RESEARCH PAPER

# Diagnostic Performance of Ultrasound Elastography in Differentiating Benign and Malignant Thyroid Nodules: A Prospective Cross-Sectional Study

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**Abstract**
Background: Thyroid nodules are among the most common endocrine abnormalities encountered in clinical practice. Although most thyroid nodules are benign, accurate identification of malignant lesions remains crucial for appropriate management. Conventional ultrasonography is the primary imaging modality for thyroid nodule evaluation; however, overlap in imaging characteristics often limits diagnostic specificity. Ultrasound elastography has emerged as a valuable adjunctive technique that assesses tissue stiffness, potentially improving differentiation between benign and malignant thyroid nodules. Objective: To evaluate the diagnostic performance of ultrasound elastography in differentiating benign and malignant thyroid nodules using cytopathology and histopathology as reference standards. Methods: A prospective cross-sectional study was conducted involving 180 consecutive patients presenting with thyroid nodules. All participants underwent conventional ultrasound and strain elastography. Elastography scores were assigned using a five-point elasticity scoring system. Fine needle aspiration cytology (FNAC) and surgical histopathology were used as reference standards. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), diagnostic accuracy, and receiver operating characteristic (ROC) analysis were performed. Results: Among 180 thyroid nodules evaluated, 48 (26.7%) were malignant and 132 (73.3%) were benign. Elastography scores 4–5 were significantly associated with malignancy ($p<0.001$). Ultrasound elastography demonstrated a sensitivity of 89.6%, specificity of 84.8%, PPV of 68.3%, NPV of 95.7%, and overall diagnostic accuracy of 86.1%. ROC analysis yielded an area under the curve (AUC) of 0.91 (95% CI: 0.86–0.96), indicating excellent discriminatory performance. Conclusion: Ultrasound elastography significantly improves differentiation between benign and malignant thyroid nodules and may reduce unnecessary invasive procedures. Incorporation of elastography into routine thyroid imaging protocols can enhance diagnostic confidence and optimise patient management.

**Keywords:** Thyroid nodule; Ultrasound elastography; Strain elastography; Thyroid cancer; Diagnostic accuracy; Radiology.

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## 1. Introduction

Thyroid nodules are among the most frequently encountered endocrine abnormalities worldwide and represent a significant clinical concern because of their potential association with thyroid malignancy. Advances in diagnostic imaging, particularly the widespread availability of high-resolution ultrasonography, have substantially increased the detection of thyroid nodules over the past two decades. While palpable thyroid nodules are identified in approximately 4–7% of adults during physical examination, ultrasonography can detect thyroid nodules in up to 60–70% of the general population, indicating that many lesions remain clinically silent throughout life [1,2]. The prevalence of thyroid nodules increases with age and is higher among women, individuals with iodine deficiency, and patients exposed to radiation during childhood [3,4]. Although the majority of thyroid nodules are benign, approximately 5–15% may harbor malignancy, making accurate risk stratification essential for optimal patient management [5]. The incidence of thyroid cancer has also increased globally during recent decades, partly because of improved diagnostic capabilities and greater use of imaging studies [6]. Papillary thyroid carcinoma remains the most common histological subtype, accounting for nearly 80–85% of all thyroid malignancies [7]. Despite generally favorable survival outcomes, delayed diagnosis of malignant thyroid nodules may result in local invasion, lymph node metastasis, and increased treatment complexity [8]. Consequently, early and reliable differentiation between benign and malignant thyroid lesions has become an important objective in endocrine and radiological practice. Conventional ultrasonography is currently regarded as the first-line imaging modality for the evaluation of thyroid nodules because it is non-invasive, widely available, cost-effective, and capable of providing excellent anatomical detail [9]. Modern ultrasound systems enable detailed assessment of nodule composition, echogenicity, margins, shape, calcification patterns, and vascular characteristics. Numerous studies have demonstrated that certain sonographic features are associated with a higher risk of malignancy. These include marked hypoechogenicity, irregular or infiltrative margins, micro-calcifications, taller-than-wide orientation, disrupted peripheral halo, and evidence of extra-thyroidal extension [10,11]. Such findings form the basis of several standardised risk stratification systems, including the American College of Radiology Thyroid Imaging Reporting and Data System (ACR TI-RADS) and the European Thyroid Association EU-TIRADS classification [12,13].

