“ASSESSMENT OF THYROID NODULES USING STRAIN ULTRASOUND ELASTOGRAPHY AND ITS COMPARISON WITH FINE NEEDLE ASPIRATION CYTOLOGY A ONE YEAR HOSPITAL BASED CROSS SECTIONAL STUDY”

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In

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LIST OF ABBREVIATIONS

Abbreviation	Full Form
USE	Strain Ultrasound Elastography
FNAC	Fine Needle Aspiration Cytology
SE	Strain Elastography
SWE	Shear Wave Elastography
TSH	Thyroid-Stimulating Hormone
T3	Triiodothyronine
T4	Thyroxine
TI-RADS	Thyroid Imaging Reporting and Data System
VEGF	Vascular Endothelial Growth Factor
LBC	Liquid-Based Cytology
PET	Positron Emission Tomography
MRI	Magnetic Resonance Imaging
B/A	Strain Ratio (Benign/Malignant Assessment)
AI	Artificial Intelligence
MAPK	Mitogen-Activated Protein Kinase
PI3K-AKT	Phosphoinositide 3-Kinase/Protein Kinase B Pathway
ATC	Anaplastic Thyroid Cancer
FTC	Follicular Thyroid Cancer
PTC	Papillary Thyroid Cancer
MTC	Medullary Thyroid Cancer
SPSS	Statistical Package for the Social Sciences

ABSTRACT

BACKGROUND

Thyroid nodules are a common clinical finding, requiring accurate differentiation between benign and malignant lesions. Strain ultrasound elastography (USE) is a non-invasive imaging modality that evaluates tissue stiffness and may serve as a complementary tool to fine-needle aspiration cytology (FNAC), the current gold standard for thyroid nodule evaluation.

OBJECTIVE

This study aims to assess the diagnostic accuracy of strain ultrasound elastography in differentiating benign from malignant thyroid nodules and to compare its performance with FNAC**.**

MATERIALS AND METHODS

A hospital based cross-sectional study was conducted over one year. Patients with clinically or radiologically detected thyroid nodules underwent both strain ultrasound elastography and FNAC. The strain ratio was calculated using the elastographic technique, with a cutoff value of 1.95 for malignancy prediction. FNAC results served as the reference standard. Diagnostic performance metrics, including sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV), were calculated**.**

RESULTS

Among the 47 patients included, elastography identified 31 cases (65.95%) as malignant and 16 cases (34.04%) as benign based on the strain ratio. FNAC confirmed 17 malignant cases (36.17%) and 30 benign cases (63.83%). Elastography demonstrated a sensitivity of 100%, specificity of 53.33%, PPV of 54.84%, and NPV of 100%. While elastography showed high sensitivity in detecting malignant nodules, it had a moderate specificity, leading to a higher false-positive rate compared to FNAC**.**

CONCLUSION

Strain ultrasound elastography is a valuable, non-invasive screening tool for thyroid nodule assessment, offering excellent sensitivity and negative predictive value. However, due to its moderate specificity, FNAC remains essential for definitive diagnosis. The integration of elastography into routine thyroid nodule evaluation may reduce unnecessary FNAC procedures while improving malignancy risk stratification. Further studies are recommended to refine cutoff values and improve specificity**.**

Keywords: Thyroid nodules, Strain ultrasound elastography (USE), Fine-needle aspiration cytology (FNAC), Strain ratio, Thyroid malignancy

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INTRODUCTION

Thyroid nodules are a common clinical finding, often detected during routine physical examinations or imaging studies. While the majority of thyroid nodules are benign, a small percentage may harbor malignancy, necessitating accurate and efficient diagnostic tools to guide clinical management. This has led to the exploration of advanced imaging modalities such as strain ultrasound elastography (USE), which provides valuable insights into tissue stiffness, a parameter often associated with malignancy. [1]

Fine Needle Aspiration Cytology (FNAC) is widely recognized as the gold standard for evaluating thyroid nodules, offering high diagnostic accuracy with minimal invasiveness. However, FNAC is not without limitations, including indeterminate cytological findings and sampling errors. These limitations highlight the need for supplementary diagnostic techniques that can provide additional information and reduce the dependency on repeat or unnecessary invasive procedures. Strain ultrasound elastography has emerged as a promising non-invasive tool in this regard. [2]

Strain ultrasound elastography (SE) operates on the principle of measuring tissue elasticity by assessing its deformation under an applied force. Malignant thyroid nodules, owing to their higher stiffness, demonstrate distinct elastographic patterns compared to benign nodules. By quantifying tissue stiffness, USE can aid in differentiating benign from malignant thyroid nodules, potentially reducing the number of unnecessary FNAC procedures. This capability has garnered significant attention in recent years as a complementary diagnostic approach. [3]

Several studies have investigated the utility of strain ultrasound elastography in evaluating thyroid nodules, with varying results. While many reports highlight its potential to enhance diagnostic accuracy, discrepancies in the standardization of techniques, interpretation of elastographic scores, and variability in study populations have led to inconsistent conclusions. These factors underscore the necessity for further research to establish the efficacy and reliability of strain ultrasound elastography, particularly in comparison to FNAC. [4, 5] This study aims to assess the diagnostic performance of strain ultrasound elastography in the evaluation of thyroid nodules and compare it with FNAC findings. By correlating elastographic results with cytological diagnoses, the study seeks to determine the sensitivity, specificity, and overall diagnostic efficacy of strain ultrasound elastography. The findings are expected to provide insights into the feasibility of incorporating USE as a routine diagnostic modality in clinical practice.

Strain ultrasound elastography (USE) is a non-invasive, radiation-free imaging technique that provides real-time insights into thyroid nodules. It's especially helpful when fine-needle aspiration cytology (FNAC) results are inconclusive or the nodule is hard to access. This makes USE a valuable addition to the diagnostic tools for thyroid nodules. [6]

Despite its advantages, the clinical application of strain ultrasound elastography is not without challenges. Strain ultrasound elastography (USE) faces challenges like operator dependency, variability in applied pressure, and inconsistent scoring systems. Addressing these issues requires thorough training, standardized protocols, and validation through large-scale studies. This study aims to evaluate USE's role in a real-world clinical setting, exploring its diagnostic accuracy and potential in risk stratification for thyroid nodules, ultimately enhancing personalized patient care. [7,8] The assessment of thyroid nodules using strain ultrasound elastography represents a significant advancement in thyroid imaging. [9] When compared with the established FNAC technique, USE offers the promise of a complementary diagnostic tool with the potential to refine patient management. [10] This study seeks to validate the role of USE and establish its diagnostic efficacy, paving the way for its broader adoption in clinical practice.

OBJECTIVE OF THE STUDY

To assess thyroid nodules using strain ultrasound elastography and to compare the diagnostic efficacy of strain ultrasound elastography with fine needle aspiration cytology.

REVIEW OF LITERATURE

Anatomy and Physiology of the Thyroid Gland

The thyroid gland, located in the anterior neck, has two lobes connected by an isthmus. It's encased in a fibrous capsule and anchored to the trachea and esophagus, supporting its endocrine functions. [11]

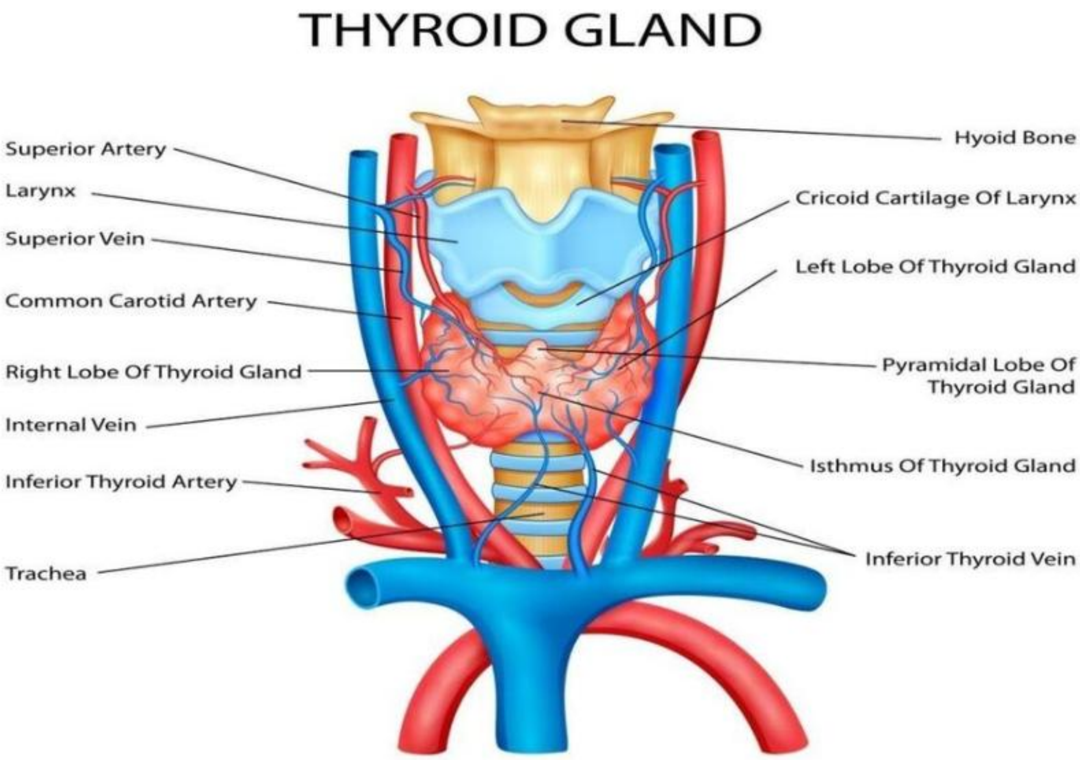


Figure 1: Anatomy of thyroid gland [11]

Blood Supply of the Thyroid Gland

The thyroid gland receives blood from the superior and inferior thyroid arteries, while venous drainage is managed by the superior, middle, and inferior thyroid veins. This network supports iodine uptake and hormone synthesis. [12]

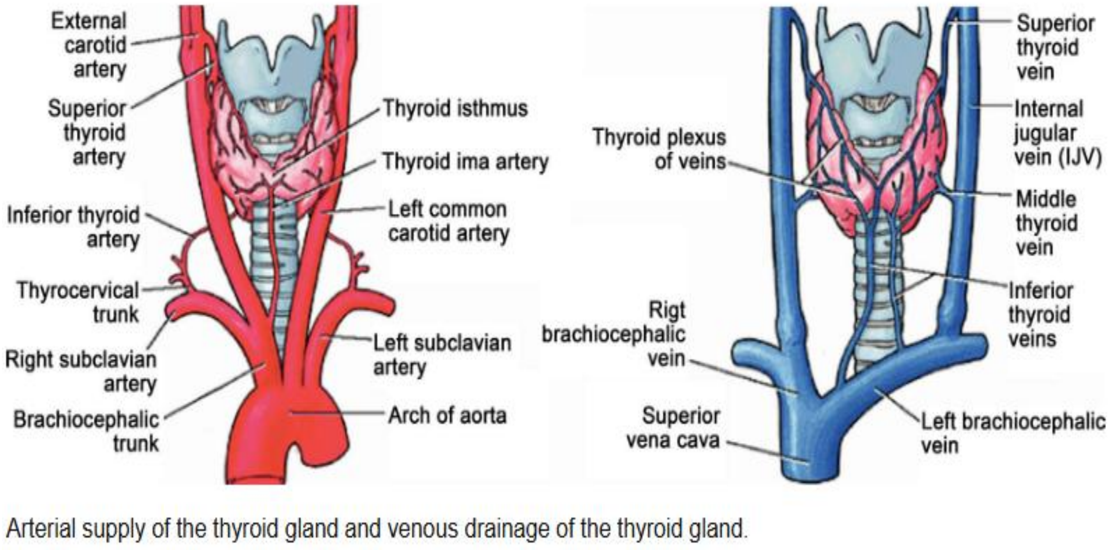


Figure 2: Arterial supply of the thyroid gland and venous drainage of the thyroid gland [12]

