SSR Institute of International Journal of Life Sciences
ISSN (O): 2581-8740 | ISSN (P): 2581-8732
Karthik *et al.*, 2025
doi: 10.21276/SSR-IIJLS.2025.11.6.20

Original Article

open access

Prospective Study in Evaluation of Thyroid Pathologies Using Color Doppler and Doppler Indices of Superior Thyroid Artery

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Received: 13 Jun 2025/ Revised: 21 Aug 2025/ Accepted: 22 Oct 2025

ABSTRACT
Background: Thyroid disorders are commonly encountered in clinical practice, and conventional ultrasonography often shows overlapping features in benign and malignant lesions. Color Doppler evaluation of the Superior Thyroid Artery (STA) and its Doppler indices—Peak Systolic Velocity (PSV), Pulsatility Index (PI) and Resistive Index (RI)—provides valuable physiological information that may improve diagnostic accuracy.
Methods: A prospective observational study was conducted in the Department of Radio-diagnosis at Dr. B.R. Ambedkar Medical College & Hospital from June 2022 to January 2024, including 60 patients with suspected thyroid disease. B-mode ultrasonography was followed by Color and Spectral Doppler assessment of the STA. Doppler parameters (PSV, PI, RI) were recorded. Statistical analysis was performed using SPSS 22, using Chi-square test, t-test/Mann–Whitney U test and ROC analysis to determine diagnostic cut-off values.
Results: Malignant nodules showed significantly higher PI and RI values compared to benign lesions ($p<0.001$ for both). The optimal PI cut-off (>1.23) yielded 91.67% sensitivity and 100% specificity. The RI cut-off (>0.73) showed 100% sensitivity and 94.44% specificity. PSV of the STA effectively differentiated Graves' disease from diffuse thyroiditis, with a cut-off >47 cm/s providing 100% sensitivity and 100% specificity.
Conclusion: STA Doppler indices—particularly PI, RI and PSV—serve as reliable, non-invasive markers for differentiating benign and malignant thyroid nodules, and for distinguishing Graves' disease from diffuse thyroiditis. Doppler evaluation significantly enhances diagnostic accuracy beyond conventional ultrasound.

Key-words: Superior Thyroid Artery, Pulsatility Index, Peak Systolic Velocity, Thyroid Nodules, Graves' Disease, ROC Curve

INTRODUCTION
The thyroid gland lies in the infrahyoid region and is one of the most superficially located endocrine organs in the human body. It is enclosed by the middle layer of the deep cervical fascia. It occupies an anatomical compartment surrounded by the strap muscles, trachea, esophagus, and carotid vessels, extending approximately from the C5 to T1 vertebral levels.

How to cite this article
Karthik N, Anushree CK, Chandramouly M. Prospective Study in Evaluation of Thyroid Pathologies Using Color Doppler and Doppler Indices of Superior Thyroid Artery. SSR Inst Int J Life Sci., 2025; 11(6): 8745-8752.

Access this article online
https://iijls.com/

The gland consists of two lateral lobes connected by an isthmus. Embryologically, it originates at the foramen cecum at the base and descends along the thyroglossal tract to reach its final position in the neck. Considerable variation in the size and configuration of the thyroid lobes is seen in normal individuals.

Its functional component, the thyroid follicle, synthesizes the hormones triiodothyronine (T3), thyroxine (T4), and calcitonin. While T3 and T4 regulate metabolic activity, tissue growth, and protein synthesis, calcitonin contributes to maintaining calcium balance in the body [1,2].

Thyroid disorders represent one of the most widespread endocrine problems globally, and India also bears a substantial disease burden. Reports suggest that nearly

doi: 10.21276/SSR-IIJLS.2025.11.6.20

42 million people in the country suffer from thyroid-related conditions. These disorders include developmental anomalies, autoimmune diseases, inflammatory conditions, and neoplastic processes. Common pathological entities include simple goiter, hypothyroidism, hyperthyroidism, thyroid nodules, thyroiditis, and thyroid malignancies [3].