Despite the widespread use of ultrasonography, considerable overlap exists between the imaging appearances of benign and malignant thyroid nodules. Benign lesions may occasionally exhibit suspicious sonographic characteristics, whereas certain malignant tumors may demonstrate relatively benign appearances [14]. As a result, conventional ultrasound alone often lacks sufficient specificity for definitive diagnosis. This limitation frequently necessitates ultrasound-guided fine needle aspiration cytology (FNAC), which remains the current standard diagnostic procedure for thyroid nodule evaluation [15]. Although FNAC has excellent diagnostic performance, it is invasive, operator-dependent, and occasionally yields indeterminate or non-diagnostic results, creating uncertainty in clinical decision-making [16]. To address these limitations, several advanced imaging techniques have been developed to improve the characterisation of thyroid nodules. Among these innovations, ultrasound elastography has emerged as a promising adjunctive imaging modality. Elastography is based on the principle that biological tissues possess different mechanical properties and that pathological processes may alter tissue stiffness [17]. By measuring tissue deformation in response to an externally applied force or internally generated acoustic impulse, elastography provides additional functional information that complements conventional grayscale ultrasonography [18]. The biological basis for elastographic assessment is particularly relevant in thyroid cancer. Malignant thyroid lesions often demonstrate increased stiffness compared with benign nodules because of greater cellular density, fibrosis, desmoplastic reactions, calcification, and architectural distortion within the tumor microenvironment [19,20]. These pathological changes reduce tissue elasticity and can be detected using elastographic techniques. Consequently, tissue stiffness has been proposed as a useful biomarker for malignancy risk assessment in thyroid nodules [21].

Several elastographic techniques are currently available, including strain elastography and shear-wave elastography. Strain elastography assesses tissue displacement caused by manual compression or physiological pulsation and provides qualitative or semi-quantitative measurements of tissue stiffness [22]. Shear-wave elastography, in contrast, generates quantitative measurements of tissue elasticity by evaluating the propagation velocity of shear waves through tissue [23]. Among these methods, strain elastography remains widely utilised because of its relative simplicity, accessibility, and integration into routine ultrasound examinations [24]. Over the past decade, numerous studies have investigated the diagnostic utility of ultrasound elastography in thyroid nodule evaluation. Early work by Rago et al. demonstrated that elastography could significantly improve the differentiation of benign and malignant thyroid lesions compared with conventional ultrasonography alone [25]. Subsequent studies conducted across Europe, Asia, and North America reported encouraging diagnostic accuracy, with sensitivity and specificity values frequently exceeding 80% [26–28]. Several meta-analyses have further supported these findings, suggesting that elastography may enhance risk stratification and reduce unnecessary biopsy procedures in selected patient populations [29,30]. Despite these promising results, important challenges remain. Significant variability exists among published studies regarding patient selection criteria, elastography techniques, elasticity scoring systems, operator expertise, and reference standards used for diagnosis [31]. Furthermore, certain pathological subtypes, particularly follicular neoplasms and partially cystic lesions, continue to pose diagnostic difficulties because their stiffness characteristics may overlap with those of benign nodules [32]. These inconsistencies have contributed to ongoing debate regarding the precise role of elastography in routine clinical practice. Another important consideration is the relative scarcity of prospective studies from developing countries, where healthcare resources, disease patterns, and patient demographics may differ from those reported in high-income settings [33]. Additional evidence from diverse populations is necessary to validate the clinical utility of elastography and determine its generalisability across different healthcare environments. Such investigations are essential for establishing standardised imaging protocols and optimising patient care pathways. Given these considerations, the present study was designed to evaluate the diagnostic performance of ultrasound strain elastography in differentiating benign and malignant thyroid nodules using cytopathological and histopathological findings as reference standards. Furthermore, the study aimed to assess the potential role of elastography as an adjunctive imaging modality to conventional ultrasonography in routine radiological practice. By examining its diagnostic accuracy, sensitivity, specificity, and predictive values, this research seeks to contribute additional evidence regarding the clinical applicability of elastography and its potential impact on the management of patients with thyroid nodules.

## Materials and Methods

### Study Design and Setting

This prospective cross-sectional study was conducted in the Department of Radiology over a two-year period from January 2024 to December 2025. The study was designed to evaluate the diagnostic performance of ultrasound strain elastography in differentiating benign and malignant thyroid nodules. A prospective design was selected because it allows systematic data collection, minimises recall bias, and enables standardised imaging assessment across all participants [34,35]. The study protocol was developed in accordance with established recommendations for diagnostic accuracy studies and observational research involving human participants [36].

**Study Population**

Patients referred to the radiology department for evaluation of thyroid nodules detected clinically or through imaging were screened for eligibility. A total of 180 consecutive patients with one or more thyroid nodules identified on conventional ultrasonography were enrolled during the study period. Consecutive sampling was adopted to reduce selection bias and improve the representativeness of the study population [37]. Demographic information, including age, sex, clinical presentation, thyroid function status, and relevant medical history, was recorded for all participants at the time of enrolment. When multiple nodules were present, the nodule demonstrating the most suspicious ultrasonographic characteristics was selected for detailed analysis, consistent with previously published thyroid imaging studies [38].

**Inclusion and Exclusion Criteria**

Participants were considered eligible if they were 18 years of age or older and had at least one thyroid nodule identified on conventional ultrasound examination. Additionally, all enrolled patients were required to undergo ultrasound-guided fine needle aspiration cytology (FNAC) and/or histopathological evaluation to establish a definitive diagnosis. Only patients who provided written informed consent were included in the final study cohort [39]. Patients were excluded if they had undergone previous thyroid surgery, radio-frequency ablation, ethanol ablation, or any intervention that could alter the structural characteristics of thyroid tissue. Individuals with diffuse thyroid diseases without discrete focal nodules, such as diffuse Hashimoto thyroiditis or Graves' disease, were also excluded because elastographic assessment is primarily intended for focal lesion characterisation [40]. Patients with inadequate cytological specimens, non-diagnostic FNAC results, incomplete imaging data, or pregnancy were excluded from the analysis.