Nerve Supply of the Thyroid Gland

The thyroid gland is innervated by sympathetic fibers from the cervical sympathetic ganglia (for vasomotor control) and parasympathetic fibers from the vagus nerve (for glandular activity). The recurrent laryngeal nerve, a branch of the vagus, is crucial for laryngeal function and must be considered during thyroid surgery to avoid vocal cord paralysis. [13]

Hormone Synthesis and Function

Thyroid hormone synthesis involves iodine uptake, oxidation, and incorporation into thyroglobulin to produce T3 and T4. These hormones, released under TSH influence, regulate metabolic rate, thermogenesis, protein synthesis, and cardiovascular and neurological functions, maintaining homeostasis. [14]

Clinical Relevance of Thyroid Anatomy and Physiology

Understanding the thyroid glands anatomy and physiology is crucial for diagnosing and managing thyroid nodules. Advanced diagnostic techniques like strain ultrasound elastography and fine-needle aspiration cytology rely on this knowledge. This comprehensive knowledge is essential for accurate diagnosis and effective management of thyroid-related pathologies. [15] These insights are particularly relevant for integrating emerging modalities like strain ultrasound elastography into clinical practice. [16]

Pathophysiology of Thyroid Nodules

Thyroid nodules are focal lesions within the thyroid gland that may arise due to a variety of pathological processes, including hyperplasia, cyst formation, neoplasia, and inflammation. The pathophysiology underlying thyroid nodules is multifactorial, involving genetic, environmental, and hormonal factors that contribute to abnormal cellular proliferation or changes in the thyroid gland's structure. [17,18]

Types of Thyroid Nodules

1. Benign Thyroid Nodules

- **Colloid Nodules:** These are the most common type and are filled with colloid, a gelatinous substance produced by the thyroid cells. They are usually benign.
- **Cystic Nodules:** These are fluid-filled and can be either benign or, in rare cases, malignant.
- **Hyperplastic Nodules:** These are non-cancerous growths that are an overgrowth of normal thyroid tissue, often resulting from benign conditions like goitre [19,20].

2. Malignant Thyroid Nodules

- **Papillary Thyroid Cancer (PTC):** This is the most common type of thyroid cancer. It is usually slow-growing and often found in younger individuals.
- **Follicular Thyroid Cancer (FTC):** This type tends to grow more quickly than papillary thyroid cancer and is more likely to spread to other parts of the body.
- **Medullary Thyroid Cancer (MTC):** This cancer originates in the C-cells of the thyroid, which produce the hormone calcitonin. It can be genetic and may be associated with other endocrine cancers.
- **Anaplastic Thyroid Cancer (ATC):** This is a rare and very aggressive form of thyroid cancer, typically affecting older individuals.

3. Multinodular Goiter

- This condition involves the presence of multiple nodules in the thyroid. These nodules can be both benign and malignant, but most are benign [21].
- Thyroid nodules develop due to genetic mutations and altered signaling pathways.
- Mutations in genes like BRAF, RAS, and RET/PTC are involved in nodule formation.
- These mutations activate the MAPK and PI3K-AKT pathways.
- Activated pathways lead to cell proliferation and survival.
- In benign nodules, these processes may be self-limiting.
- In malignant nodules, unchecked signaling can cause invasive and metastatic behaviors.

- Understanding these mechanisms is crucial for diagnosing and predicting the prognosis of thyroid nodules. [22]

Iodine availability is key in thyroid nodule development. Deficiency leads to nodule formation via gland hypertrophy and hyperplasia, while excess iodine disrupts hormone synthesis and causes oxidative stress. This highlights the complex environmental factors in nodule pathogenesis. [23]

Inflammation, especially in Hashimoto's thyroiditis, plays a key role in thyroid nodule development by destroying thyroid follicles and promoting cell proliferation and angiogenesis. Autoimmune processes highlight the need to evaluate inflammatory markers and thyroid autoantibodies in patients with nodules. [24]

Elevated TSH levels, often seen in hypothyroidism, stimulate thyroid cell growth, increasing nodule risk. TSH effects are mediated through its receptor, activating growth pathways. This growth can be worsened by genetic mutations and other risk factors, highlighting the importance of hormonal regulation in nodule development. [25]

Thyroid nodules have distinct vascular patterns seen with Doppler ultrasonography. Malignant nodules show increased blood flow due to angiogenic factors like VEGF, supporting tumor growth. Vascular patterns help distinguish benign from malignant nodules. [26]

Thyroid nodules can undergo cystic degeneration, fibrosis, and calcification. Cystic nodules are often the result of degenerative changes in pre-existing solid nodules, while fibrosis may occur due to chronic inflammation or as a reparative response to tissue injury. Calcification, commonly observed in malignant nodules, is associated with increased stiffness. These changes, detectable by ultrasound elastography, alter the physical characteristics of the thyroid tissue and help in nodule evaluation. [27]

Malignant thyroid nodules evade the immune system by suppressing T-cell activity and recruiting immunosuppressive cells. This helps them evade immune surveillance and progress. Understanding this aids in developing immunotherapy for thyroid cancer. [28]

Systemic factors influencing thyroid nodule development include:

1. **Age:** Prevalence increases with age due to genetic mutations and reduced repair mechanisms.
2. **Gender:** Women are more likely to develop nodules, possibly due to hormonal differences and estrogen effects.
3. **Radiation:** Exposure from environmental sources or medical treatments is a significant risk factor, especially in young individuals.

These factors provide a broader understanding of thyroid nodule risk profiles. [29]

Thyroid nodules may progress from benign to malignant due to genetic, environmental, and hormonal factors. Identifying predictive biomarkers is crucial for risk stratification and personalized management. Integrating molecular diagnostics with traditional methods can improve evaluation accuracy and efficiency. [30]

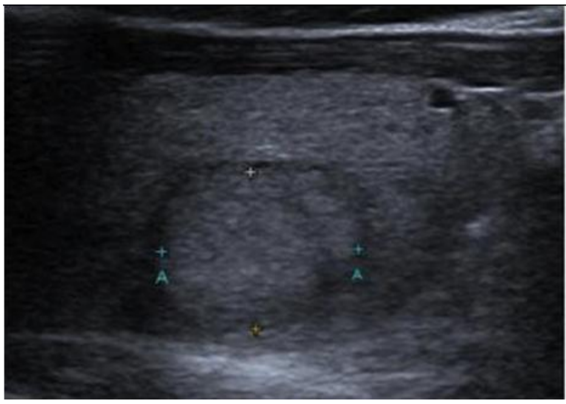
B-mode ultrasonography (USG)

It is a primary imaging modality used to assess thyroid nodules. Certain ultrasound features help differentiate between benign and malignant nodules.

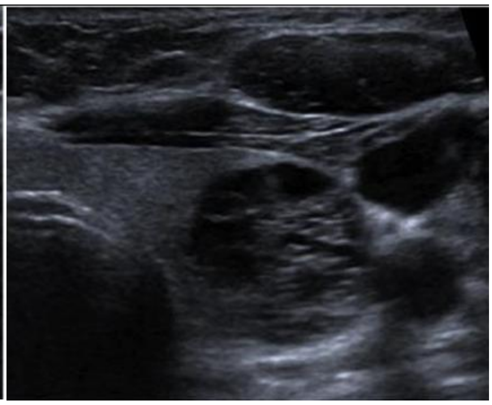
Benign Thyroid Nodule USG Features

- **Shape:** Wider than tall (oval or round).
- **Margins:** Smooth and well-defined.
- **Echogenicity:** Hyperechoic or isoechoic (brighter or similar to thyroid tissue).
- **Composition:** Cystic or spongiform (honeycomb appearance).
- **Calcifications:** None or coarse macrocalcifications.
- **Vascularity:** Peripheral vascularity.

Example:



a)



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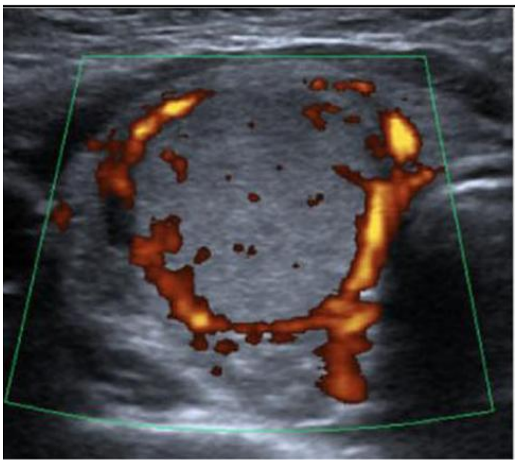


c)

Figure 3: a) A benign nodule. Iso-echoic nodule relative to the thyroid, surrounded by a hypoechogenic halo. b) A benign nodule with hypo-echoic cystic spaces resulting in a spongiform or honeycomb appearance. c) A benign nodule with peripheral vascularity on doppler assessment.

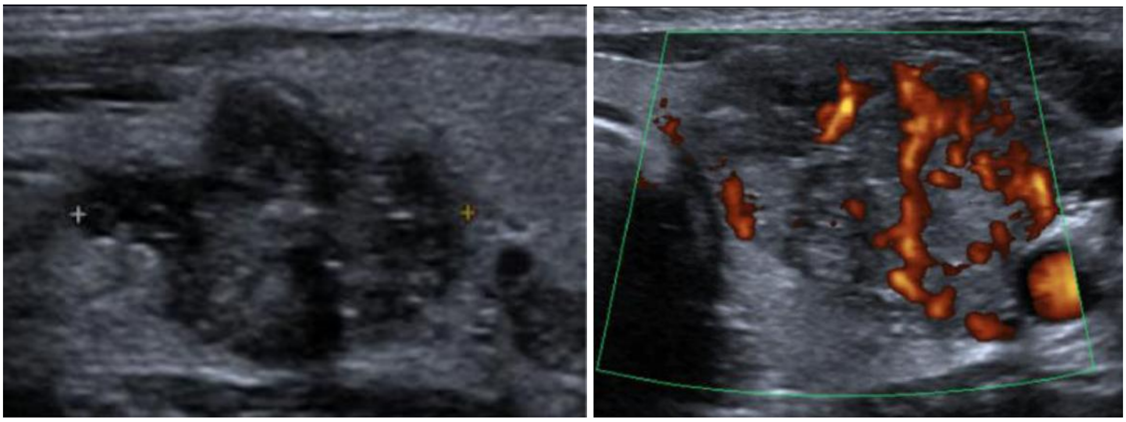
Malignant Thyroid Nodule USG Features

- **Shape:** Taller than wide (grows perpendicular to thyroid capsule).
- **Margins:** Irregular, microlobulated, or infiltrative.
- **Echogenicity:** Hypoechoic (darker than thyroid tissue).
- **Composition:** Solid or predominantly solid.
- **Calcifications:** Microcalcifications (tiny bright spots).
- **Vascularity:** Increased central vascularity.

