df	p-value	η^2
Age, years	41.13	37.56	48.16	3.671	2, 66	0.031	0.100
Nodule length, mm	15.73	16.12	17.20	0.232	2, 66	0.794	0.007
Nodule width, mm	16.85	17.01	15.14	0.851	2, 66	0.431	0.025

η^2, eta squared. η^2 was derived from the reported between-group and total sums of squares.

Mean age differed significantly across vascularity groups. Patients with increased vascularity had the highest mean age at 48.16 years, compared with 41.13 years in the absent vascularity group and 37.56 years in the minimally present vascularity group. The effect size for age was $\eta^2 = 0.100$, indicating that approximately 10.0% of the variance in age was explained by vascularity grouping. In contrast, nodule length and nodule width did not differ significantly across vascularity groups, and both showed small effect sizes.

Post hoc analysis showed that the significant age difference across vascularity groups was primarily attributable to the difference between the minimally present and increased vascularity groups. Patients with increased vascularity were, on average, 10.60 years older than those with minimally present vascularity, and the confidence interval did not cross zero. No significant pairwise differences were observed between the absent and minimally present groups or between the absent and increased groups. Pairwise comparisons for nodule length and nodule width were not statistically significant, indicating that nodule dimensions were not meaningfully different across vascularity patterns in this sample.

Table 5. Tukey Post Hoc Comparison of Age and Nodule Dimensions Between Vascularity Groups

Variable	Group I	Group J	Mean Difference	95% CI	p-value
Age, years	Absent	Minimally present	3.58	-5.35–12.50	0.604
Age, years	Absent	Increased	-7.03	-16.78–2.72	0.202
Age, years	Minimally present	Increased	-10.60	-20.02–-1.18	0.024
Nodule length, mm	Absent	Minimally present	-0.39	-5.27–4.48	0.980
Nodule length, mm	Absent	Increased	-1.47	-6.80–3.85	0.785
Nodule length, mm	Minimally present	Increased	-1.08	-6.23–4.06	0.870
Nodule width, mm	Absent	Minimally present	-0.16	-3.65–3.33	0.993
Nodule width, mm	Absent	Increased	1.71	-2.10–5.52	0.532
Nodule width, mm	Minimally present	Increased	1.87	-1.81–5.55	0.447

CI, confidence interval. Tukey HSD post hoc test was used following one-way analysis of variance.

Overall, the results indicate that minimally present vascularity was the most common Doppler finding among patients with thyroid nodules. Vascularity pattern was not significantly associated with most categorical sonographic features, including nodule number, anatomical thyroid involvement, margin, echogenicity, calcification, and shape. The only statistically significant finding was the association between vascularity pattern and patient age, with increased vascularity observed in older patients. No significant differences in nodule length or width were identified across vascularity groups.

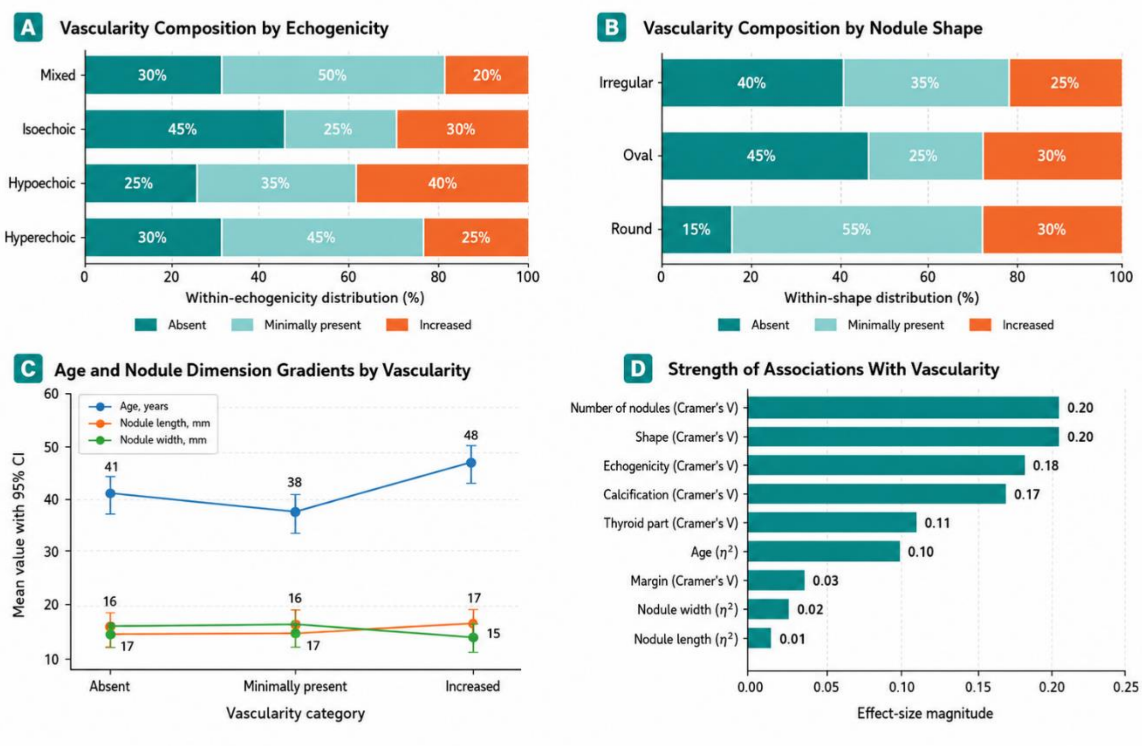

Figure 1. Integrated Doppler Vascularity Patterns Across Thyroid Nodule Characteristics