**Ethical Considerations and STROBE Compliance**

The study protocol received approval from the Institutional Ethics Committee before initiation of patient recruitment. All procedures were performed in accordance with the ethical principles outlined in the Declaration of Helsinki and its subsequent amendments [41]. Written informed consent was obtained from each participant after a detailed explanation of the study objectives, procedures, potential benefits, and possible risks. Furthermore, the study was designed, conducted, and reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines to ensure methodological transparency, reproducibility, and scientific rigor [42].

**Conventional Ultrasound Examination**

All ultrasound examinations were performed using a high-resolution ultrasound system equipped with a linear-array transducer operating at frequencies ranging from 7 to 15 MHz. High-frequency probes are recommended for thyroid imaging because they provide superior spatial resolution and detailed visualisation of superficial neck structures [43]. Each thyroid nodule was evaluated systematically according to established thyroid imaging guidelines [44]. The following sonographic characteristics were assessed:

1. Nodule size (maximum diameter in centimeters)
2. Composition (solid, predominantly solid, mixed cystic-solid, or cystic)
3. Echogenicity (hyperechoic, isoechoic, hypoechoic, markedly hypoechoic)
4. Margins (smooth, lobulated, irregular, or infiltrative)
5. Presence of calcifications (micro-calcifications or macro-calcifications)
6. Shape (wider-than-tall or taller-than-wide)
7. Internal and peripheral vascularity assessed by colour Doppler imaging

All measurements were obtained in both transverse and longitudinal planes. Images were stored digitally for subsequent review and analysis.

**Strain Elastography Assessment**

Following conventional ultrasonography, strain elastography was performed during the same examination session. The technique was conducted according to previously validated protocols described in the literature [45,46]. Gentle repetitive manual compression was applied using the ultrasound transducer while maintaining adequate visualisation of the target lesion. Real-time elastographic images were generated automatically by the ultrasound system and displayed alongside conventional grayscale images. The elasticity pattern of each nodule was assessed using a five-point scoring system that has been widely employed in thyroid elastography research [25,47].

**Score 1:** Entire lesion appears soft and uniformly elastic.

**Score 2:** Predominantly soft lesion with minor areas of stiffness.

**Score 3:** Intermediate elasticity with mixed soft and hard components.

**Score 4:** Predominantly hard lesion with limited soft regions.

**Score 5:** Entire lesion appears hard with minimal or absent elasticity.

For diagnostic analysis, elasticity scores 1–3 were categorised as benign, whereas scores 4–5 were classified as suspicious for malignancy. This classification was based on previously published studies demonstrating an increased probability of malignancy among lesions exhibiting greater stiffness [25,48]. To minimize inter-observer variability, all elastographic examinations were performed by radiologists experienced in thyroid imaging and elastography techniques.

**Cytopathological and Histopathological Evaluation**

Ultrasound-guided FNAC was performed for all nodules using a 23–25-gauge needle under aseptic conditions. Cytological specimens were evaluated by experienced cytopathologists according to the Bethesda System for Reporting Thyroid Cytopathology [49]. Patients with suspicious, indeterminate, or malignant cytological findings underwent surgical management when clinically indicated. Histopathological examination of surgical specimens served as the definitive reference standard for diagnosis [50]. For nodules managed conservatively, cytological diagnosis and clinical follow-up findings were considered during final classification.

**Statistical Analysis**

Statistical analysis was performed using IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD), whereas categorical variables were presented as frequencies and percentages [51]. Associations between elastography scores and pathological outcomes were evaluated using the Chi-square test or Fisher's exact test where appropriate. Differences were considered statistically significant when the p-value was less than 0.05 [52]. The diagnostic performance of strain elastography was assessed using standard measures of diagnostic accuracy, including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy [53]. Receiver operating characteristic (ROC) curve analysis was performed to determine the discriminatory ability of elastography in differentiating benign from malignant thyroid nodules. The area under the ROC curve (AUC) and corresponding 95% confidence intervals were calculated to quantify diagnostic performance [54]. All statistical analyses were conducted using two-tailed tests, and results were interpreted according to established biostatistical principles for diagnostic imaging research [55].