Other Concerning Features

- Extrathyroidal Extension → Suggests malignancy
- Lymph Node Enlargement → May indicate metastasis [31]

Example:



a) b)

Figure 4: a) Hypoechoic nodule has small hyper-echoic foci of calcification and an irregular lobulated contour likely malignant b) Thyroid nodule with intra-nodular vascularity. Later confirmed to be papillary thyroid cancer

Principles of Ultrasound Elastography

(Diagnostic ultrasound, 5th edition, Carol M. Rumack and Deborah Levine, chapter 1 ultrasound physics)

Ultrasound elastography imaging is fundamentally based on the tissue bulk modulus, which reflects molecular interactions within the tissue. Changes in tissue stiffness, as indicated by the tissue shear modulus, are critical markers of disease. Ultrasound elastography provides both relative and quantitative assessments of tissue stiffness, making it a valuable diagnostic tool.

Tissue stiffness, or elasticity, is quantified using the Young modulus, which is the ratio of compression pressure (stress) to the resulting deformation (strain). This relationship helps to express how resistant a tissue is to deformation, which can be crucial in identifying pathological changes.

$$E = \sigma / \varepsilon$$

Where, E is Young modulus (expressed in Pa (pascals).

σ is the stress (expressed in Newtons).

ε is displacement (expressed in m^2).

Ultrasound-based elastography permits study of the elastic behaviour of tissue through two general approaches:

A) Strain elastography (SE)

key principles

1. **Basic Concept:** Strain elastography measures the relative strain (deformation) of tissue when a force is applied. The more a tissue deforms, the higher the strain and the softer the tissue; conversely, the less a tissue deforms, the lower the strain and the stiffer the tissue.

2. **Force Application:** The force can be applied externally using a transducer or using physiological pulsations.

3. **Qualitative & semiquantitative Assessment:** Strain elastography provides a qualitative & semiquantitative assessment of tissue stiffness. It compares the stiffness of a lesion to the surrounding tissues within the field of view (FOV), but it does not provide exact stiffness values.

4. **Clinical Applications:** This technique is widely used in clinical settings to evaluate various conditions, such as liver fibrosis, breast lesions, thyroid nodules, and prostate abnormalities.

5. **Imaging Modes:** Strain elastography is one of the two major types of ultrasound elastography, the other being shear wave elastography (SWE). While strain elastography focuses on relative strain, SWE measures shear wave speed to quantify tissue stiffness.

   It is useful in superficial accessible diseases.

   The precompression and post compression frames are compared.

Disadvantages: it is operator dependent.

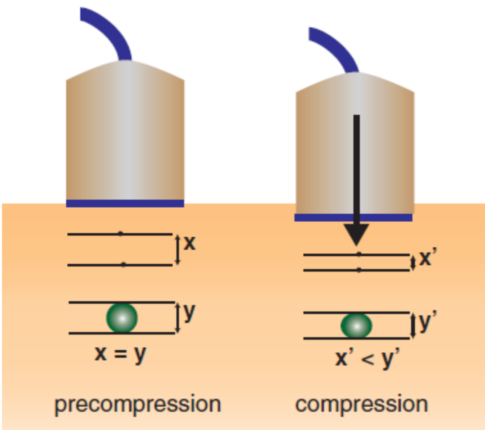


Figure 5: Strain elastography: In this example, the lesion is compressed much less than the surrounding tissue, indicating relative stiffness [31]

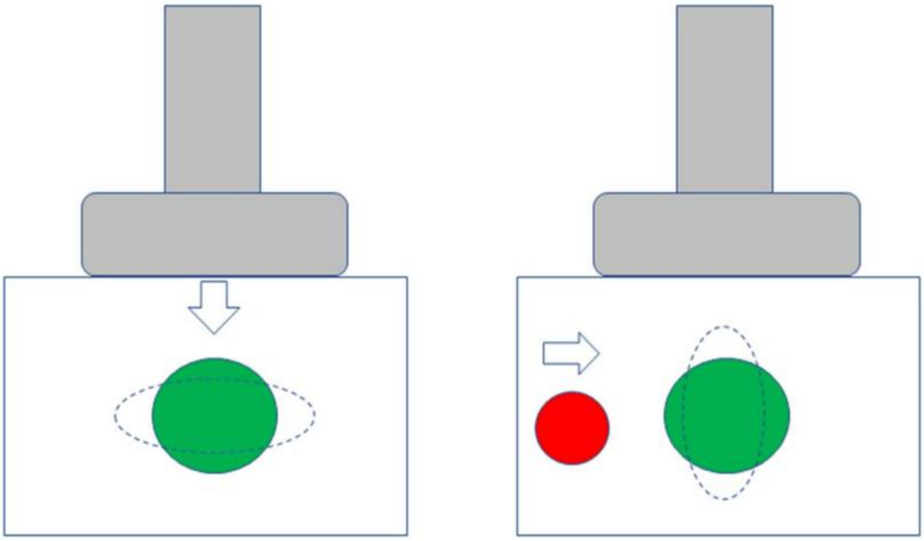


Figure 6: Schematic representation of strain elastography with external & internal force [32]

B) Shear wave elastography (SWE)

When high-intensity compression pulses from the ultrasound transducer target the area of interest, they generate low-frequency shear waves within the tissue. The displacement of speckles (tiny features within the tissue) caused by these shear waves is tracked across multiple imaging frames. By analyzing this displacement, the velocity of the shear waves can be estimated.

The velocity of shear waves is directly related to the Young modulus, enabling a quantitative measurement of tissue stiffness (strain modulus). This makes shear wave elastography a valuable technique for assessing tissue elasticity and diagnosing various conditions based on changes in tissue stiffness.

It is useful in diffuse diseases and deeper tissues.

Advantages: it is operator independent and has good reproducibility

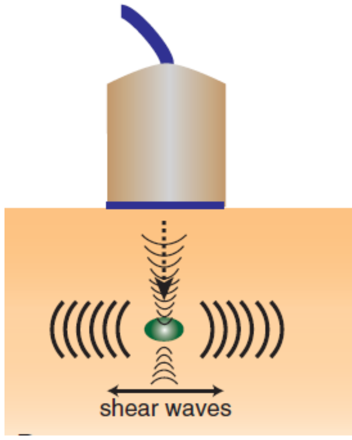


Figure 7: Shear wave elastography: Shear waves are generated by repetitive compression produced by high-intensity pulses from the ultrasound transducer and Shear waves are tracked with high frame rate images to determine their velocity [31]

Ultrasound elastography is a non-invasive imaging technique that evaluates the mechanical properties of tissues, specifically their stiffness and elasticity, which are critical in distinguishing benign from malignant lesions. The principles of ultrasound elastography are grounded in the ability of tissues to deform under an applied force, with stiffer tissues showing less deformation compared to softer ones. This method has gained prominence in the evaluation of thyroid nodules, as malignant nodules are generally stiffer due to increased cellular density and fibrosis. The ability to quantify these differences has made ultrasound elastography a valuable tool in clinical diagnostics. [31]

Benefits of Strain Ultrasound Elastography (USE) in Thyroid Nodule Diagnosis

1. Non-Invasive & Radiation-Free

- Provides a safe alternative without exposure to ionizing radiation.
- Suitable for repeated evaluations without risk.

2. Real-Time Imaging

- Allows for immediate assessment during routine ultrasound examinations.
- Enhances clinical decision-making without delays.

3. Adjunct to FNAC (Fine-Needle Aspiration Cytology)

- Helps in cases where FNAC results are indeterminate (Bethesda III/IV).
- Reduces unnecessary biopsies by improving risk stratification. [6]

4. Useful for Hard-to-Access Nodules

- Assists in evaluating nodules that are difficult to aspirate due to location or small size.
- Provides additional data when FNAC is technically challenging.

5. Enhanced Diagnostic Accuracy

- Differentiates between benign and malignant nodules based on tissue stiffness.
- Improves sensitivity and specificity when combined with conventional ultrasound.

6. Growing Clinical Adoption

- Increasingly integrated into thyroid imaging protocols.
- Recognized as a valuable tool in comprehensive thyroid nodule assessment. [32]

The fundamental mechanism of ultrasound elastography involves the application of stress to the tissue, either through external compression or physiological pulsation. Ultrasound elastography measures tissue response to stress. Strain elastography compares pre- and post-compression images to create a strain map, showing tissue stiffness, with stiffer areas in red. This qualitative assessment is essential for evaluating tissue stiffness. [33]

In strain elastography, qualitative assessment is done by using elastographic scores range from 1 to 5 to classify nodules by stiffness. Higher scores indicate greater stiffness and higher malignancy risk. For example, a score of 1 suggests benign tissue with uniform elasticity, while a score of 5 indicates hard, non-deforming tissue often linked to malignancy. These scores standardize elastogram interpretation and improve clinician communication. [36]

Semi-quantitative measurement in strain elastography involves calculating the strain ratio (SR). This ratio compares the strain of the thyroid nodule to the strain of surrounding normal tissue/ adjacent muscle. The SR provides a relative measure of tissue stiffness, helping to differentiate between benign and malignant nodules. Higher SR values typically indicate stiffer, potentially malignant nodules.