Although thyroid function tests remain the primary approach for evaluating functional status, ultrasonography has become an essential imaging modality for assessing thyroid anatomy. It is widely preferred due to its safety, non-invasive nature, low cost, and lack of ionizing radiation. Ultrasound effectively evaluates gland size, margins, echogenicity, the number and morphology of nodules, calcifications, and vascularity. Early vascular changes associated with diffuse thyroid disorders can often be appreciated on Doppler imaging. However, conventional ultrasonography cannot determine whether the gland is hypo-, hyper-, or normally functioning [4].

Doppler ultrasonography, particularly the measurement of Peak Systolic Velocity (PSV), Pulsatility Index (PI), and Resistive Index (RI), provides additional functional information. Prior studies indicate significant variations in these indices between normal and abnormal thyroid states, and STA and ITA Doppler values may help differentiate causes of hyperthyroidism. In practice, the inferior thyroid artery is difficult to visualize consistently. In contrast, the superior thyroid artery is easily accessible at the upper pole of the thyroid, making it more suitable for Doppler evaluation [5,6].

Evidence regarding the usefulness of Doppler parameters of thyroid-supplying arteries in early disease detection is limited, and only a few studies have explored these indices in pathological thyroid conditions. Therefore, there is a need for a systematic evaluation of the Doppler characteristics of the superior thyroid artery to improve early diagnosis of thyroid abnormalities. To address this gap, the present study aims to analyze STA Doppler indices in patients with thyroid diseases and compare them with euthyroid reference values [7].

MATERIALS AND METHODS

Study Setting- This prospective observational study was conducted in the Department of Radio-diagnosis at Dr. B.R. Ambedkar Medical College & Hospital from June 2022 to January 2024.

Study Population- All patients referred for ultrasound of the neck (both inpatient and outpatient) to the Department of Radiodiagnosis at Dr. B.R. Ambedkar Medical College.

Inclusion Criteria

1. Clinically suspected cases of thyroid diseases.
2. Patients attending OPD/IPD for neck ultrasonography with available Thyroid Function Test reports.
3. Patients undergoing pre-operative evaluation for thyroid diseases.
4. Patients with focal or nodular lesions of the thyroid.

Exclusion Criteria

1. Pregnant patients.
2. Patients unwilling to undergo ultrasonography or fine-needle aspiration cytology.
3. Patients with partial or total thyroidectomy.
4. Non-consenting subjects.

Sample Size

The sample size was calculated using the formula:

$$N=4PQ / d^2$$

Where: p=75.8% (proportion)
Q=100 – P
d=15% of P (allowable error)

Study Tools

- A pre-designed, pre-tested questionnaire.
- GE VERSANA ultrasound machine (7–12 MHz linear probe).

Data Collection Procedure- All ultrasonographic examinations were performed using a GE VERSANA system equipped with a 7–12 MHz linear transducer, with ultrasound gel used as a coupling agent. Each patient was examined in the supine position with the neck hyperextended to allow optimal visualization of the thyroid gland, including its inferior margins near the clavicle. Initially, a B-mode scan was performed to assess the echogenicity of the gland and to detect any focal or diffuse lesions. The Superior Thyroid Artery (STA), which is the first anterior branch of the external carotid artery at the level of the hyoid bone, was then identified and traced to the upper pole of the thyroid gland, where Color Doppler mode was applied. After proper vessel localization, Spectral Doppler waveforms were obtained.

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Using standard Doppler settings to measure flow velocities and assess vascular parameters.

Statistical Analysis- Data were analyzed using SPSS 22. Categorical variables were compared using the Chi-square test. Continuous variables (mean±SD) were tested for normality, and group differences were assessed using the Independent t-test or Mann-Whitney U test. Diagnostic performance of PI, RI and PSV was evaluated using ROC curves. A p-value<0.05 was considered statistically significant.