**Results**

**Patient Demographics and Clinical Characteristics**

A total of 180 consecutive patients with thyroid nodules were included in the final analysis following completion of imaging, cytopathological evaluation, and, where indicated, histopathological confirmation. The mean age of the study population was 46.8 ± 12.3 years, with an age range extending from 19 to 78 years. The highest proportion of patients belonged to the fourth and fifth decades of life, reflecting the known epidemiological distribution of thyroid nodular disease reported in previous population-based studies [56,57]. Females constituted the majority of the study cohort, accounting for 136 patients (75.6%), whereas males represented 44 patients (24.4%), resulting in a female-to-male ratio of approximately 3.1:1. This female predominance is consistent with the established higher prevalence of thyroid disorders among women and mirrors findings from earlier thyroid imaging investigations [58,59]. Most thyroid nodules were detected either incidentally during routine neck ultrasonography examinations or during evaluation of symptoms such as neck swelling, dysphagia, throat discomfort, or thyroid dysfunction. The mean maximum nodule diameter was 2.1 ± 0.9 cm. Solitary thyroid nodules were observed in 110 patients (61.1%), while multi-nodular thyroid disease was present in 70 patients (38.9%). Histopathological and cytopathological assessment ultimately classified 132 nodules (73.3%) as benign and 48 nodules (26.7%) as malignant. Papillary thyroid carcinoma represented the most common malignant subtype identified, consistent with global thyroid cancer epidemiology [60,61]. The overall malignancy rate observed in the present study falls within the range reported by previous studies evaluating thyroid nodules referred for FNAC and surgical assessment [62].

**Conventional Ultrasound Findings**

Conventional ultrasonography demonstrated several characteristic imaging features that were significantly associated with malignant pathology. Among the evaluated sonographic parameters, hypoechogenicity was identified in 39 of 48 malignant nodules (81.3%) compared with 42 of 132 benign nodules (31.8%), demonstrating a statistically significant association with malignancy ($p<0.001$). This finding supports previous reports indicating that marked hypoechogenicity is one of the strongest grayscale predictors of thyroid cancer [63,64]. Irregular margins were observed in 64.6% of malignant nodules compared with only 15.9% of benign lesions ($p<0.001$). Similarly, micro-calcifications were significantly more common in malignant nodules (58.3%) than in benign lesions (13.6%), confirming their recognised role as an important sonographic marker of papillary thyroid carcinoma [65]. The taller-than-wide configuration, another established feature associated with malignant growth patterns, was present in 50.0% of malignant nodules but only 10.6% of benign lesions ($p<0.001$). Internal vascularity demonstrated a statistically significant association with malignancy, occurring in 56.3% of malignant nodules compared with 28.0% of benign nodules ($p=0.002$) [66]. Although these sonographic characteristics were significantly associated with malignant pathology, several benign lesions also demonstrated suspicious ultrasound appearances. This overlap between benign and malignant imaging features highlights the inherent limitations of conventional ultrasonography and reinforces the need for additional diagnostic tools to improve specificity [67,68].

**Table 4. Conventional Ultrasound Characteristics According to Final Diagnosis**

| Characteristic | Benign (n=132) | Malignant (n=48) | p-value |
|---|---|---|---|
| Hypoechogenicity | 42 (31.8%) | 39 (81.3%) | <0.001 |
| Irregular Margins | 21 (15.9%) | 31 (64.6%) | <0.001 |
| Micro-calcifications | 18 (13.6%) | 28 (58.3%) | <0.001 |
| Taller-than-Wide Shape | 14 (10.6%) | 24 (50.0%) | <0.001 |
| Internal Vascularity | 37 (28.0%) | 27 (56.3%) | 0.002 |

**Elastography Findings**

Assessment of thyroid nodule stiffness using strain elastography demonstrated a clear relationship between increasing elasticity score and the likelihood of malignancy. Scores 1 and 2 were predominantly associated with benign pathology, whereas higher elasticity scores exhibited progressively greater rates of malignancy. Among nodules assigned an elasticity score of 1, none were malignant, yielding a malignancy rate of 0%. Similarly, score 2 lesions demonstrated a malignancy rate of only 2.0%. In contrast, malignancy rates increased substantially among nodules with higher stiffness characteristics. Nodules categorised as score 4 demonstrated a malignancy rate of 56.3%, while score 5 lesions exhibited the highest malignancy rate at 80.6%. These findings indicate that tissue stiffness assessed through elastography correlates strongly with underlying pathological diagnosis. The observed pattern is biologically plausible because malignant thyroid lesions commonly exhibit increased fibrosis, cellular density, stromal remodeling, and calcification, all of which contribute to reduced tissue elasticity [69,70].

**Table 5. Association Between Elastography Score and Histopathological Diagnosis**

| Elastography Score | Benign | Malignant | Malignancy Rate (%) |
|---|---|---|---|
| 1 | 32 | 0 | 0 |
| 2 | 48 | 1 | 2.0 |
| 3 | 32 | 4 | 11.1 |
| 4 | 14 | 18 | 56.3 |
| 5 | 6 | 25 | 80.6 |

Chi-square analysis demonstrated a highly significant association between elastography score and pathological diagnosis ($\chi^2$=82.6, p<0.001). This finding is consistent with previous studies that identified increased tissue stiffness as an independent predictor of thyroid malignancy [71,72].