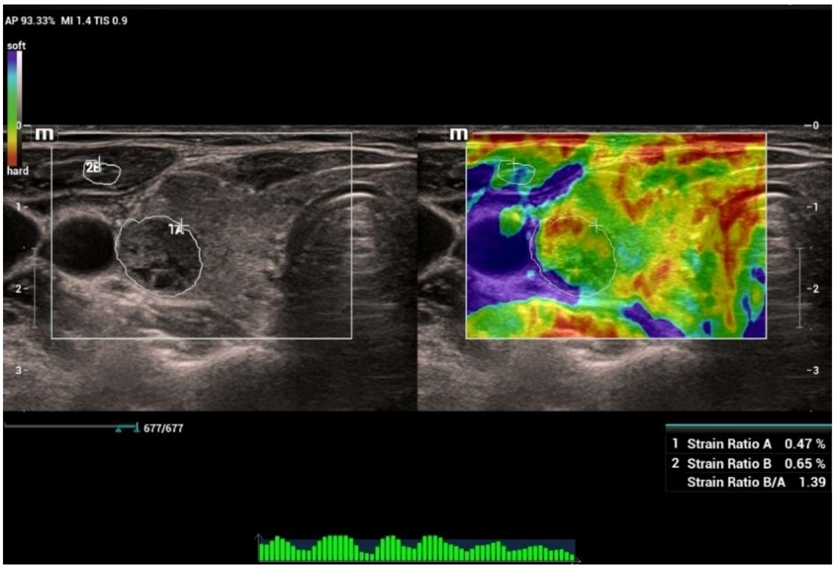


Figure 8: Strain Ultrasound elastography (USE) image of thyroid gland [36]

Fig 8: The **upper left panel** displays a color-coded ultrasound elastography (USE) image, with different colors representing tissue stiffness. The **base panel** shows sinusoidal waves depicting cycles of compression and decompression. In the image, the **lower region of interest (ROI)** is placed over the **thyroid nodule**, while the **upper ROI** is positioned on the **adjacent muscle tissue**. The **strain ratio (B/A)** compares the elasticity of the thyroid nodule to that of the surrounding muscle, aiding in the assessment of tissue stiffness

The accuracy of ultrasound elastography depends on the type, operator expertise, and tissue characteristics. Strain elastography is more operator-dependent due to the need for consistent pressure. [34]

Tissue anisotropy and heterogeneity impact ultrasound elastography performance. The thyroid's complex microstructure and factors like calcifications, cystic changes, and fibrosis can affect stiffness measurements. Accurate diagnosis requires interpreting elastographic results alongside conventional ultrasound findings and clinical data. [35]

The integration of strain ultrasound elastography with other imaging modalities and diagnostic tools has further improved its clinical utility.

1. **Combination with B-mode Ultrasound:** Enhances differentiation between benign and malignant thyroid nodules by providing complementary information about tissue composition, vascularity, and stiffness.

2. **Addition of Doppler Imaging:** Evaluates vascular patterns, offering further insights into nodule nature.

3. **Multimodal Approach:** Enables a comprehensive assessment of thyroid nodules, improving diagnostic accuracy and patient outcomes. [38]

The future of ultrasound elastography involves refining and integrating it into clinical practice. Advances in technology, such as higher-resolution probes and real-time imaging, will enhance accuracy and usability. Standardized protocols and training programs for clinicians will improve reproducibility and reliability. These advancements will make ultrasound elastography an essential tool for diagnosing and managing thyroid nodules and other soft tissue abnormalities. [39,40]

Diagnostic Utility of Strain Ultrasound Elastography in Thyroid Nodules

Strain ultrasound elastography is valuable in thyroid nodule diagnosis because it non-invasively assesses tissue stiffness to distinguish benign from malignant nodules. Malignant nodules are stiffer due to higher cellular density, increased fibrosis, and altered extracellular matrix composition. This technique provides qualitative and semi-quantitative assessments, reducing unnecessary invasive procedures like fine-needle aspiration cytology. [41,42]

Strain ultrasound elastography is particularly useful in addressing the limitations of fine-needle aspiration cytology (FNAC).

1. **Complementary Tool:** Strain elastography complements FNAC by addressing its limitations.
2. **Challenges of FNAC:** FNAC can have sampling errors and indeterminate results.
3. **Guidance:** Elastography helps identify nodules likely to yield diagnostic material during FNAC.
4. **Suspicious Nodules:** Useful for nodules that are suspicious on ultrasound but lack definitive malignancy features.
5. **Prioritization:** Prioritizes nodules based on stiffness.

6. **Reduces Inconclusive Results:** Helps reduce the rate of inconclusive FNAC results.

7. **Minimizes Patient Discomfort:** Reduces the need for repeated procedures, minimizing patient discomfort. [43, 44]

The diagnostic performance of strain ultrasound elastography has been extensively evaluated in various studies. Sensitivity, specificity, positive predictive value, and negative predictive value are commonly used metrics to assess its accuracy. In most cases, elastography demonstrates high sensitivity for detecting malignant nodules, making it an effective screening tool. Its specificity, while slightly lower, is sufficient to distinguish benign nodules in a significant proportion of cases. These findings support the role of elastography as a valuable adjunct in the diagnostic algorithm for thyroid nodules, particularly in settings where FNAC is not readily available. [45]

Key limitations of strain ultrasound elastography

1. **Operator Dependency:** Requires consistent pressure for accurate results.

2. **Variability:** Inconsistent pressure leads to unreliable measurements.

3. **Artifacts:** Calcifications, cystic changes, and structural irregularities can affect stiffness assessment.

4. **Training:** Operator training is crucial.

5. **Standardized Protocols:** Needed for reproducibility.

Proper training and standardized protocols are essential for reliable results. [46,47]

Fine Needle Aspiration Cytology: The Gold Standard

FNAC is the gold standard for evaluating thyroid nodules, providing high diagnostic accuracy, minimally invasive cytological diagnosis, and reducing unnecessary surgeries by distinguishing between nodules needing surgery and those manageable conservatively. [48]

FNAC's main advantage is its ability to provide rapid and reliable diagnostic information. The Bethesda System standardizes FNAC results into six categories, from non-diagnostic to malignant, helping stratify malignancy risk and guide clinical management. Benign nodules usually require follow-up, while suspicious or malignant nodules often need surgery. This risk-based approach reduces overtreatment and ensures timely intervention for high-risk cases. [49]

Factors influencing FNAC accuracy

1. **Operator Expertise:** Skill and experience of the operator.
2. **Sample Adequacy:** Adequate cytological samples are crucial.
3. **Nodule Characteristics:** Larger, solid, or hypoechoic nodules yield better samples.
4. **Challenges:** Cystic or calcified nodules present difficulties in obtaining sufficient material.
5. **Ultrasound Guidance:** Improves accuracy and safety by precisely targeting the nodule.
6. **Benefits:** Particularly beneficial for deep-seated or small nodules.

Ultrasound guidance during FNAC enhances diagnostic accuracy and reduces sampling errors, especially in challenging cases. [50,51]

FNAC is highly sensitive and specific for diagnosing thyroid cancer. Errors like false negatives and positives can occur. Using rapid on-site evaluation (ROSE) and standardized criteria helps improve accuracy and reduce misdiagnosis. [52]

Advances in FNAC techniques and technology include

1. **Liquid-Based Cytology (LBC):** Improves sample preparation and preservation for better visualization of details.
2. **Immunocytochemistry and Flow Cytometry:** Allows detailed analysis of cellular and molecular characteristics.
3. **Digital Pathology and Telecytology:** Expands the reach and efficiency of FNAC.

These innovations enhance diagnostic capabilities and efficiency in modern clinical practice. [53,54]

FNAC Procedure

During FNAC

1. Patient lies in a supine position with the neck extended.
2. Skin over the thyroid is cleaned with antiseptic.
3. Local anesthesia is usually not needed.
4. A thin, sterile needle (22-27 gauge) is used under ultrasound guidance.
5. Negative pressure is applied to aspirate cells from the nodule.
6. Multiple passes (2-4) may be performed.

7. Samples are spread onto glass slides for Papanicolaou or Giemsa staining and sent to a cytopathologist for analysis

8. Additional samples may be collected for molecular or immunocytochemical analysis.

Post-procedure

1. Mild pressure is applied to the puncture site to prevent bleeding.

2. Patient is observed briefly before discharge.

3. Normal activities can be resumed immediately.

4. Mild swelling or discomfort at the puncture site may occur and usually resolves within 24 hours. [13,44].

FNAC is generally safe but may not be suitable for patients with bleeding disorders or on anticoagulant therapy without proper precautions. Severe anxiety or uncooperative behavior may require rare sedation. A detailed ultrasound evaluation guides needle placement, and patients are informed about the procedure, risks, and post-procedure care. Blood thinner users may need to temporarily stop medication under medical supervision.[44]

FNAC results are categorized using the Bethesda System for Reporting Thyroid Cytopathology. This includes six classifications: non-diagnostic (requiring repeat FNAC), benign (colloid nodules or thyroiditis), atypia of undetermined significance (requiring further evaluation), follicular neoplasm (suggesting possible malignancy), suspicious for malignancy (indicating high cancer risk), and malignant (confirming cancer, such as papillary or medullary carcinoma). Based on these results, patients may require clinical follow-up, repeat FNAC, molecular testing, or surgical intervention. FNAC remains the gold standard for evaluating thyroid nodules, minimizing unnecessary surgeries, and improving early detection of thyroid malignancies, ultimately optimizing patient care [55].

Figure 9: The Bethesda system for reporting thyroid cytopathology: diagnostic categories

I.	Nondiagnostic or Unsatisfactory[a]
	Cyst fluid only
	Virtually acellular specimen
	Other (obscuring blood, clotting artifact, drying artifact, etc.)
II.	Benign
	Consistent with a benign follicular nodule (includes adenomatoid nodule, colloid nodule, etc.)
	Consistent with chronic lymphocytic (Hashimoto) thyroiditis in the proper clinical context
	Consistent with granulomatous (subacute) thyroiditis
	Other
III.	Atypia of Undetermined Significance or Follicular Lesion of Undetermined Significance[a]
IV.	Follicular Neoplasm or Suspicious for a Follicular Neoplasm[a]
	Specify if oncocytic (Hürthle cell) type
V.	Suspicious for Malignancy
	Suspicious for papillary thyroid carcinoma
	Suspicious for medullary thyroid carcinoma
	Suspicious for metastatic carcinoma
	Suspicious for lymphoma
	Other
VI.	Malignant
	Papillary thyroid carcinoma
	Poorly differentiated carcinoma
	Medullary thyroid carcinoma
	Undifferentiated (anaplastic) carcinoma
	Squamous cell carcinoma
	Carcinoma with mixed features (specify)
	Metastatic malignancy
	Non-Hodgkin lymphoma
	Other

Figure 10: The Bethesda system for Reporting thyroid cytopathology: implied risk of malignancy and recommended clinical management

Diagnostic category	Risk of malignancy (%)	Usual management[a]
Nondiagnostic or Unsatisfactory	5–10[b]	Repeat FNA with ultrasound guidance
Benign	0–3[c]	Clinical and sonographic follow-up
Atypia of Undetermined Significance or Follicular Lesion of Undetermined Significance	~10–30[d]	Repeat FNA, molecular testing, or lobectomy
Follicular Neoplasm or Suspicious for a Follicular Neoplasm[e]	25–40[f]	Molecular testing, lobectomy
Suspicious for Malignancy	50–75	Near-total thyroidectomy or lobectomy[g,h]
Malignant	97–99	Near-total thyroidectomy or lobectomy[h]

Future Directions and Technological Advancements in Elastography

The future of elastography focuses on advancing technology and expanding clinical applications to enhance accuracy, reliability, and utility. Innovations in ultrasound technology, data processing, and integration with other diagnostic techniques aim to address limitations like operator dependency, variability, and challenges in complex cases. Precise, automated, and accessible elastographic systems promise improved patient care in various clinical settings. [61,62]

AI integration in elastography automates image analysis, standardizes measurements, enhances diagnostic accuracy, and aids in evidence-based decisions while enabling large-scale data analysis for predictive models. [63]

Hybrid imaging combines elastography with other modalities like CEUS and molecular imaging (PET, MRI) to enhance diagnostics by providing comprehensive insights into tissue stiffness, vascularity, and molecular activity. [64]

