Evaluation of the Relationship Between Resistive Index, Elastographic Stiffness, and TI-RADS Category in Thyroid Nodules

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Abstract

Aim: To investigate the relationship between Doppler-derived resistive index (RI) values, TI-RADS categories, and shear-wave elastography (SWE) parameters in solid thyroid nodules, and to determine whether RI contributes additional value to imaging-based characterization.

Methods: This retrospective study included 52 patients with 52 solid thyroid nodules larger than 1 cm. All nodules were evaluated with grayscale ultrasonography, Doppler sonography, and SWE. TI-RADS categories were assigned according to standard B-mode criteria. Vascularity was classified into four Doppler patterns, and RI was measured from intranodular arterial flow in nodules exhibiting pattern 2 or 3 vascularization. SWE measurements included mean shear-wave velocity (Vmean) and velocity standard deviation (Vsd). Associations between RI and demographic (age, sex), morphologic (nodule size, TI-RADS), and elastographic (Vmean, Vsd) variables were analyzed using correlation and nonparametric tests. Histopathology was available only in a limited subgroup and was therefore not used as a primary endpoint.

Results: The mean age was 49.28 ± 14.55 years; 88.5% of patients were male. TI-RADS categories were TI-RADS 2 in 19 nodules (36.5%), TI-RADS 3 in 29 nodules (55.8%), and TI-RADS 4 in 4 nodules (7.7%). Mean nodule diameter was 17.06 ± 6.63 mm. Vmean and Vsd were 2.47 ± 0.86 m/s and 0.62 ± 0.39 m/s, respectively. Mean RI was 0.52 ± 0.14. RI showed no significant association with age, sex, nodule side, size, Vmean, or Vsd. Although RI values were slightly higher in TI-RADS ≥ 3 nodules compared to lower TI-RADS categories, this difference was not statistically significant (p = 0.054).

Conclusions: In this preliminary cohort, RI was not significantly associated with TI-RADS classification or SWE-derived stiffness parameters. These findings suggest that RI offers limited additional diagnostic value beyond conventional ultrasonography and elastography in the structural evaluation of thyroid nodules.

Keywords: *Shear wave elastography; resistive index; thyroid nodule; TI-RADS; Doppler sonography*

1. Introduction

Thyroid nodules are commonly encountered in the general population, although only approximately 5% are malignant. [1-4] Most thyroid nodules, whether benign or malignant, are asymptomatic and are typically detected incidentally during routine physical examinations or ultrasonographic imaging. While grayscale ultrasonography can diagnose papillary thyroid carcinoma with a reported accuracy of nearly 90%, its sensitivity is limited when it comes to identifying all types of nodules, particularly follicular lesions (e.g., adenoma, follicular carcinoma, and the follicular variant of papillary carcinoma). This limitation arises because the definitive diagnosis of a follicular neoplasm depends on the identification of capsular or vascular invasion, which generally requires histopathological evaluation or surgical excision.[5]

However, a significant proportion of patients undergoing surgery for suspected follicular lesions are ultimately found to have benign pathology.[6] Therefore, there is a growing need to develop non-invasive methods to improve the accuracy of differentiating benign from malignant nodules, reducing unnecessary surgical interventions.

Although considerable advances have been made in this area through artificial intelligence (AI) and texture analysis software, the integration of these technologies into routine clinical practice remains limited and is expected to take time. In the interim, numerous studies have explored various imaging-based approaches to enhance diagnostic accuracy using currently available tools.[7,8]

To this end, the Thyroid Imaging Reporting and Data System (TI-RADS) was developed by the American College of Radiology. This system stratifies nodules into five categories based on ultrasonographic features and their corresponding risk of malignancy.[9] Despite its widespread use, the application of TI-RADS remains somewhat subjective, as interpretation can vary depending on the experience and perspective of the examiner, and full standardization has yet to be achieved.

Therefore, the aim of this study was to investigate the relation-

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ship between Doppler-derived resistive index (RI), TI-RADS categories, and shear-wave elastography (SWE) parameters in solid thyroid nodules. Rather than focusing on definitive benign-malignant discrimination, this study was designed to explore imaging-based correlations that may contribute to a better understanding of the complementary role of Doppler and elastography findings within established ultrasound risk stratification systems.

2. Materials and Methods

Study Population

This retrospective study included patients who underwent thyroid ultrasonography (US) for routine check-ups and were followed for thyroid nodules at our clinic between January 2020 and April 2021. Patients with a history of radiotherapy to the head and neck region, a diagnosis of connective tissue disease, previous thyroid surgery, or those with thyroid parenchymal diseases (e.g., Hashimoto's thyroiditis, Graves' disease, or subacute thyroiditis) identified clinically or via ultrasonography were excluded.