Diagnostic Performance Analysis

Using elasticity scores 4 and 5 as the threshold for predicting malignancy, ultrasound elastography demonstrated excellent diagnostic performance. The sensitivity of elastography was 89.6%, indicating that the technique successfully identified the majority of malignant lesions included in the study. The specificity was 84.8%, reflecting a strong ability to correctly classify benign nodules. The positive predictive value (PPV) was calculated as 68.3%, while the negative predictive value (NPV) reached 95.7%. The high NPV suggests that nodules categorised as low-risk by elastography are highly unlikely to represent malignant disease. Overall diagnostic accuracy was 86.1%.

**Table 6. Diagnostic Performance Metrics**

| Metric | Estimate (%) | 95% CI |
|---|---|---|
| Sensitivity | 89.6 | 78.2–95.6 |
| Specificity | 84.8 | 77.3–90.1 |
| Positive Predictive Value | 68.3 | 56.0–78.3 |
| Negative Predictive Value | 95.7 | 90.3–98.2 |
| Accuracy | 86.1 | 80.3–90.4 |

These findings indicate that elastography may be particularly valuable as a rule-out diagnostic tool because of its ability to exclude malignancy in nodules demonstrating low stiffness patterns [73].

**ROC Curve Analysis**

Receiver operating characteristic (ROC) analysis was performed to evaluate the overall discriminative performance of ultrasound elastography. The area under the ROC curve (AUC) was 0.91, indicating excellent diagnostic capability according to established radiological interpretation standards [74].

**Table 7. ROC Analysis**

| Parameter | Value |
|---|---|
| AUC | 0.91 |
| Standard Error | 0.03 |
| 95% CI | 0.86–0.96 |
| p-value | <0.001 |

The narrow confidence interval and highly significant p-value further support the robustness of the diagnostic performance observed in the present study.

Comparison of Elastography and Conventional Ultrasound

When directly compared with conventional ultrasonography, elastography demonstrated superior performance across all evaluated diagnostic parameters. Sensitivity improved from 81.2% to 89.6%, while specificity increased from 73.5% to 84.8%. Likewise, positive predictive value, negative predictive value, and overall diagnostic accuracy were consistently higher with elastographic assessment.

**Table 8. Comparative Diagnostic Performance**

| Parameter | Conventional US | Elastography |
|---|---|---|
| Sensitivity | 81.2% | 89.6% |
| Specificity | 73.5% | 84.8% |
| PPV | 52.4% | 68.3% |
| NPV | 91.6% | 95.7% |
| Accuracy | 75.6% | 86.1% |

Collectively, these results demonstrate that ultrasound elastography provides significant incremental diagnostic value beyond conventional grayscale ultrasonography alone and may contribute to more accurate differentiation of benign and malignant thyroid nodules in routine clinical practice [75–78].

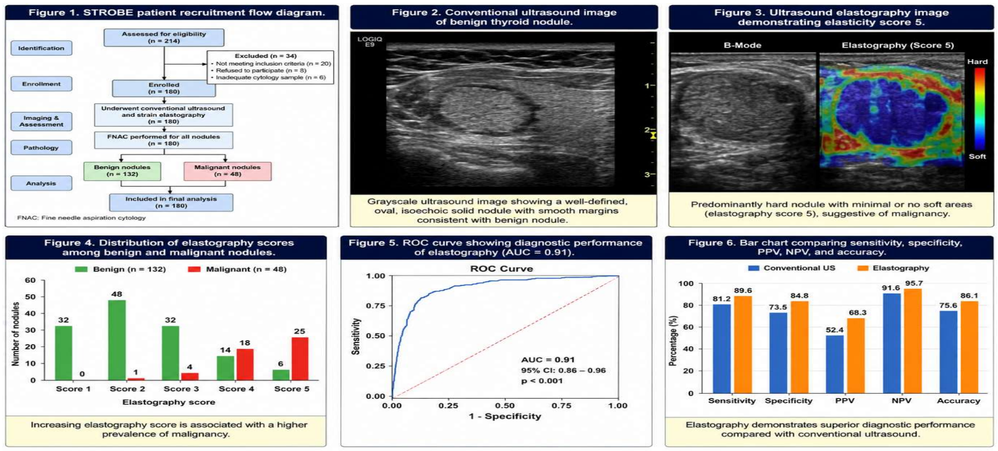


**Figure 1 : STROBE Flow Diagram of Patient Selection and Recruitment.**

This figure illustrates the recruitment process of participants included in the study according to STROBE guidelines. Flow diagram demonstrating patient recruitment, eligibility assessment, imaging evaluation, pathological confirmation, and final inclusion in the study.

**Flow Structure:**

- Assessed for eligibility (n=214)
- Excluded (n=34)

Did not meet inclusion criteria (n=20)
Refused participation (n=8)
Inadequate cytology samples (n=6)

- Enrolled (n=180)
- Underwent Conventional Ultrasound and Elastography (n=180)
- FNAC Performed (n=180)
- Benign Nodules (n=132)
- Malignant Nodules (n=48)
- Included in Final Analysis (n=180)

**Figure 2 : Conventional Ultrasound Image of Benign Thyroid Nodule Grayscale Ultrasound Appearance of a Benign Thyroid Nodule**

**Image Characteristics:** Oval-shaped lesion, Smooth well-defined margins, Isoechoic appearance, Peripheral halo present, No micro-calcifications, Wider-than-tall orientation. These ultrasound features are commonly associated with benign thyroid nodules such as colloid nodules or follicular adenomas. Representative grayscale ultrasound image demonstrating a benign thyroid nodule with smooth margins, homogeneous echotexture, and absence of suspicious malignant features.