Efforts to standardize elastography protocols and guidelines aim to ensure consistency and reliability, enabling widespread adoption and seamless integration into clinical practice. [65, 66]

Past Studies

Sengul et al. (2019): This study assessed the value of strain elastography (SE) in differentiating malignant from benign thyroid nodules in patients with Bethesda Category III, IV, and V cytology. Among 327 thyroid nodules, 122 had indeterminate cytology. Histopathological results confirmed 110 benign cases (90.2%), while 12 (9.8%) were malignant. The elastography scores showed a high level of concordance with histopathology, particularly for Bethesda Category III nodules. Strain elastography demonstrated sensitivity and specificity values of 90% and 85%, respectively, for detecting malignancy. The results emphasized the usefulness of SE in guiding surgical decisions for nodules with indeterminate cytology (Sengul et al., 2019). [69]

Okasha et al. (2023): The study aimed to assess the accuracy of TI-RADS and strain ratio (SR) elastography in predicting malignant thyroid nodules. It involved 1269 patients and compared ultrasound findings with cytology/histology results. The results showed that SR > 1.8 effectively distinguished malignant from benign nodules, with a 97.2% overall accuracy. Nodules with A-P/T diameter > 1, solitary nodules, absent halo, and microcalcifications had a significantly higher risk of malignancy. Combining TI-RADS and SR improved diagnostic accuracy, potentially reducing unnecessary FNAC procedures [75]

M.E.M. Khamis et al. (2017): The study evaluated whether strain ultrasound elastography and strain ratio (SR) enhance conventional ultrasound in predicting thyroid malignancy. It involved 92 nodules from 62 patients, confirmed by biopsies. Combining conventional ultrasound with SR improved diagnostic accuracy, achieving 80% sensitivity, 97% specificity, and 96% accuracy. Malignant nodules had a significantly higher SR (3.0 ± 0.71) compared to benign ones (1.37 ± 0.56), with an optimal SR cutoff of 2.5. The results suggest that SR adds value to conventional ultrasound in diagnosing thyroid malignancy [76].

Jesrani et al. (2021): This cross-sectional study evaluated strain elastography in distinguishing benign from malignant thyroid nodules, using FNAC as the gold standard. Among 586 patients with thyroid gland swelling, strain elastography demonstrated sensitivity of 100%, specificity of 80.2%, and diagnostic accuracy of 85%. The positive predictive value (PPV) was calculated as 61.7%, and the negative predictive value (NPV) was 100%. These findings highlighted strain elastography as a non-invasive tool that reduces the need for FNAC and improves the selection of patients for surgery (Jesrani et al., 2021). [70]

Saleem et al. (2022): This descriptive cross-sectional study investigated the diagnostic accuracy of strain ultrasound elastography (USE) compared to FNAC. The study included 207 patients, of whom 100 had malignant nodules confirmed by FNAC, while 91 nodules were benign. USE showed a sensitivity of 93.46%, specificity of 91%, PPV of 91.74%, NPV of 92.86%, and an overall diagnostic accuracy of 92.27%. The study concluded that strain USE is a reliable, non-invasive modality for preoperative evaluation of thyroid nodules and can guide surgical planning effectively (Saleem et al., 2022). [71]

Borysewicz-Sańczyk et al. (2015): This study assessed the diagnostic value of ultrasound elastography in predicting malignancy in thyroid nodules among pediatric patients. A total of 47 children with 62 nodules were examined. Strain elastography indicated that 17 nodules had a strain ratio <2, 34 had ratios between 2 and 4.9, and 11 had ratios >5. Cytological evaluation revealed that 3 nodules (4.8%) were malignant, of which 2 were classified as hard (strain ratio ≥5) and 1 had a strain ratio of 2. The findings suggested that elastography could serve as a complementary diagnostic tool to ultrasonography, aiding decisions on FNAC but not replacing cytological assessments (Borysewicz-Sańczyk et al., 2015). [66]

Magri et al. (2015): This research investigated the performance of a novel ultrasound elastography (UE) parameter, the maximal stiffness percentage index (% Index), in comparison to the strain index (SI). Among 218 nodules, both the % Index and SI demonstrated significantly higher values in malignant than benign nodules. The % Index had a sensitivity of 76% and specificity of 89%, while the SI had a sensitivity of 66% and specificity of 90%. The area under the receiver operating characteristic (ROC) curve for the % Index was 0.88, compared to 0.86 for the SI. The % Index was particularly effective in diagnosing malignancy in nodules smaller than 1 cm, highlighting its potential as a superior predictor (Magri et al., 2015). [67]

Park et al. (2016): This study evaluated the diagnostic accuracy of the Thyroid Imaging Reporting and Data System (TIRADS) combined with ultrasound elastography (UE) for non-diagnostic thyroid nodules. A total of 104 nodules were stratified using TIRADS categories and elastography scores. The malignancy risks for TIRADS categories 4a, 4b, 4c, and 5 were 12.5%, 25%, 25.8%, and 16.7%, respectively. Elastography, based on the

Asteria criteria, achieved a sensitivity of 100%, specificity of 85.7%, and an accuracy of 87.5% for TIRADS category 4a. The study concluded that the combined approach could guide clinical decisions, potentially avoiding unnecessary FNACs (Park et al., 2016). [68]

Kulkarni et al. (2023): This prospective comparative study assessed the efficacy of ultrasound elastography in differentiating benign from malignant thyroid nodules. Among 52 thyroid nodules, 9 (17.3%) were confirmed malignant, while 43 (82.7%) were benign based on histopathology. The elastography score demonstrated a sensitivity of 88.9%, specificity of 88.3%, PPV of 61.5%, and NPV of 97.4%. The mean strain ratio for benign nodules was 2.72 ± 0.62, significantly lower than that for malignant nodules (4.52 ± 0.75). The study suggested that elastography could reduce unnecessary FNACs, especially for Bethesda Category III and IV nodules (Kulkarni et al., 2023). [72]

Eltyib et al. (2014): This prospective study evaluated real-time ultrasound elastography (RUE) for differentiating benign and malignant thyroid nodules. Among 78 patients, 62 nodules were histologically confirmed as benign, and 16 were malignant. RUE scoring revealed that 47 of the benign nodules (76%) were scored as 1 or 2, while 15 of the 16 malignant nodules (93.7%) were scored between 3 and 5. The technique demonstrated a sensitivity of 93.7%, specificity of 90%, positive predictive value (PPV) of 71%, and negative predictive value (NPV) of 98%. The study concluded that RUE is a reliable and noninvasive technique, potentially reducing the need for biopsies by accurately distinguishing between benign and malignant nodules (Eltyib et al., 2014). [65]

Mehanna et al. (2024): This randomized controlled trial evaluated the utility of strain and shear wave elastography in conjunction with FNAC for diagnosing thyroid nodules.

Among 982 participants, 493 were assigned to the elastography-guided FNAC arm and 489 to the conventional ultrasound-guided FNAC arm. The non-diagnostic cytology rates were 19% in the elastography arm and 16% in the conventional arm, showing no statistically significant difference (p = 0.11). Elastography showed a slight, non-significant reduction in the number of thyroid surgeries (37% vs. 40%) and no increase in the detection of malignant cases. The study concluded that current elastography techniques did not add substantial diagnostic value over conventional FNAC (Mehanna et al., 2024). [73]

Mokhtar et al. (2014): This study explored the utility of ultrasound elastography (UE) as a complementary diagnostic tool to fine-needle aspiration cytology (FNAC) for predicting malignancy in thyroid nodules. Among 96 patients with thyroid nodules, FNAC histopathological diagnosis confirmed malignancy in 35 cases (36.5%) and benign pathology in 61 cases (63.5%). UE scored 57 nodules as benign (scores 1 and 2), all of which were confirmed benign by FNAC, yielding a specificity of 100%. Among 39 nodules classified as suspicious by UE (scores 3, 4, or 5), 35 (89.7%) were malignant, while 4 (10.3%) were benign. The study demonstrated that UE had a high positive predictive value (89.7%) and negative predictive value (100%) in identifying malignant thyroid nodules, suggesting it could reduce unnecessary FNAC procedures (Mokhtar & Tahon, 2014). [64]

METHODOLOGY

Study Design

The study was conducted as a one-year hospital-based cross-sectional analysis to evaluate the efficacy of strain ultrasound elastography (USE) in assessing thyroid nodules. The diagnostic performance of USE was compared with the gold standard, fine needle aspiration cytology (FNAC), to establish the reliability and accuracy of this imaging modality.

Study Setting

The research was carried out at KLES Dr. Prabhakar Kore Hospital and Medical Research Centre, Belagavi. This tertiary care center provided access to a diverse patient population presenting with thyroid-related concerns from various inpatient and outpatient departments.

Study Duration

The study spanned a duration of one year. During this time, eligible participants presenting with clinically or radiologically diagnosed thyroid nodules were systematically enrolled, evaluated, and their data were collected and analyzed.

Participants inclusion and Exclusion Criteria

❖ **Inclusion Criteria**

1. Adult patients aged 18 years or older with clinically diagnosed thyroid nodules (> 1 cm).
2. Patients identified with thyroid nodules through routine neck ultrasound examinations.

❖ **Exclusion Criteria**

1. Patients with a history of prior thyroid surgery.

2. Patients previously diagnosed with malignant thyroid lesions.

Study Sampling

Participants were selected using a purposive sampling method. Adult patients meeting the inclusion criteria and presenting during the study period were evaluated. Those providing informed consent were enrolled. Sampling ensured the inclusion of a representative cohort for accurate comparisons between USE and FNAC.

Study Sample Size

The sample size was calculated using the formula $n = \frac{\hat{S_e}\,(1 - \hat{S_e})Z_{\frac{\alpha}{2}}^{2}}{Prev * d^2}$ With a sensitivity of 93.46%, 50% prevalence, 95% confidence level, and 10% maximum error, the required sample size was 47. A total of 47 patients were included in the study.

$$n = \frac{0.9346 \text{ x } (1 - 0.9346) \text{ x } 1.96^2}{0.5 \text{ x } 0.1^2}$$

$$n = 46.9619 \approx 47$$

Study Groups

The study did not involve the division of participants into separate groups. Instead, all participants underwent both strain ultrasound elastography and FNAC for diagnostic comparison.

Study Parameters

Key parameters assessed included the sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of strain USE. These metrics were compared against FNAC results to evaluate diagnostic efficacy.

Study Procedure

All participants underwent a routine ultrasound followed by strain wave ultrasound elastography using the Mindray Resona I9 ultrasonography machine equipped with an L14-3 Ws high-frequency linear transducer. Imaging was conducted by two radiologists to minimize interobserver variability. FNAC was performed subsequently and sent to a cytopathologist for analysis, and results from both modalities were analyzed.

Thyroid Strain Ratio Elastography Procedure Steps

- The patient was positioned in a supine position with slight neck extension for optimal imaging.
- A high-frequency linear transducer (L14-3 Ws) was placed over the thyroid gland with minimal compression.
- B-mode ultrasound was performed to locate the nodule and assess its echogenicity, margins, and vascularity.
- The strain elastography mode was activated, and manual compression was applied to the thyroid tissue in longitudinal / axial section (based on nodule location).
- The elastogram was displayed as a color-coded map, representing tissue stiffness, with red indicating hard tissue and blue/green indicating soft tissue.