Figure 1

Demonstration of intranodular flow patterns in the evaluation of nodules by Doppler ultrasonography.

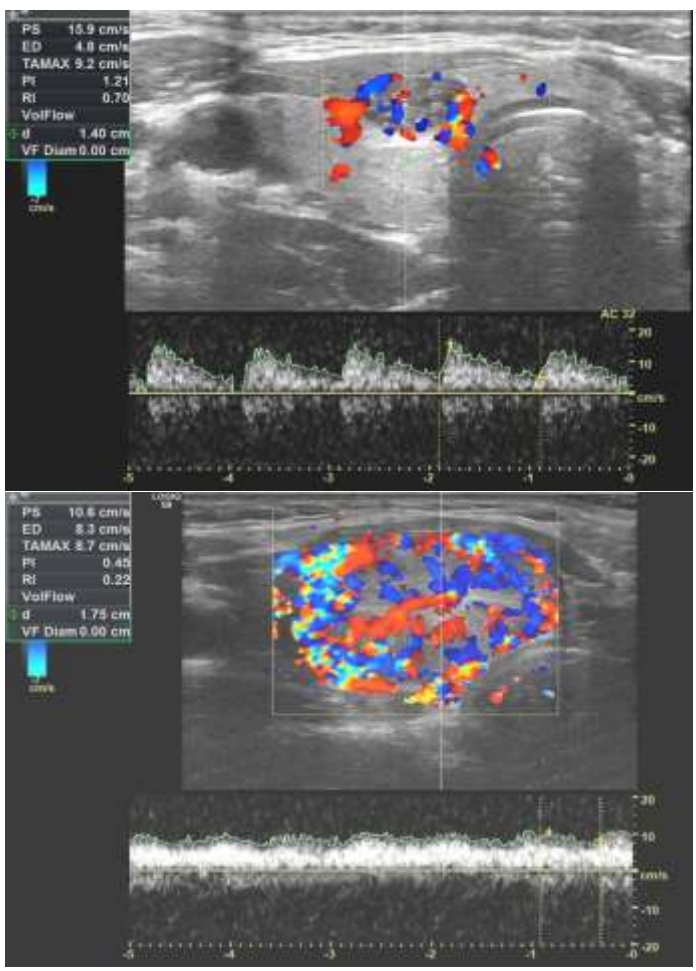

Figure 1a. Peripheral weighted blood supply pattern showing moderate internal blood supply (pattern 2); Figure 1b. nodule with extensive internal blood supply (pattern 3)

Only solid thyroid nodules larger than 1 cm were included in the analysis. Cystic, mixed cystic, and nodules smaller than 1 cm were excluded to maintain homogeneity. Thus, the final analysis included only solid thyroid nodules >1 cm in size.

Imaging Protocol

All patients underwent grayscale ultrasonography, Doppler sonography, and shear wave elastography (SWE) of the thyroid gland. All imaging was performed using a LOGIQ S8 (GE HealthCare, XDclear 2.0+ Ultrasound System) by a single radiologist with over 10 years of experience in head and neck imaging (D.E.T.S). A M6-15 probe was used for grayscale imaging, while a 9L probe was employed for both Doppler and SWE evaluations.

Gray-scale Ultrasonography Evaluation

Each nodule was evaluated for the following features: maximum diameter, echogenicity (hyperechoic, isoechoic, hypoechoic), shape (oval, round), margins (smooth, indistinct, irregular, extrathyroidal extension), and the presence of calcifications (comet-tail artifact, macrocalcifications, peripheral calcifications, punctate echogenic foci). Based on these sonographic features, TI-RADS categories were assigned in accordance with established criteria.[10]

Figure 2

Spectral Doppler and shear-wave elastography (SWE) evaluation of a representative solid thyroid nodule