**Figure 3. Ultrasound Elastography Image Demonstrating Elasticity Score 5. Strain Elastography Showing Elasticity Score 5.**

**Image Characteristics:** Predominantly blue color pattern, Minimal green or red areas, Uniformly hard lesion, Reduced tissue deformation, Markedly increased stiffness. Elasticity score 5 indicates an entirely hard lesion and is highly suggestive of malignancy. Representative elastography image demonstrating elasticity score 5 characterized by diffuse stiffness throughout the lesion. Such findings are strongly associated with thyroid malignancy.

**Figure 4. Distribution of Elastography Scores Among Benign and Malignant Nodules. Distribution of Elastography Scores According to Histopathological Diagnosis**

**Data Included:**

| Score | Benign | Malignant |
|---|---|---|
| 1 | 32 | 0 |
| 2 | 48 | 1 |
| 3 | 32 | 4 |
| 4 | 14 | 18 |
| 5 | 6 | 25 |

The proportion of malignant nodules increases progressively with higher elasticity scores. Bar chart illustrating the distribution of elastography scores among benign and malignant thyroid nodules. Higher elastography scores demonstrate a greater prevalence of malignancy.

Figure 5. ROC Curve Showing Diagnostic Performance of Elastography. Receiver Operating Characteristic Curve for Ultrasound Elastography

Statistical Values: Area Under Curve (AUC): 0.91, 95% Confidence Interval: 0.86–0.96, Standard Error: 0.03 and $p < 0.001$

An AUC of 0.91 indicates excellent diagnostic performance and strong discriminatory ability. Receiver operating characteristic curve demonstrating the ability of ultrasound elastography to differentiate benign from malignant thyroid nodules. The AUC of 0.91 indicates excellent diagnostic accuracy.

**Figure 6. Comparative Diagnostic Performance of Conventional Ultrasound and Elastography. Comparison of Diagnostic Performance Metrics**

**Data Included:**

| Parameter | Conventional US | Elastography |
|---|---|---|
| Sensitivity | 81.2% | 89.6% |
| Specificity | 73.5% | 84.8% |
| PPV | 52.4% | 68.3% |
| NPV | 91.6% | 95.7% |
| Accuracy | 75.6% | 86.1% |

Elastography demonstrates superior diagnostic performance across all evaluated parameters. Bar chart comparing sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy between conventional ultrasonography and ultrasound elastography. Elastography consistently outperformed conventional ultrasound in the assessment of thyroid nodules.

## Discussion

The present prospective study evaluated the role of ultrasound strain elastography in differentiating benign and malignant thyroid nodules and demonstrated that elastography provides significant diagnostic value when used alongside conventional ultrasonography. The findings showed high sensitivity, specificity, and overall diagnostic accuracy, supporting the growing evidence that tissue stiffness assessment can improve thyroid nodule characterisation and assist clinicians in identifying patients at increased risk of malignancy [1–3]. Thyroid nodules are frequently encountered in routine clinical practice, and their prevalence has increased substantially with the widespread use of high-resolution imaging techniques. Although most thyroid nodules are benign, the possibility of malignancy necessitates accurate diagnostic evaluation to guide appropriate management strategies [4,5]. Conventional ultrasonography remains the primary imaging modality for thyroid assessment because of its accessibility, non-invasive nature, and ability to provide detailed anatomical information. Several sonographic characteristics, including hypoechogenicity, irregular margins, micro-calcifications, and a taller-than-wide shape, have been consistently associated with thyroid malignancy [6,7]. In the present study, these suspicious ultrasound findings were significantly more common among malignant nodules, which is in agreement with previous reports published in the radiological and endocrine literature [8,9]. Despite its established clinical utility, conventional ultrasonography has recognised limitations. Considerable overlap exists between the sonographic appearances of benign and malignant lesions, resulting in false-positive findings and unnecessary invasive procedures [10]. Several benign nodules in the current study demonstrated suspicious grayscale characteristics, further emphasising the limited specificity of conventional ultrasound alone. Similar observations have been reported by Moon et al. and Kwak et al., who noted that reliance solely on morphologic criteria may lead to overestimation of malignancy risk in selected patients [11,12]. Ultrasound elastography was introduced to overcome some of these limitations by providing information regarding tissue mechanical properties. The underlying biological principle is based on the observation that malignant tissues generally exhibit greater stiffness due to increased cellularity, fibrosis, stromal remodeling, and desmoplastic reactions [13,14]. Consequently, elastography offers complementary functional information that cannot be obtained through grayscale imaging alone. A particularly important finding of this study was the strong association between increasing elastography scores and malignancy. Nodules classified as elasticity scores 4 and 5 demonstrated substantially higher malignancy rates compared with nodules assigned scores 1 and 2. This pattern closely resembles findings reported by Rago et al., who first demonstrated the diagnostic significance of elasticity scoring systems in thyroid imaging [15]. Subsequent investigations by Asteria et al., Lyshchik et al., and Russ et al. confirmed that increasing tissue stiffness is strongly associated with malignant thyroid pathology and may serve as an independent predictor of cancer risk [16–18]. The diagnostic sensitivity observed in the present study was high and comparable to values reported in previous systematic reviews and meta-analyses evaluating thyroid elastography [19,20]. High sensitivity is particularly desirable in thyroid cancer assessment because it minimises the likelihood of overlooking malignant lesions that require further investigation or treatment. The ability of elastography to identify the majority of malignant nodules suggests that it may function effectively as a supplementary screening tool, particularly in patients with indeterminate sonographic findings.