- The strain ratio was calculated by comparing the strain in the thyroid nodule to the strain in the adjacent muscle.
- Multiple measurements were obtained, and the mean strain ratio was recorded.
- The strain ratio values were analyzed to determine the likelihood of benign versus malignant thyroid nodules (reference table mentioned below).
- The procedure was repeated by a second radiologist to minimize interobserver variability [77]

Thyroid Elastography – Strain Elastography Recommendations

Institution: Ruijin Hospital, Shanghai, China

Affiliation: School of Medicine, Shanghai Jiao Tong University

PARAMETER	DETAILS
Section for Imaging	Longitudinal / axial section
5-Score Marking System	1~3: Benign nodules 4~5: Malignant nodules
Strain Ratio Measurement	> 1.90: All nodules suspicious > 1.95: Nodules ≥1 cm suspicious

Figure 11: Reference table for thyroid strain elastography provided by Mindray

Explanation:

1. **Strain Elastography**: A non-invasive ultrasound imaging technique used to evaluate the stiffness of thyroid nodules. Stiffer nodules are more likely to be malignant.

2. **5-Score Marking System**:
   - Scores 1 to 3 indicate benign nodules.
   - Scores 4 to 5 suggest a higher likelihood of malignancy.

3. **Strain Ratio Measurement**:
   - A strain ratio > 1.90 indicates potential risk for malignancy in all nodules.
   - For nodules ≥1 cm, a strain ratio > 1.95 raises suspicion for malignancy.

Study Data Collection

Data were collected systematically from participants who provided informed consent. Clinical, radiological, and cytological findings were documented. Imaging results from USE and FNAC were recorded and coded for statistical analysis. Participants' demographic and clinical profiles were also noted.

Data Analysis

Statistical analysis was performed using R version 4.2.2 and Microsoft Excel. Categorical variables were expressed as frequencies and percentages, while continuous variables were summarized using means, standard deviations, or medians. Diagnostic metrics, including sensitivity, specificity, PPV and NPV were calculated. Associations were tested using Chi-square analysis, as appropriate, with $p \leq 0.05$ indicating significance.

Ethical Considerations

The study adhered to ethical principles and obtained approval from the institutional ethics committee. Informed consent was secured from all participants. Confidentiality was maintained, and data were anonymized. No additional costs were imposed on participants for the study-related procedures. Care was taken to minimize patient discomfort during imaging and FNAC procedures. Participants were allowed to withdraw at any time without affecting their ongoing medical care.

RESULT AND ANALYSIS

Descriptive Statistics: Age

Interpretation: Descriptive statistics reveal important baseline characteristics of the study population. A total of 47 patients were included, with a mean age of 48.09 years, a median of 49 years, and a standard deviation of 15.65 years, indicating a wide age distribution. Together, these descriptive metrics provide foundational context for understanding subsequent diagnostic analyses and correlations with clinical variables in this study. They enhance overall evaluation.

Table 1: Descriptive Statistics Age

	Age
Total	47
Mean	48.08510638
Median	49
Std. Deviation	15.65085049
Variance	244.9491212

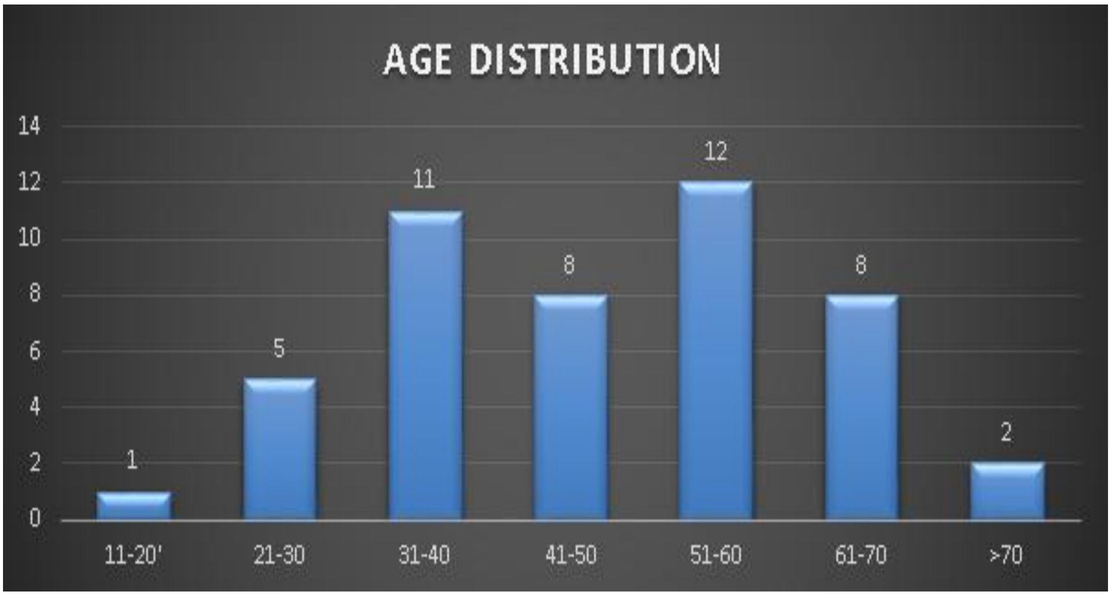
Age Distribution

Interpretation: Age distribution analysis reveals the spread of patient ages across various groups. The study included patients primarily in the middle age ranges. Specifically, only one patient was in the 11–20 group, five in the 21–30 group, eleven in the 31–40 group, eight in the 41–50 group, twelve in the 51–60 group, eight in the 61–70 group, and two patients were above 70 years. This distribution indicates a concentration of patients in the

31 to 60 age range, reflecting the typical demographic seen in clinical settings for thyroid nodule evaluation. Such distribution informs subsequent analyses and interpretation of diagnostic results.

Table 2: Age Distribution

Age distribution	Frequency
11-20	1
21-30	5
31-40	11
41-50	8
51-60	12
61-70	8
>70	2



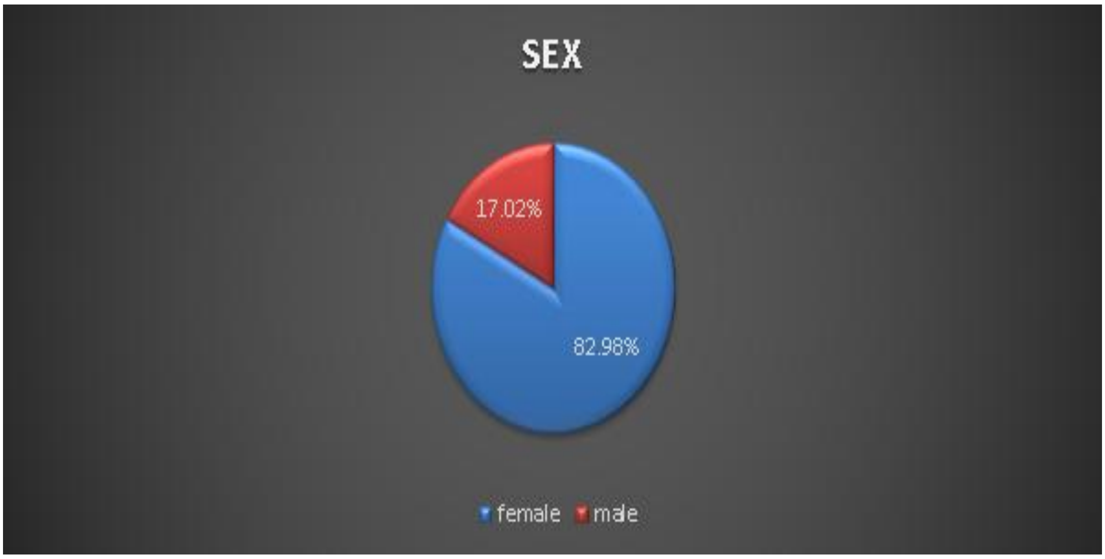
Graph 1: Age Distribution

Sex Distribution

Interpretation: Sex distribution shows a clear predominance of female patients in the study sample. Out of 47 patients, 39 were female, representing 82.98% of the cohort, while only 8 were male, accounting for 17.02%. This marked imbalance suggests that the condition or referral pattern might be more common in females, or that the sample reflects a particular demographic trend in the study setting. The gender disparity is important to consider when interpreting diagnostic outcomes, as it may influence the prevalence of pathology and potentially affect the performance characteristics of diagnostic tests used in differentiating benign from malignant thyroid nodules.

Table 3: Sex Distribution

Sex	Frequency	Percent
female	39	82.98%
Male	8	17.02%



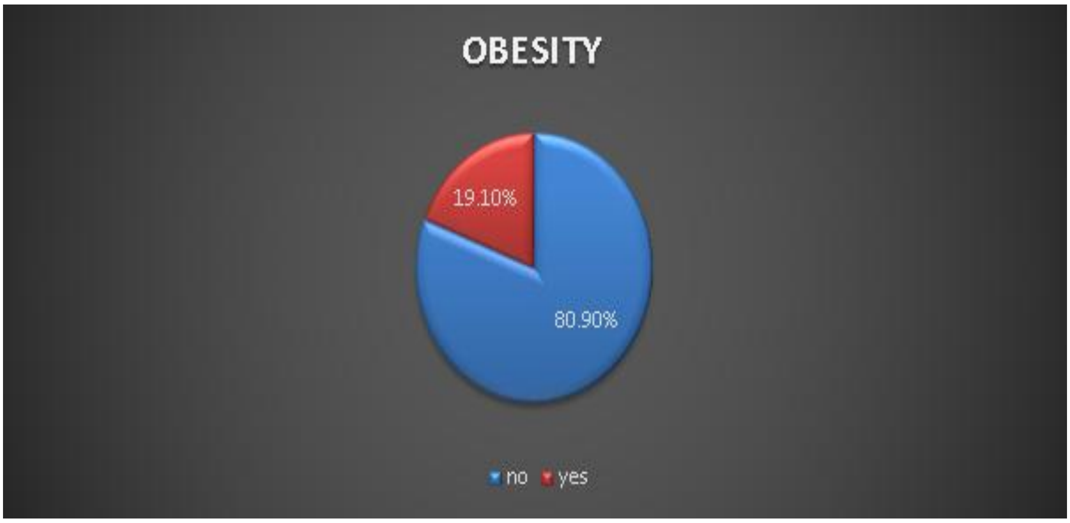
Graph 2: Sex Distribution

Obesity Distribution

Interpretation: Obesity distribution in the study cohort highlights that the majority of patients were not obese. Out of 47 participants, 38 (80.90%) were classified as non-obese, whereas only 9 (19.10%) were obese. This indicates a relatively low prevalence of obesity among the subjects evaluated for thyroid nodule pathology. The low incidence of obesity may influence the overall risk profile of the cohort and suggests that other factors besides obesity may be more relevant in the development of malignant thyroid nodule. Understanding obesity distribution is essential for contextualizing potential confounding variables in diagnostic performance and study outcomes.