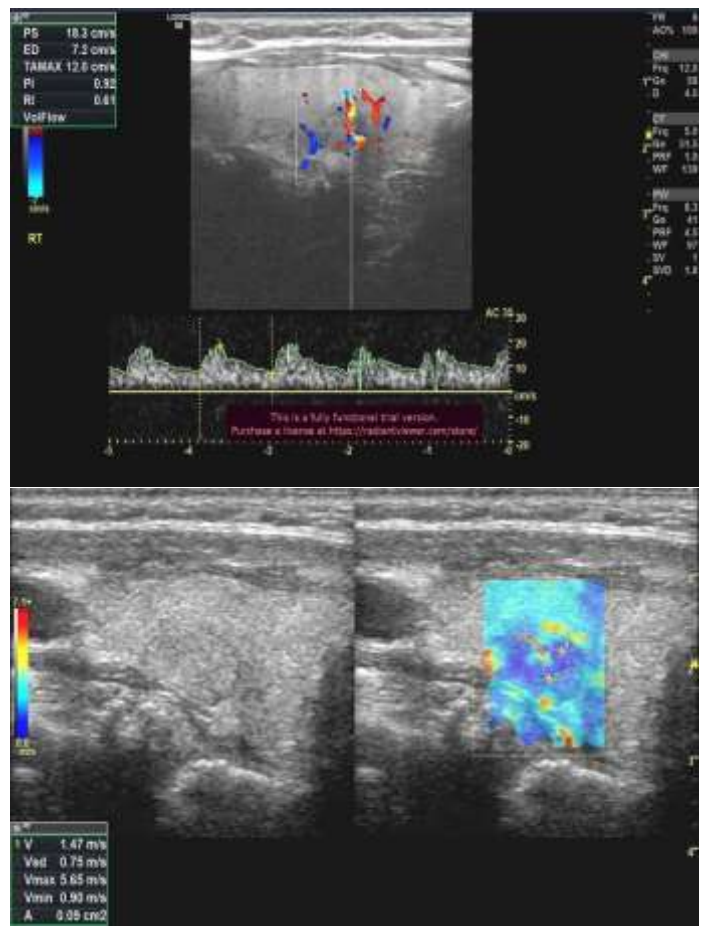

Figure 2a demonstrates RI measurement obtained from a representative intranodular feeding artery using spectral Doppler analysis. Figure 2b shows SWE assessment, in which the color-coded elastographic map represents shear-wave velocity distribution (with warmer colors indicating higher stiffness and cooler colors indicating lower stiffness). The region of interest (ROI) was manually adjusted to include the entire nodule while avoiding surrounding thyroid parenchyma, and mean shear-wave velocity (Vmean) and velocity standard deviation (Vsd) values were calculated accordingly.

Doppler Sonography Evaluation

Intranodular vascularization patterns were classified into four categories[11]:

Pattern 0: No visible blood flow; Pattern 1: Peripheral vascular

ring with minimal or no internal flow; Pattern 2: Peripheral vascular ring with mild to moderate internal flow; Pattern 3: Extensive internal flow with or without a peripheral vascular ring

To evaluate resistive index (RI) values, only nodules with Pattern 2 or Pattern 3 vascularization were included (Figure 1). Spectral Doppler analysis was then used to measure RI from intranodular arterial flow, and values were automatically calculated and recorded by the ultrasound system. RI measurements were obtained from a single representative intranodular artery showing the most prominent and stable arterial waveform in each nodule, and a single measurement was recorded for analysis.

Shear Wave Elastography (SWE) Evaluation

During SWE, a gel pad was applied to improve acoustic contact, and patients were instructed to hold their breath during measurements. SWE was performed to measure mean shear wave velocity (Vmean) and velocity standard deviation (Vsd) in m/s. The region of interest (ROI) was adjusted to encompass the entire nodule, to ensure accurate representation of stiffness parameters (Figure 2).

Ethical Approval

This retrospective study was approved by the Acıbadem Mehmet Ali Aydınlar University Medical Research Evaluation Committee (ATADEK) with decision number 2021-15/22. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Statistical Analysis

Descriptive statistics (mean, standard deviation, median, minimum, maximum, frequency) were used to summarize the data. The Shapiro-Wilk test and graphical methods were used to assess the normality of quantitative variables. For comparison between two groups of non-normally distributed variables, the Mann-Whitney U test was applied. Pearson and Spearman correlation analyses were used to assess the relationships between quantitative variables. A p-value < 0.05 was considered statistically significant. All statistical analyses were performed using standard software.

3. Results

A total of 52 patients with 52 solid thyroid nodules were included in the study. The general demographic and ultrasonographic characteristics of the cohort are summarized in Table 1. The mean age of the patients was 49.28 ± 14.55 years (range: 21–85), and the majority were male (88.5%), reflecting the referral pattern of the study population. Twenty-eight nodules (53.8%) were located in the right lobe and 24 (46.2%) in the left lobe. The mean nodule diameter was 17.06 ± 6.63 mm (range: 10–35).