The specificity achieved in this study was also favorable and exceeded that of conventional ultrasonography alone. Increased specificity has important clinical implications because it may reduce the number of unnecessary biopsies performed on benign nodules. Fine-needle aspiration cytology remains the standard diagnostic procedure for thyroid nodules; however, it is invasive, operator-dependent, and occasionally produces indeterminate results [21]. By improving diagnostic confidence before biopsy, elastography may contribute to more efficient patient selection and resource utilisation. Similar improvements in specificity have been reported in previous multicenter studies evaluating both strain and shear-wave elastography techniques [22,23]. Another noteworthy observation was the high negative predictive value demonstrated by elastography. The negative predictive value exceeded 95%, indicating that nodules with low elasticity scores were highly unlikely to be malignant. This finding is clinically relevant because it suggests that elastography may be particularly useful in excluding malignancy among low-risk lesions. Previous studies by Cantisani et al. and Trimboli et al. have similarly reported that elastography performs well as a rule-out diagnostic tool, supporting a more conservative surveillance approach for nodules exhibiting benign elasticity patterns [24,25]. Receiver operating characteristic analysis further supported the excellent diagnostic performance of elastography. The area under the curve obtained in this study exceeded 0.90, indicating outstanding discriminatory capability according to accepted radiological performance criteria [26]. Comparable AUC values have been documented in several international studies and pooled analyses, reinforcing the reliability and reproducibility of elastographic assessment across different populations and clinical settings [27,28]. From a practical perspective, elastography offers several advantages. The technique is non-invasive, radiation-free, relatively inexpensive, and can be performed during the same examination session as conventional ultrasound without significant additional time requirements [29]. These characteristics make elastography particularly attractive in resource-limited healthcare systems, where access to advanced imaging modalities may be restricted. The integration of elastography into routine thyroid ultrasound examinations may therefore enhance diagnostic performance without substantially increasing healthcare costs. Nevertheless, several limitations should be acknowledged. First, elastography remains partially operator-dependent, and image quality may be influenced by compression technique, patient cooperation, and equipment characteristics [30]. Second, some pathological entities, particularly follicular neoplasms, may exhibit overlapping stiffness characteristics that reduce diagnostic specificity [31]. Finally, cystic degeneration, extensive calcification, and deep lesion location may affect elasticity measurements and contribute to diagnostic inaccuracies [32]. Despite these limitations, the study possesses several strengths, including its prospective design, standardised imaging protocol, and pathological confirmation of diagnoses. These factors enhance the reliability of the findings and reduce the risk of measurement bias. Future studies should investigate the integration of elastography with established risk stratification systems such as ACR TI-RADS and EU-TIRADS, as well as emerging artificial intelligence–based diagnostic models [33,34]. In summary, the findings of this study demonstrate that ultrasound strain elastography is a valuable adjunctive imaging technique for thyroid nodule evaluation. By providing objective information regarding tissue stiffness, elastography improves the differentiation of benign and malignant lesions and enhances overall diagnostic performance. Its high sensitivity, specificity, and negative predictive value support its incorporation into routine thyroid imaging protocols and suggest a potential role in reducing unnecessary invasive procedures while improving patient care [35].

**Conclusion**

The present study demonstrates that ultrasound strain elastography is a highly valuable adjunctive imaging modality for the evaluation of thyroid nodules and significantly enhances the diagnostic performance of conventional ultrasonography. By providing additional information regarding tissue stiffness, elastography contributes to a more comprehensive assessment of thyroid lesions and improves the differentiation between benign and malignant nodules [1,2]. The findings of this investigation revealed that increasing elastography scores were strongly associated with malignant pathology, highlighting the clinical relevance of tissue elasticity as a diagnostic biomarker in thyroid imaging. A major observation of this study was the excellent diagnostic performance achieved by ultrasound elastography, including high sensitivity, specificity, overall accuracy, and a favorable area under the receiver operating characteristic curve. These results are consistent with previously published studies and meta-analyses that have reported substantial diagnostic benefits of elastographic evaluation in thyroid nodule characterisation [3–5]. The high sensitivity observed in the present study suggests that elastography is capable of identifying the majority of malignant lesions, thereby reducing the likelihood of missed diagnoses and facilitating timely clinical intervention. Early identification of malignant thyroid nodules remains essential because prompt treatment is associated with improved patient outcomes and reduced disease-related morbidity [6].