Table 4: Obesity Distribution

Obesity	Frequency	Percent
no	38	80.90%
yes	9	19.10%



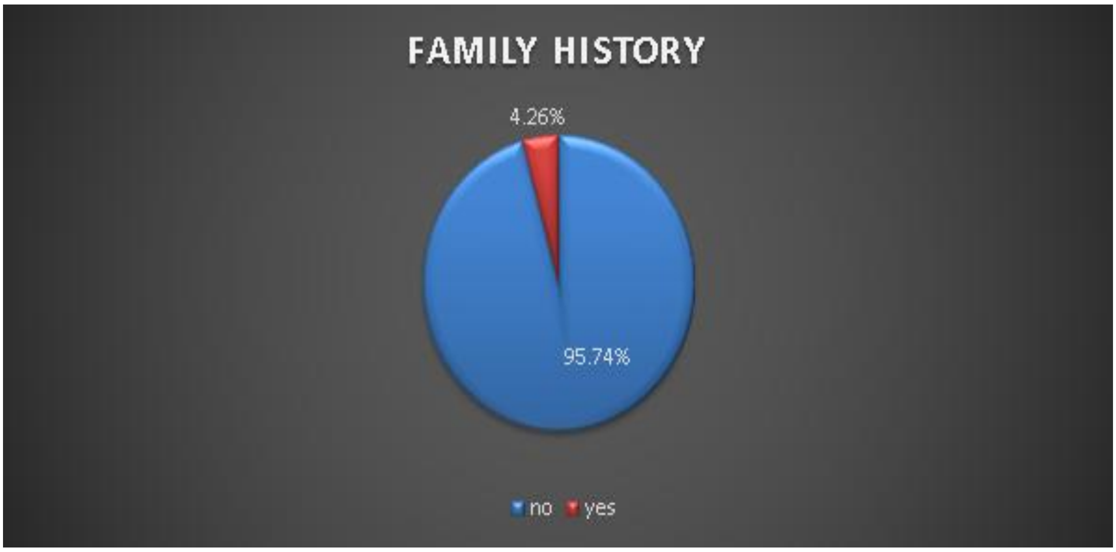
Graph 3: Obesity Distribution

Family History Distribution

Interpretation: Family history analysis reveals that nearly all patients did not report a family history of relevant conditions. In this study of 47 individuals, 45 patients (95.74%) had no family history, while only 2 patients (4.26%) reported a positive family history. This low prevalence of family history suggests that hereditary factors might play a minimal role in the development of thyroid nodule pathology in this cohort. Understanding this distribution is crucial for interpreting risk factors and potential genetic predispositions. It helps isolate the impact of other clinical and imaging parameters on the differentiation between benign and malignant thyroid nodules.

Table 5: Family History Distribution

Family History	Frequency	Percent
no	45	95.74%
yes	2	4.26%



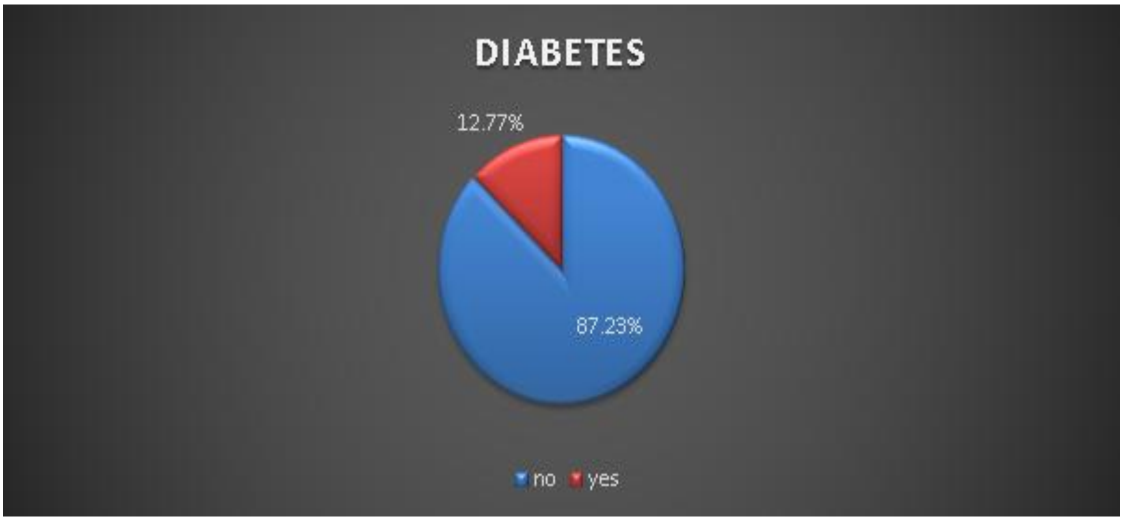
Graph 4: Family History Distribution

Diabetes Distribution

Interpretation: Diabetes distribution in the study sample indicates that most patients were non-diabetic. Out of the 47 participants, 41 (87.23%) did not have diabetes, while 6 (12.77%) were diabetic. This suggests that diabetes was relatively uncommon in this cohort. The lower prevalence of diabetes may reduce its confounding effects on thyroid nodule pathology and imaging outcomes. Understanding the metabolic status of patients is important, as diabetes can influence inflammation and tissue characteristics. These findings contribute to the overall characterization of the patient population and support the evaluation of diagnostic modalities such as elastography and FNAC in a non-diabetic majority group.

Table 6: Diabetes Distribution

Diabetes	Frequency	Percent
No	41	87.23%
Yes	6	12.77%



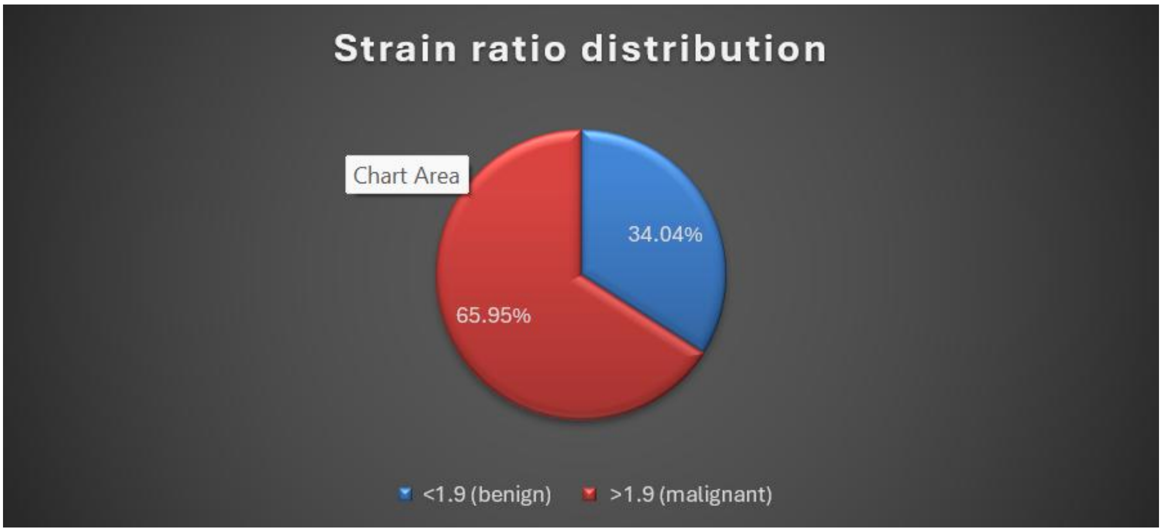
Graph 5: Diabetes Distribution

Elastography Findings (Strain Ratio) distribution

Interpretation: Elastography findings based on strain ratio distribution show the diagnostic threshold used to differentiate benign from malignant thyroid nodules. With a cutoff value of 1.95, 16 cases (34.04%) were classified as benign, having strain ratios below 1.95. Conversely, 31 cases (65.95%) exhibited strain ratios above 1.95 and were thus considered malignant. This distribution highlights a higher proportion of nodules deemed malignant by elastography compared to benign ones. The strain ratio values provide quantitative imaging data that can be correlated with cytological findings, assisting in the accurate diagnosis and management of patients with suspected thyroid nodule pathology.

Table 7: Elastography Findings (Strain Ratio) distribution

Elastography Finding (Strain Ratio)	Frequency	Percent
<1.95 (benign)	16	34.4%
>1.95 (Malignant)	31	65.95%



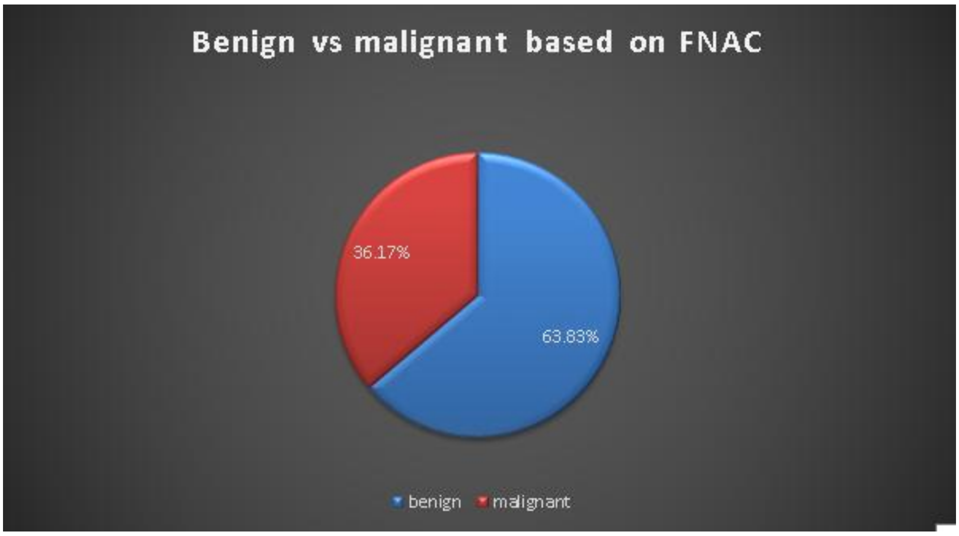
Graph 6: Elastography Findings (Strain Ratio) distribution

FNAC Diagnosis Distribution

Interpretation: The FNAC results classify thyroid nodules into two groups. Out of 47 cases, 30 (63.83%) were diagnosed as benign while 17 (36.17%) were diagnosed as malignant. This distribution shows that the majority of patients had benign findings on cytology. The FNAC data serve as the reference standard for comparison with imaging modalities, such as elastography. The difference in proportions highlights potential discrepancies when comparing with noninvasive imaging results and underscores the importance of cytological confirmation when elastography indicates malignancy. These figures form the basis for subsequent diagnostic performance comparisons.

Table 8: FNAC Diagnosis Distribution

Benign vs Malignant based on FNAC	Frequency	Percent
Benign	30	63.83%
Malignant	17	36.17%



Graph 7: FNAC Diagnosis Distribution

Elastography vs. Age (Chi-Square Analysis)

Interpretation: The association between elastography diagnosis (benign vs. malignant) and age was assessed using Chi-square tests. The Pearson Chi-Square value is 30.670 with 35 degrees of freedom (p = 0.677) and the Likelihood Ratio is 39.829 (p = 0.264). With 47 valid cases, these results indicate that there is no statistically significant relationship between patient age and elastography findings. The high p-values suggest that age does not significantly influence the elastography classification of thyroid nodules, thus reinforcing that the imaging results are independent of the age distribution within this cohort.