According to TI-RADS categorization, 19 nodules (36.5%) were classified as TI-RADS 2, 29 (55.8%) as TI-RADS 3, and 4 nodules (7.7%) as TI-RADS 4. The relatively small number of TI-RADS 4 nodules limited the ability to perform robust subgroup comparisons across TI-RADS categories. The mean shear-wave elastography values were 2.47 ± 0.86 m/s for Vmean and 0.62 ± 0.39 m/s for Vsd. The mean resistive index (RI) measured from intranodular arterial flow was 0.52 ± 0.14 (range: 0.2–0.9).

Histopathological results were available in a limited subgroup of 12 nodules and were not used for statistical comparisons due to insufficient sample size; therefore, the primary outcomes of the study focused on imaging-based correlations rather than benign–malignant differentiation.

Relationship between RI and clinical/sonographic variables

RI values did not differ significantly according to sex (p = 0.812) or side of the nodule (p = 0.304) (Table 2). There was no significant correlation between RI and patient age (r = 0.203, p = 0.157) or nodule diameter (r = 0.058, p = 0.681).

Table 1

General characteristics of cases and nodules

Age	*Mean±SD*	49.28±14.55
	Median (Min-Max)	46.5 (21-85)
Gender *n(%)*	Female	6 (11,5)
	Male	46 (88.5)
Side *n(%)*	Right	28 (53.8)
	Left	24 (46.2)
TIRADS category *n(%)*	2	19 (36.5)
	3	29 (55.8)
	4	4 (7.7)
Diameter *(mm)*	*Mean±SD*	17.06±6.63
	Median (Min-Max)	16 (10-35)
Vmean *(m/sn)*	*Mean±SD*	2.47±0,86
	Median (Min-Max)	2.3 (1.2-4.8)
Vsd	*Mean±SD*	0.62±0.39
	Median (Min-Max)	0.5 (0.1-2.1)
RI	*Mean±SD*	0.52±0.14
	Median (Min-Max)	0.5 (0.2-0.9)

TIRADS Thyroid imaging reporting and data system; Vsd Velocity standard deviation; RI resistive index

Table 2

The statistical relationship between RI and other parameters

		RI		
		Mean±SD	Median (Min-Max)	p
Gender	Female	0,51±0,06	0,5 (0,4-0,6)	[a]*0,812*
	Male	0,53±0,15	0,5 (0,2-0,9)	
Side	Right	0,51±0,15	0,5 (0,3-0,9)	[a]*0,304*
	Left	0,55±0,13	0,5 (0,3-0,9)	
TIRADS category	<3	0,49±0,14	0,5 (0,3-0,9)	[a]*0,054*
	≥3	0,55±0,14	0,6 (0,3-0,9)	
Age	ǂ*r*		*0,203*	
	p		*0,157*	
Diameter	†*r*		*0,058*	
	p		*0,681*	
Vmean	†*r*		*-0,106*	
	p		*0,456*	
Vsd	†*r*		*0,265*	
	p		*0,058*	

[a]*MannWhitney U Test, ǂr: Pearson correlation coefficient, †r: Spearman's correlation coefficient*

Relationship between RI and TI-RADS categories

Although nodules with TI-RADS ≥ 3 tended to show slightly higher RI values than those with TI-RADS < 3 (0.55 ± 0.14 vs. 0.49 ± 0.14), this difference did not reach statistical significance (p = 0.054). This finding did not reach statistical significance and should therefore be interpreted with caution, particularly given the limited sample size.

Relationship between RI and elastography parameters

No significant correlation was observed between RI and Vmean (r = –0.106, p = 0.456). Similarly, the association between RI and Vsd did not reach significance (r = 0.265, p = 0.058), although a mild trend toward higher RI with increased elastographic heterogeneity was noted.

Representative Imaging Examples

Color Doppler images demonstrated a range of intranodular vas-

cularity patterns, from moderate internal flow with higher RI values (Figure 1a; RI = 0.70) to extensive internal hypervascularity with low resistance flow profiles (Figure 1b; RI = 0.22). Additional nodules showed intermediate RI values with mixed internal-peripheral vascularity patterns (Figure 1c; RI = 0.61). Shear-wave elastography examples highlighted nodules with low stiffness (Vmean = 1.47 m/s) and moderate heterogeneity (Vsd = 0.75 m/s) (Figure 2), consistent with the wide variability observed across the cohort.