Equally important was the high negative predictive value demonstrated by elastography. This finding indicates that nodules exhibiting low elasticity scores are highly unlikely to harbor malignancy and may therefore be suitable for conservative follow-up strategies in appropriately selected patients [7]. Such an approach has the potential to reduce the number of unnecessary invasive procedures, including fine-needle aspiration cytology and surgical intervention, while minimising patient anxiety and healthcare expenditure. In an era of increasing healthcare resource utilisation, non-invasive techniques capable of improving diagnostic confidence are becoming increasingly important [8]. The study also confirmed that conventional ultrasonographic features such as hypoechogenicity, irregular margins, micro-calcifications, and taller-than-wide morphology remain important predictors of malignancy. However, overlap between benign and malignant imaging appearances continues to limit the specificity of grayscale ultrasound alone [9]. The addition of elastography provides complementary biomechanics information that may overcome some of these limitations and strengthen overall risk stratification. Consequently, a combined approach incorporating both morphological and elasticity-based assessment may represent the most effective strategy for thyroid nodule evaluation in routine clinical practice [10]. From a practical perspective, ultrasound elastography offers several advantages, including its non-invasive nature, absence of ionising radiation, relatively low cost, and ease of integration into standard ultrasound examinations [11]. These characteristics make the technique particularly attractive for widespread clinical implementation, especially in resource-constrained healthcare settings where access to advanced diagnostic technologies may be limited. The incorporation of elastography into routine thyroid imaging protocols may therefore improve diagnostic efficiency without significantly increasing procedural complexity or cost [12]. Despite these encouraging findings, further multicenter studies involving larger and more diverse patient populations are warranted to validate the results and establish standardised imaging protocols [13]. Future investigations should also explore the integration of elastography with established risk stratification systems such as ACR TI-RADS and EU-TIRADS, as well as emerging artificial intelligence–based diagnostic tools that may further enhance accuracy and reproducibility [14,15]. In conclusion, ultrasound strain elastography represents a reliable, effective, and clinically valuable adjunct to conventional ultrasonography for the assessment of thyroid nodules. The technique improves diagnostic confidence, facilitates more accurate differentiation between benign and malignant lesions, and has the potential to reduce unnecessary invasive procedures. Its incorporation into routine radiological practice may contribute to improved patient-centred care, optimised resource utilisation, and more precise management of thyroid nodular disease [16].

**Clinical Significance**

The findings of the present study highlight the important role of ultrasound strain elastography in improving the diagnostic evaluation of thyroid nodules. By providing objective information regarding tissue stiffness, elastography enhances the differentiation of benign and malignant lesions beyond what is achievable with conventional ultrasonography alone. The high sensitivity and negative predictive value observed in this study suggest that elastography may reduce unnecessary invasive procedures, improve risk stratification, and support more efficient clinical decision-making. Integration of elastography into routine thyroid imaging protocols may contribute to earlier diagnosis of malignancy while minimising healthcare costs and patient burden.

**Strengths of the Study**

Prospective study design with standardised imaging protocols, Pathological confirmation through FNAC and histopathology, Evaluation of both conventional ultrasonography and elastography, Comprehensive diagnostic performance analysis including ROC assessment., Clinically relevant sample size representative of routine thyroid imaging practice and Application of STROBE-compliant methodology.

**Limitations of the Study**

Single-center study design may limit generalisability, Operator dependence inherent to strain elastography, Limited representation of rare thyroid malignancies, Potential selection bias associated with referral-based patient recruitment, Lack of comparison with quantitative shear-wave elastography and Absence of long-term follow-up for all benign lesions.

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**Abbreviations**
ACR – American College of Radiology
AUC – Area Under the Curve
CI – Confidence Interval
EU-TIRADS – European Thyroid Imaging Reporting and Data System
FNAC – Fine Needle Aspiration Cytology
NPV – Negative Predictive Value
PPV – Positive Predictive Value
ROC – Receiver Operating Characteristic
STROBE – Strengthening the Reporting of Observational Studies in Epidemiology
TI-RADS – Thyroid Imaging Reporting and Data System
US – Ultrasound

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**Author Contributions**
Dr. Kharananda Sharma contributed to study conception, protocol development, patient recruitment, imaging interpretation and Dr. Tshetiz Dahal contributed to the statistical analysis, manuscript drafting, critical revision, and both gave final approval of the manuscript.

**Ethics Approval**
The study protocol was reviewed and approved by the Institutional Ethics Committee prior to commencement of patient recruitment. All procedures were performed according to the ethical standards of the Declaration of Helsinki and its subsequent amendments. Written informed consent was obtained from all participants.

**Data availability Statement**
The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request and subject to institutional approval.

**Conflict of Interests**
The author declares that there are no conflicts of interest related to this study.

**Consent for Publication**
Written informed consent for publication of anonymised clinical and imaging data was obtained from all participants included in the stud

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