Ethical Approval- Institutional Ethical Committee approval was obtained prior to initiation of the study.

RESULTS

In the study 30% had benign lesions, 20% had malignant lesions, 33.3% had Diffuse Thyroiditis and 16.7% had Grave's Thyrotoxicosis (Table 1).

Table 1: Type of Lesion Distribution among Subjects

Type of lesion	Count	Percentage (%)
Benign	18	30
Malignant	12	20
Diffuse Thyroiditis	20	33.3
Grave's Thyrotoxicosis	10	16.7
Total	60	100

Table 2 compares three key parameters—Age, Pulsatility Index (PI), and Resistive Index (RI)—between benign and malignant thyroid lesions. Malignant lesions demonstrated significantly higher PI and RI values than benign lesions, indicating increased vascular resistance commonly associated with malignancy. Age was also found to be significantly higher in malignant cases. An independent samples t-test was used to assess statistical significance, with p<0.05 considered statistically significant.

Table 2: Comparison of Age, PI, and RI Between Benign and Malignant Thyroid Lesions

Group	Parameters	Mean	SD	Median	p-value
Benign	Age (years)	33.72	7.54	33	0.011*
Malignant	Age (years)	43.50	12.06	42	
Benign	Pulsatility Index (PI)	0.76	0.21	0.69	<0.001*
Malignant	PI	1.56	0.25	1.61	
Benign	Resistive Index (RI)	0.59	0.08	0.57	<0.001*
Malignant	RI	0.83	0.06	0.83	

In the study among subjects with benign lesions, 11.1% were positive for Intranodular vascularity and 88.9% were negative for Intranodular vascularity. In subjects with malignant lesions, 16.7% were positive for Intranodular vascularity and 83.3% were negative for Intranodular vascularity. There was a significant difference in Intranodular vascularity between benign and malignant lesions (Table 3).

Table 3: Intranodular vascularity comparison between benign and malignant lesions

Intranodular vascularity	Group			
	Benign		Malignant	
	Count	Percentage (%)	Count	Percentage (%)
Negative	16	88.9	2	16.7
Positive	2	11.1	10	83.3

χ2 =15.64, df =1, p<0.001 (Chi-square test)*

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Table 4 shows that the mean age of subjects with Diffuse Thyroiditis was 35.75 ± 6.30 years, whereas the mean age among patients with Grave's disease was 48.80±6.82 years. The median age was 36 years and 47 years, respectively. This difference in age distribution between the two groups was highly significant (p<0.001), indicating that patients with Grave's disease tended to be older compared to those with Diffuse Thyroiditis.

Table 4: Age distribution comparison between diffuse thyroiditis and grave's disease

Groups	Age			p-value
	Mean	SD	Median	
Diffuse Thyroiditis	35.75	6.30	36	<0.001*
Grave's disease	48.80	6.82	47	

In subjects with Diffuse Thyroiditis, 90% were negative for TSHrAB and 10% were positive for TSHrAB and in subjects with Grave's disease, 100% were positive for TSHrAB. There was a significant difference in TSHrAB between Diffuse Thyroiditis and Grave's disease (Table 5).

Table 5: Tshrab Comparison Between Diffuse Thyroiditis and Grave's Disease

TSHrAB	Group			
	Diffuse Thyroiditis		Grave's disease	
	Count	%	Count	Percentage (%)
-	18	90.0%	0	0
+	2	10.0%	10	100

χ2=22.5, df =1, p<0.001 (Chi-square test)*

Table 6 presents the comparison of Peak Systolic Velocity (PSV) between Diffuse Thyroiditis and Grave's disease. The mean PSV in patients with Diffuse Thyroiditis was 33.25 ± 8.39 cm/s, with a median value of 33 cm/s. In contrast, patients with Grave's disease demonstrated a markedly higher mean PSV of 76.60±10.64 cm/s, with a median of 76 cm/s. The difference in PSV values between the two groups was highly significant (p<0.001), indicating that STA PSV is substantially elevated in Grave's disease compared to Diffuse Thyroiditis.