Overall, no statistically significant relationships were found between Doppler RI and TI-RADS category, nodule stiffness (Vmean), or elastographic heterogeneity (Vsd). The results indicate that, within this preliminary cohort, RI did not provide additional characterization beyond conventional ultrasonography and elastographic assessment.

4. Discussion

In this study, we evaluated the relationship between Doppler-derived resistive index (RI) values and both TI-RADS categorization and shear-wave elastography parameters in solid thyroid nodules. Consistent with the statistical analysis, no significant associations were identified between RI and TI-RADS category or elastographic stiffness. These findings suggest that RI does not provide substantial additional information for imaging-based characterization of thyroid nodules. These results should be interpreted as imaging-based correlations rather than definitive measures of diagnostic performance, particularly in the absence of comprehensive histopathological confirmation.

Grayscale ultrasonography remains the primary determinant of TI-RADS scoring, and features such as punctate echogenic foci, microlobulated or irregular margins, extrathyroidal extension, marked hypoechogenicity, and a taller-than-wide shape are well-established predictors of higher malignancy risk. In contrast, vascularity characteristics are not incorporated into the TI-RADS system, largely because previous studies have demonstrated inconsistent or limited diagnostic value. The absence of a meaningful relationship between RI and TI-RADS in our cohort supports this rationale, indicating that Doppler parameters alone should not be relied upon for risk stratification.

Many studies have investigated the predictive role of TDUS parameters in assessing malignancy risk in thyroid nodules. Among these Doppler-based features, peripheral versus central vascularity patterns, power Doppler findings, and RI values have been the most frequently evaluated. While several reports have shown that vascularity patterns alone are not reliable indicators of malignancy[12], some studies suggest that a predominantly peripheral perfusion pattern may favor benignity, whereas centrally dominant or mixed internal vascularization tends to be more common in malignant nodules.[11,13] These heterogeneous results in the literature further support the limited standalone utility of vascularity-based Doppler parameters, including RI, in routine thyroid nodule assessment.

The spectral Doppler-derived resistive index (RI) has been proposed as a more objective hemodynamic marker for differentiating malignant from benign thyroid lesions.[14,15] Several analyses have suggested that malignant nodules tend to show higher RI values, a finding attributed to increased intranodular resistance and reduced vascular compliance resulting from heightened cellularity, stromal fibrosis, and altered microvascular architecture.[13,14,16,17] Holden et al. reported mean RI values of 0.76 in carcinomas, 0.66 in adenomas, and 0.57 in colloid nodules, supporting the potential discriminatory value of RI.[16] Similarly, other studies have proposed RI thresholds above 0.70-0.75 as being strongly suggestive of malignancy.[13,17] However, the heterogeneity of reported cutoff values and the inconsistent performance of RI across different study populations highlight that its diagnostic utility may be context-dependent rather than universal.

In our series, the mean RI value for benign nodules was 0.53, which is consistent with previously published data. Interestingly, the mean RI of the few malignant nodules with histopathological confirmation (papillary thyroid carcinoma) was 0.51, slightly lower than that of the benign group. Although this observation contrasts with most prior reports, it must be interpreted with caution given the very limited number of malignant cases in our study. Moreover, malignant thyroid nodules, particularly papillary carcinomas, may demonstrate immature, thin-walled neovessels with reduced smooth muscle development, resulting in lower vascular resistance and consequently lower RI values. Such hemodynamic characteristics have been described in rapidly proliferating tumors and may partially explain the unexpectedly low RI measurements observed in our small malignant subgroup.

Blood supply is indispensable for tumor formation and progression, and malignant thyroid nodules frequently induce neoangiogenesis in response to growth factors secreted by tumor cells.[13] However, the neovessels formed in this process are typically immature, lacking fully developed smooth muscle layers and normal structural integrity. As a result, they demonstrate reduced vascular resistance and increased permeability, which may lead to unexpectedly low RI values in some malignant nodules. This physiological explanation supports the possibility that papillary carcinomas with rapid cellular turnover may exhibit low-resistance flow profiles despite their malignant nature.

The paradox of why certain malignant nodules in other studies demonstrate *high* RI values has been addressed by Bude and Rubin, who proposed that RI is influenced not only by resistance but also by vascular compliance.[18] According to this model, higher RI values may occur when vessel walls, although abnormal, exhibit increased stiffness or reduced distensibility. In addition, the high cellular density and increased intranodular pressure associated with rapidly growing malignant nodules may elevate downstream resistance, thereby contributing to higher RI measurements in some cases. Taken together, these mechanisms illustrate why malignant nodules can display either low or high RI values and highlight the complexity of relying on a single Doppler parameter for diagnostic stratification.