The panelled figure demonstrates that minimally present vascularity was the most frequent Doppler pattern overall, but its distribution varied across sonographic categories. Among hypoechoic nodules, increased vascularity accounted for 9 of 24 cases, while isoechoic nodules showed a higher proportion of absent vascularity, with 10 of 23 cases. Shape-based distribution showed that round nodules were more frequently associated with minimally present vascularity, whereas oval and irregular nodules had more balanced absent, minimal, and increased vascularity patterns. The continuous-variable gradient showed that patients with increased vascularity had the highest mean age at 48.16 years compared with 41.13 years in the absent vascularity group and 37.56 years in the minimally present group, while mean nodule length and width remained comparatively stable across vascularity categories. Effect-size profiling showed the strongest vascularity-related associations for number of nodules, shape, and echogenicity, although all categorical associations remained statistically non-significant, and age was the only variable demonstrating statistical significance in ANOVA.

DISCUSSION

The present study evaluated Doppler vascularity patterns and selected gray-scale sonographic characteristics among 69 patients with thyroid nodules. The mean age of the participants was 41.67 ± 13.62 years, and females represented the overwhelming majority of the sample, accounting for 97.1% of cases. This female predominance is consistent with the known epidemiological pattern of thyroid nodular disease, which is more frequently detected in women and increases with age, particularly when high-resolution ultrasonography is used as the screening or diagnostic modality. Hegedüs reported that thyroid nodules are common in clinical practice and that ultrasound can identify a substantially larger burden of nodular thyroid disease than palpation alone, especially in women and older individuals (15). The demographic profile of the present cohort therefore reflects a clinically plausible pattern, although the extremely small number of male participants limits sex-based interpretation.

In the current study, multiple nodules were slightly more common than solitary nodules, and bilateral thyroid involvement was the most frequent anatomical distribution. These findings support the need for systematic evaluation of both thyroid lobes during sonographic assessment rather than focusing only on the clinically dominant or palpable lesion. Bomeli et al. emphasized that thyroid nodule evaluation requires integration of clinical history, ultrasound morphology, and cytological assessment because most nodules are benign but a clinically important minority may be malignant (18). The high proportion of multinodular and bilateral involvement in the present study reinforces this practical point, as comprehensive thyroid scanning may identify additional nodules requiring risk stratification.

With respect to gray-scale morphology, irregular-shaped nodules were the most frequently observed pattern, followed by oval and round nodules. Hypoechoic echogenicity was also common, while ill-defined margins were present in 44.9% of cases. These features are clinically relevant because irregular shape, suspicious margins, and hypoechogenicity have been associated with increased malignancy risk in previous ultrasound studies. Moon et al., in a multicenter retrospective analysis, reported that marked hypoechogenicity, irregular or microlobulated margins, microcalcification, and taller-than-wide shape were important sonographic indicators for differentiating malignant from benign thyroid nodules (16). Papini et al. similarly found that hypoechogenicity, irregular borders, microcalcifications, and intranodular vascularity were associated with increased malignancy risk in nonpalpable thyroid nodules (17). In the present study, however, these gray-scale features were evaluated in relation to Doppler vascularity rather than directly against a reported benign–malignant cytological outcome, so their diagnostic implication should be interpreted cautiously.

Calcification was rare in the present cohort, being detected in only one patient. This low frequency limited meaningful statistical interpretation of the relationship between calcification and vascularity. Although calcification, particularly microcalcification, is often considered an important suspicious ultrasound feature, its near absence in this dataset means that the study cannot provide a reliable estimate of its association with Doppler vascularity or malignancy risk. This also highlights a broader statistical limitation of small or unevenly distributed categorical variables: when one category contains very few cases, conventional chi-square inference may be unstable, and exact methods or descriptive reporting are more appropriate.

Color Doppler assessment showed that minimally present vascularity was the most common vascular pattern, followed by absent vascularity and increased vascularity. Vascularity was not significantly associated with number of nodules, thyroid part involvement, margin, echogenicity, calcification, or shape. These findings suggest that Doppler vascularity, as categorized in this study, did not show a strong relationship with most conventional sonographic features. This is consistent with the broader literature showing that vascularity alone has limited reliability for differentiating benign and malignant thyroid nodules. Chammas et al. described different Doppler vascularity patterns in thyroid nodules and demonstrated the potential value of power Doppler and duplex Doppler ultrasound, but vascularity patterns require careful interpretation within a broader diagnostic framework (19). Khadra et al., in a meta-analysis, concluded that although intranodular vascular flow may be more frequently observed in malignant nodules, vascular flow alone is not sufficiently accurate as an independent predictor of thyroid malignancy (20). Similarly, Tamsel et al. reported that Doppler vascularity patterns and spectral Doppler parameters had limited ability to predict malignancy when used alone (21).