Table 6: PSV comparison between diffuse thyroiditis and grave's disease

Groups	PSV			p-value
	Mean	Standard Deviation	Median	
Diffuse Thyroiditis	33.250	8.385	33	<0.001*
Grave's disease	76.600	10.637	76	

This ROC curve demonstrates the diagnostic performance of Pulsatility Index (PI) for distinguishing benign from malignant thyroid nodules. The PI showed excellent discriminative ability, with an AUC of 0.99, indicating near-perfect accuracy. At the optimal cut-off value of >1.23**,** the sensitivity was 91.67% and the specificity was 100%, highlighting PI as a highly reliable parameter for malignancy evaluation (Fig. 1).

doi: 10.21276/SSR-IIJLS.2025.11.6.20

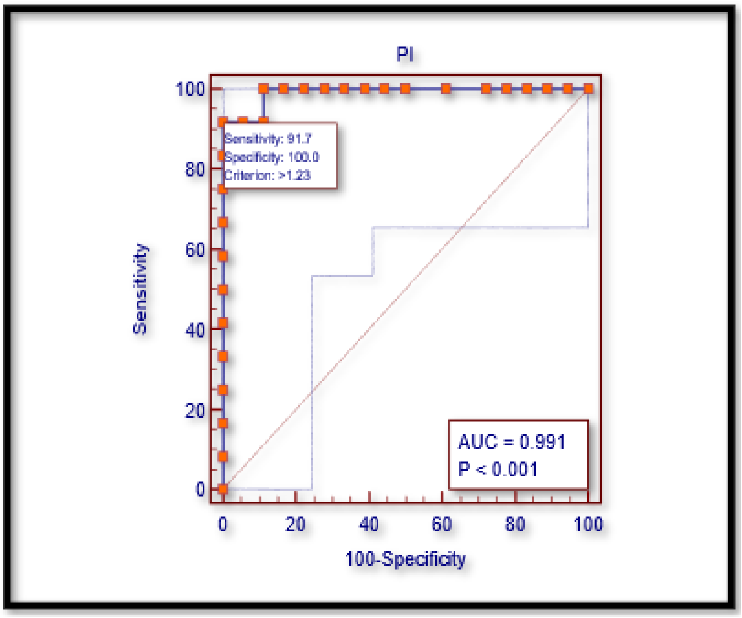

Fig. 1: ROC Curve showing Area under the curve for PI in differentiating benign and malignant nodules

This ROC curve illustrates the diagnostic accuracy of the Resistive Index (RI) in differentiating benign from malignant thyroid lesions. The RI demonstrated strong performance with an AUC of 0.98**.** Using an optimal cut-off value of >0.73, the sensitivity reached 100%, and specificity was 94.44%**,** confirming RI as a robust indicator of malignant vascular patterns (Fig. 2).