Elastography has become an important modality for differentiating benign from malignant thyroid nodules, as malignant lesions are generally firmer due to increased myofibroblast activity and stromal remodeling.[19] In a meta-analysis of 20 studies, Nell et al. demonstrated that completely soft nodules on elastography rarely harbor malignancy, thereby highlighting the potential of elastographic assessment to reduce unnecessary biopsies.[14,20] Additional studies have supported the diagnostic utility of elastographic parameters: Liao et al. reported elastography as an independent predictor of malignancy, while Yeon et al. found that among several elastographic markers, only Emax remained independently associated with cancer risk.[19,21] Similarly, Park et al. identified both Emean and Emax as significant independent predictors.[22] On the other hand, Yoo et al. noted that Emean correlates more strongly with histopathologic fibrosis rather than malignancy itself, with Emax showing only weak diagnostic value.[23]

Despite these inconsistencies, many studies have proposed threshold values to aid clinical interpretation. In general, Vmean values above approximately 3.0 m/s raise suspicion for malignancy.[24] Azizi et al. suggested a Vmean cutoff of 3.54 m/s for benign–malignant differentiation, whereas Baş et al. reported that Emean values exceeding 33 kPa (equivalent to a shear wave speed of roughly 4.5 m/s) were strongly predictive of malignancy.[25,26] In

addition to absolute stiffness, intranodular heterogeneity is typically greater in malignant nodules because neoplastic cells often exist at different stages of the cell cycle and demonstrate variable stromal composition.[27,28] This increased heterogeneity translates into a broader range of shear-wave velocities on elastography, reflected in higher Vsd values.[27]

For this reason, our study evaluated both Vmean and Vsd parameters. However, Vsd values were identical between benign and malignant nodules (0.62 in both groups), and no significant relationship was observed between RI and Vsd. These findings likely reflect the very limited number of malignant nodules in our cohort, which restricts the ability to detect subtle differences in stiffness or heterogeneity. Larger, adequately powered studies are needed to clarify the relationship between RI, elastographic parameters, and the biological behavior of thyroid nodules.

Limitations related to shear-wave elastography (SWE) must also be considered. Velocity measurements can yield both false-negative and false-positive results, particularly in nodules smaller than 1 cm or in very large lesions.[29] While large nodules may appear misleadingly stiff, small malignant nodules can present as deceptively soft. Moreover, rapidly growing malignant nodules may develop central necrosis, which can reduce stiffness and lead to unexpectedly low elastographic values. These technical and biological factors must be taken into account when interpreting SWE findings. In the present study, we attempted to minimize such sources of error by excluding nodules smaller than 1 cm, and the largest nodule in our cohort measured 35 mm, a size that is unlikely to introduce extreme stiffness artifacts.

Despite these methodological precautions, our study has several important limitations. The most significant is the absence of histopathological confirmation for the majority of nodules, which restricts the ability to draw firm conclusions regarding the diagnostic performance of RI or SWE in malignancy differentiation. Additionally, the overall sample size was relatively small, and the number of malignant nodules was particularly limited, reducing statistical power and increasing the likelihood of type II error. These factors underscore the need for larger, prospectively designed studies with adequate histopathological sampling to more definitively assess the relationships among RI, elastographic parameters, and TI-RADS categorization.

5. Conclusions

In this preliminary imaging-based study, Doppler-derived resistive index (RI) values showed no significant association with TI-RADS categories or shear-wave elastography parameters in solid thyroid nodules. These findings indicate that RI provides limited additional value beyond conventional ultrasonography and elastography for the structural characterization of thyroid nodules. Larger studies with adequate histopathological confirmation are required to further clarify the potential role of RI in thyroid nodule assessment.

Statement of ethics

This retrospective study was approved by the Acıbadem Mehmet Ali Aydınlar University Medical Research Evaluation Committee (ATADEK) with decision number 2021-15/22. The study was conducted in accordance with the principles of the Declaration of Helsinki.

genAI

No artificial intelligence-based tools or generative AI technologies were used in this study. The entire content of the manuscript was originally prepared, reviewed, and approved by both authors.

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Conflict of interest statement

The authors declare that they have no conflict of interest.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author Contributions

D.E.T.S.: Data curation, Software, Supervision, Validation, Visualization, Writing original draft, Writing – review & editing.
B.T.: Conceptualization, Methodology, Supervision, Formal analysis, Writing – review & editing.

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