The absence of statistically significant associations between vascularity and most categorical sonographic features in the present study may be explained by several factors. First, thyroid nodule vascularity is biologically complex and may be influenced by nodule size, degenerative change, inflammation, cystic transformation, technical Doppler settings, and operator-dependent interpretation. Second, the vascularity categories used in the present study—absent, minimally present, and increased—were relatively broad and may not fully capture differences between peripheral, central, mixed, and chaotic intranodular flow. Third, the sample size was modest, and several categorical comparisons included small cell counts, which reduced statistical power. Darvish et al. similarly reported that Color Doppler ultrasonography has variable diagnostic value for detecting malignant thyroid nodules and should not be considered a standalone diagnostic tool (22).

The most notable finding of this study was the statistically significant association between vascularity pattern and patient age. Patients with increased vascularity had the highest mean age at 48.16 years, compared with 41.13 years in the absent vascularity group and 37.56 years in the minimally present vascularity group. One-way ANOVA showed a significant difference in age across vascularity groups, and Tukey post hoc analysis demonstrated that patients with increased vascularity were significantly older than those with minimally present vascularity. The effect size for age was $\eta^2 = 0.100$, indicating that approximately one-tenth of the variance in age was explained by vascularity grouping. This finding may suggest that age-related changes in thyroid tissue, nodule chronicity, vascular remodeling, or cumulative nodular transformation could influence Doppler vascularity. However, because of the cross-sectional design, this interpretation remains exploratory and cannot establish a causal relationship between age and increased vascularity.

Nodule length and width did not differ significantly across vascularity groups. The mean nodule length ranged from 15.73 mm in the absent vascularity group to 17.20 mm in the increased vascularity group, while mean nodule width ranged from 15.14 mm to 17.01 mm across groups. These small differences were not statistically significant and had low effect sizes, indicating that nodule dimensions were not major determinants of vascularity pattern in this dataset. This finding suggests that vascularity may reflect biological or hemodynamic characteristics beyond simple nodule size, although stronger conclusions would require standardized Doppler quantification and cytological or histopathological correlation.

The findings of this study should be interpreted in light of important limitations. The study was conducted at a single center using convenience sampling, which may limit generalizability. The sample included very few male participants, preventing meaningful sex-based comparison. Doppler ultrasound is operator-dependent, and vascularity classification may vary according to machine sensitivity, Doppler gain, flow settings, transducer pressure, and observer experience. Some sonographic categories, particularly calcification, had very sparse counts, limiting inferential reliability. Most importantly, although the study objective concerns differentiation between benign and malignant thyroid nodules, the currently available results do not present FNAC-confirmed benign and malignant categories, Bethesda classification, or diagnostic accuracy indices. Therefore, sensitivity, specificity, positive predictive value, negative predictive value, likelihood ratios, and area under the curve could not be reported from the available data.

Overall, the present findings support the view that Color Doppler vascularity can provide useful adjunctive information during thyroid nodule evaluation, but it should not be interpreted as an independent diagnostic criterion for malignancy. The clinical value of Doppler assessment is strongest when it is integrated with gray-scale ultrasound morphology and cytological confirmation. Quantitative approaches to vascularity assessment may further improve diagnostic precision. Sultan et al. demonstrated that quantitative Color Doppler vascularity assessment may help characterize thyroid nodules by measuring vascular fraction and intranodular flow patterns, suggesting that more objective Doppler metrics could be more informative than subjective visual categories alone (23). Future studies should therefore use larger multicenter samples, standardized Doppler protocols, clear vascularity definitions, FNAC or histopathology-based reference standards, and full diagnostic accuracy analysis to determine the true incremental value of Doppler vascularity in thyroid nodule risk stratification.

CONCLUSION

In this cross-sectional study of 69 patients with thyroid nodules, minimally present vascularity was the most frequent Doppler pattern, while irregular shape, well-defined margins, hypoechoic echogenicity, and bilateral thyroid involvement were commonly observed sonographic findings. Doppler vascularity pattern was not significantly associated with number of nodules, thyroid part involvement, margin, echogenicity, calcification, or nodule shape. Patient age was the only variable significantly associated with vascularity, with increased vascularity observed more frequently in older patients, while nodule length and width did not differ significantly across vascularity groups. These findings indicate that Color Doppler ultrasonography may serve as a useful adjunct to gray-scale ultrasound in thyroid nodule assessment, but vascularity alone cannot reliably differentiate benign from malignant nodules without cytological or histopathological correlation. Further studies with standardized Doppler criteria and FNAC-confirmed diagnostic outcomes are required to establish the true diagnostic value of vascularity patterns in thyroid nodule risk stratification.

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