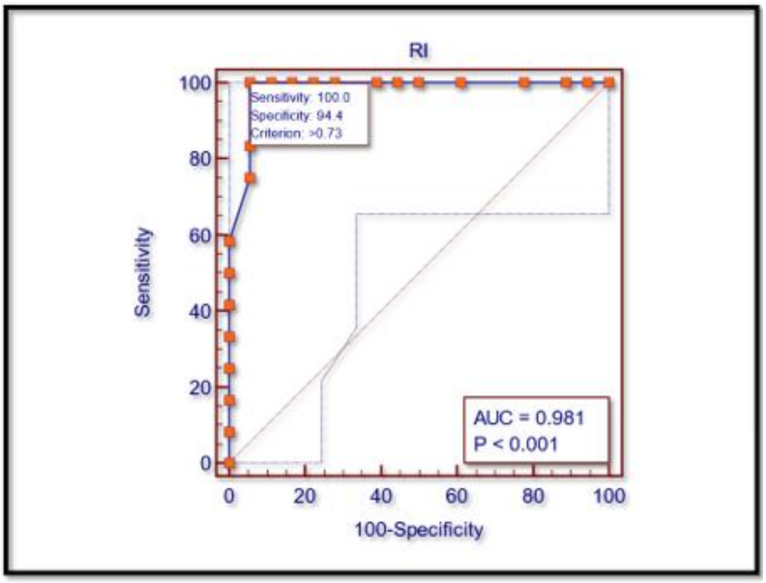

Fig. 2: ROC Curve for Resistive Index (RI) in Differentiating Benign and Malignant Thyroid Nodules

This ROC curve shows the ability of Peak Systolic Velocity (PSV) of the superior thyroid artery to distinguish Graves' disease from diffuse thyroiditis. The parameter achieved an AUC of 1.000, indicating perfect diagnostic accuracy. A PSV cut-off value of >47 cm/s provided 100% sensitivity and 100% specificity, establishing PSV as an excellent non-invasive marker for differentiating thyrotoxicosis etiologies (Fig. 3).

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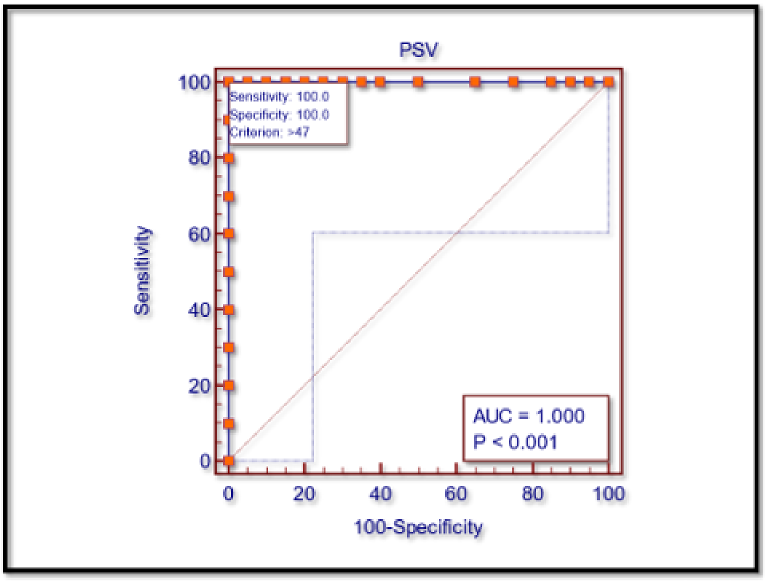

Fig. 3: ROC Curve for Peak Systolic Velocity (PSV) in Differentiating Graves' Disease from Diffuse Thyroiditis

DISCUSSION

Thyroid nodules represent a wide clinical spectrum, and differentiating benign from malignant lesions remains a frequent diagnostic challenge. Although high-resolution ultrasonography has significantly improved detection rates for thyroid nodules, B-mode features alone are often insufficient for confidently determining malignancy. Since routine FNAC is impractical for all nodules—particularly those<10 mm—functional vascular assessment through Doppler ultrasonography provides an important complementary tool [8].

In our study, Doppler indices of the Superior Thyroid Artery (STA) demonstrated clear differences between benign and malignant nodules. Malignant lesions showed significantly higher PI and RI values, indicating increased vascular impedance. These findings correspond with earlier literature where malignant nodules consistently exhibit elevated RI and PI due to architectural distortion, increased cellularity, and altered intranodular blood flow [9–12]. Bakhshaee et al. reported PI and RI values of 1.15±0.33 and 0.72±0.13 in malignant nodules, while Chammas *et al.* found PI 1.53±0.63 and RI 0.74±0.12, supporting the hemodynamic trend observed in our study [13,14]. The higher vascular resistance in malignant nodules is thought to result from compression or narrowing of intratumoral vessels, producing high systolic and reduced diastolic flow, thereby raising PI and RI [15]. A significant association between intranodular vascularity and malignancy was also observed in the present study. Increased internal vascularity has been widely documented as a suspicious sonographic marker and our findings reinforce this pattern [16].

The second objective of our study was to differentiate Graves' disease (GD) from Diffuse Thyroiditis (DT). Clinically, distinguishing these two etiologies of thyrotoxicosis can be difficult, especially when classical signs such as ophthalmopathy are absent. Although RAIU and TRAb are helpful, their application may be limited by cost, availability, or contraindications. Doppler ultrasonography offers a safe, rapid and widely accessible alternative for functional thyroid assessment [17].

Our results demonstrated that the peak systolic velocity of the STA (PSV-STA) was markedly elevated in GD compared to DT. This is consistent with earlier studies showing that GD produces a highly vascular thyroid gland, whereas DT shows normal or reduced flow due to inflammatory destruction [18,19]. Uchida et al. reported a mean PSV-STA of 78.48±36.28 cm/s in GD versus 28.0±12.84 cm/s in DT, values that closely resemble our findings [19]. Previous studies have proposed STA-PSV cut-offs such as >40 cm/s with high sensitivity and specificity [20], while another study suggested >50.5 cm/s as an optimal threshold [21]. In our study, a cut-off >47 cm/s yielded 100% sensitivity and 100% specificity (AUC=1.00), demonstrating exceptionally high diagnostic accuracy.

An Indian cohort by Sundarram et al. also reported significantly higher PSV-STA in GD, although no definitive cut-off was proposed [22]. A positive correlation between

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TRAb levels and Doppler flow has been described in previous research, and our results similarly demonstrated that elevated STA-PSV corresponded with TRAb positivity, supporting its diagnostic role in distinguishing GD from DT [23].

Overall, the present study confirms that STA Doppler indices (PI, RI, PSV) are robust, reproducible, and clinically valuable parameters. PI and RI assist in differentiating malignancy in thyroid nodules, while PSV-STA serves as an excellent marker for separating GD from DT. Incorporating these Doppler parameters into routine thyroid ultrasound examinations can significantly improve diagnostic confidence, reduce unnecessary FNAC procedures, and provide rapid non-invasive differentiation of thyrotoxicosis etiologies.

CONCLUSIONS

The present study demonstrates that Doppler evaluation of the Superior Thyroid Artery (STA) is a reliable, non-invasive, and easily reproducible tool for assessing thyroid vascularity and differentiating functional states of the gland. STA peak systolic velocity and other Doppler indices showed a clear correlation with thyroid hormone status, with significantly higher values in hyperthyroid subjects compared to euthyroid individuals. These vascular changes reflect the underlying physiological hypervascularity associated with increased thyroid activity. The findings also support the usefulness of STA Doppler in distinguishing Graves' disease from thyroiditis, where vascular patterns often overlap on gray-scale imaging. Incorporating STA Doppler assessment into routine thyroid ultrasonography can therefore enhance diagnostic accuracy, reduce dependence on laboratory markers in ambiguous cases, and assist in treatment monitoring. Overall, this modality offers an efficient extension of conventional ultrasound and holds substantial clinical value in the evaluation of thyroid disorders.

CONTRIBUTION OF AUTHORS

Research concept- Karthik N, Anushree CK, Chandramouly M
Research design- Karthik N, Anushree CK
Supervision- Chandramouly M
Materials- Karthik N, Anushree CK, Chandramouly M
Data collection- Karthik N, Anushree CK
Data analysis and interpretation- Karthik N, Anushree CK
Literature search- Karthik N, Anushree CK, Chandramouly M
Writing article- Karthik N, Anushree CK, Chandramouly M
Critical review- Chandramouly M
Article editing- Karthik N, Anushree CK
Final approval- Chandramouly M

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