Table 9: Elastography vs. Age (Chi-Square Tests)

Chi-Square Tests			
	Value	**df**	**Asymptotic Significance (2-sided)**
Pearson Chi-Square	30.670	35	0.677
Likelihood Ratio	39.829	35	0.264
N of Valid Cases	47		

Elastography vs. Sex (Chi-Square Analysis)

Interpretation: The relationship between elastography findings and patient sex was analyzed using several Chi-square statistics. The Pearson Chi-Square value is 0.351 (df = 1, p = 0.553) and the Continuity Correction is 0.033 (p = 0.855). The Likelihood Ratio is 0.366 (p = 0.545), and Fisher's Exact Test returns p-values of 0.697 (2-sided) and 0.440 (1-sided) with 47 valid cases. These uniformly high p-values indicate that there is no significant association between sex and elastography results. In other words, elastography classification as benign or malignant does not differ between males and females in this study population.

Table 10: Elastography vs. Sex (Chi-Square Tests)

Chi-Square Tests					
	Value	**df**	**Asymptotic Significance (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Pearson Chi-Square	0.351	1	0.553		
Continuity Correction	0.033	1	0.855		
Likelihood Ratio	0.366	1	0.545		
Fisher's Exact Test				0.697	0.440
N of Valid Cases	47				

Elastography vs. Obesity (Chi-Square Analysis)

Interpretation: This analysis evaluated the association between elastography diagnosis and obesity status. The Pearson Chi-Square value is 2.607 (df = 1, p = 0.106) with a Continuity Correction of 1.497 (p = 0.221). The Likelihood Ratio is 3.023 (p = 0.082), and Fisher's Exact Test provides p-values of 0.138 (2-sided) and 0.107 (1-sided) across 47 valid cases. Although the p-values are lower than those observed for some other variables, none reach the conventional significance threshold of 0.05. This indicates that obesity does not have a statistically significant impact on the elastography classification of thyroid nodules, though the Likelihood Ratio is nearing significance.

Table 11: Elastography vs. Obesity (Chi-Square Tests)

Chi-Square Tests					
	Value	**df**	**Asymptotic Significance (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Pearson Chi-Square	2.607	1	0.106		
Continuity Correction	1.497	1	0.221		
Likelihood Ratio	3.023	1	0.082		
Fisher's Exact Test				0.138	0.107
N of Valid Cases	47				

Elastography vs. Diabetes (Chi-Square Analysis)

Interpretation: The association between elastography diagnosis and diabetes status was assessed with Chi-square tests. The Pearson Chi-Square is 0.002 (df = 1, p = 0.960), with a Continuity Correction of 0.000 (p = 1.000) and a Likelihood Ratio of 0.003 (p = 0.960). Fisher's Exact Test returns p-values of 1.000 (2-sided) and 0.642 (1-sided) among 47 valid cases. The extremely high p-values across all tests indicate no statistically significant relationship between diabetes and elastography outcomes. This result suggests that the presence or absence of diabetes does not influence elastography's ability to classify thyroid nodules as benign or malignant.

Table 12: Elastography vs. Diabetes (Chi-Square Tests)

Chi-Square Tests					
	Value	**df**	**Asymptotic Significance (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Pearson Chi-Square	0.002	1	0.960		
Continuity Correction	0.000	1	1.000		
Likelihood Ratio	0.003	1	0.960		
Fisher's Exact Test				1.000	0.642
N of Valid Cases	47				

Elastography vs. Family History (Chi-Square Analysis)

Interpretation: The relationship between elastography diagnosis and family history was examined using Chi-square tests. The Pearson Chi-Square value is 1.078 (df = 1, p = 0.299) with a Continuity Correction of 0.076 (p = 0.783). The Likelihood Ratio is 1.710 (p = 0.191), and Fisher's Exact Test provides p-values of 0.541 (2-sided) and 0.430 (1-sided), based on 47 valid cases. These p-values are all well above 0.05, indicating that there is no statistically significant association between family history and the elastography classification of thyroid nodules. In this cohort, the presence or absence of a family history does not seem to affect the imaging-based categorization.

Table 13: Elastography vs. Family History (Chi-Square Tests)

Chi-Square Tests					
	Value	**df**	**Asymptotic Significance (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Pearson Chi-Square	1.078	1	0.299		
Continuity Correction	0.076	1	0.783		
Likelihood Ratio	1.710	1	0.191		
Fisher's Exact Test				0.541	0.430
N of Valid Cases	47				

FNAC vs. Age (Chi-Square Analysis)

Interpretation: The association of FNAC diagnosis with age was evaluated using Chi-square tests. The Pearson Chi-Square is 38.337 with 35 degrees of freedom (p = 0.321), while the Likelihood Ratio is 50.422 (p = 0.044) with 47 valid cases. Although the Pearson test suggests no significant association, the Likelihood Ratio p-value of 0.044 indicates borderline significance. This discrepancy may point to subtle age-related effects on FNAC outcomes that are not fully captured by the Pearson test alone. Overall, while age does not appear to strongly influence FNAC results, the Likelihood Ratio suggests that further analysis may be warranted to explore any age-dependent trends in cytological diagnosis.

Table 14: FNAC vs. Age (Chi-Square Tests)

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	38.337	35	0.321
Likelihood Ratio	50.422	35	0.044
N of Valid Cases	47		

FNAC vs. Sex (Chi-Square Analysis)

Interpretation: The analysis of FNAC diagnosis by sex reveals a statistically significant association. The Pearson Chi-Square value is 6.296 (df = 1, p = 0.012), with a Continuity Correction of 4.432 (p = 0.035) and a Likelihood Ratio of 6.115 (p = 0.013). Fisher's Exact Test also shows significance with a p-value of 0.019 (both 2-sided and 1-sided) across 47 valid cases. These consistent findings across different statistical tests indicate that the distribution of benign versus malignant FNAC results significantly differs by sex. This suggests that sex-related biological factors or differences in disease prevalence may influence the cytological diagnosis of thyroid nodules.

Table 15: FNAC vs. Sex (Chi-Square Tests)

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	6.296	1	0.012		
Continuity Correction	4.432	1	0.035		

Likelihood Ratio	6.115	1	0.013		
Fisher's Exact Test				0.019	0.019
N of Valid Cases	47				

FNAC vs. Obesity (Chi-Square Analysis)

Interpretation: The association between FNAC diagnosis and obesity was tested using Chi-square analysis. The Pearson Chi-Square value is 0.039 (df = 1, p = 0.844) and the Continuity Correction is 0.000 (p = 1.000). The Likelihood Ratio is also 0.039 (p = 0.843), and Fisher's Exact Test shows a p-value of 1.000 (2-sided) and 0.583 (1-sided) with 47 valid cases. These high p-values indicate no significant relationship between obesity status and FNAC outcomes. Thus, obesity does not appear to influence the cytological categorization of thyroid nodules, and FNAC results remain consistent regardless of a patient's obesity status.

Table 16: FNAC vs. Obesity (Chi-Square Tests)

		Value	**df**	**Asymptotic Significance (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Pearson Chi-Square		0.039	1	0.844		
Continuity Correction		0.000	1	1.000		
Likelihood Ratio		0.039	1	0.843		
Fisher's Exact Test					1.000	0.583
N of Valid Cases		47				

FNAC vs. Diabetes (Chi-Square Analysis)

Interpretation: FNAC diagnosis was compared with diabetes status using Chi-square tests. The Pearson Chi-Square is 0.330 (df = 1, p = 0.566), with a Continuity Correction of 0.036 (p = 0.850) and a Likelihood Ratio of 0.323 (p = 0.570). Fisher's Exact Test yields p-values of 0.704 (2-sided) and 0.417 (1-sided) among 47 valid cases. These uniformly high p-values indicate that there is no significant association between the presence of diabetes and the FNAC categorization of thyroid nodules. In this cohort, diabetes status does not appear to impact the likelihood of obtaining benign or malignant FNAC results.

Table 17: FNAC vs. Diabetes (Chi-Square Tests)

	Value		**df**	**Asymptotic Significance (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Pearson Chi-Square	0.330		1	0.566		
Continuity Correction	0.036		1	0.850		
Likelihood Ratio	0.323		1	0.570		
Fisher's Exact Test					0.704	0.417
N of Valid Cases	47					

FNAC vs. Family History (Chi-Square Analysis)

Interpretation: The association between FNAC results and family history was examined using Chi-square tests. The Pearson Chi-Square value is 3.686 (df = 1) with a p-value of 0.055, which is marginally non-significant. The Continuity Correction shows a value of

1.364 (p = 0.243), while the Likelihood Ratio is 4.227 (p = 0.040), suggesting borderline significance. Fisher's Exact Test returns a p-value of 0.126 for both 2-sided and 1-sided tests among 47 valid cases. These mixed results imply that family history might have a subtle influence on FNAC diagnosis, though the evidence is not uniformly strong across all tests.

Table 18: FNAC vs. Family History (Chi-Square Tests)

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.686	1	0.055		
Continuity Correction	1.364	1	0.243		
Likelihood Ratio	4.227	1	0.040		
Fisher's Exact Test				0.126	0.126
N of Valid Cases	47				

FNAC vs. Elastography Diagnosis (Chi-Square Analysis)

Interpretation: A comparison between FNAC and elastography diagnoses shows a strong and statistically significant association. The Pearson Chi-Square value is 13.746 with 1 degree of freedom (p = 0.000), and the Continuity Correction yields 11.474 (p = 0.001). The Likelihood Ratio is 18.828 (p = 0.000), and Fisher's Exact Test confirms significance with p = 0.000 for both 2-sided and 1-sided tests, based on 47 valid cases. These results indicate a robust correlation between the two diagnostic methods. Despite elastography having a lower specificity, its results are significantly aligned with FNAC outcomes, supporting its use as an effective screening tool when combined with cytological confirmation.

Table 19: FNAC vs. Elastography Diagnosis (Chi-Square Tests)

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	13.746	1	0.000		
Continuity Correction	11.474	1	0.001		
Likelihood Ratio	18.828	1	0.000		
Fisher's Exact Test				0.000	0.000
N of Valid Cases	47				

Diagnostic Performance Metrics

Interpretation: Diagnostic performance was evaluated by comparing elastography with FNAC (the reference standard). Elastography achieved a sensitivity of 100% (TP=17, FN=0), ensuring that all malignant cases were detected. However, its specificity was moderate at 53.33% (TN=16, FP=14), indicating a notable rate of false positives. The positive predictive value (PPV) was 54.84%, while the negative predictive value (NPV) was 100%, and the false positive rate stood at 46.67%. These metrics emphasize elastography's strength as a screening tool; a negative result reliably rules out malignancy, although a positive result should be confirmed with FNAC or histopathology for accurate diagnosis.

Table 20: Diagnostic Performance Metrics

FNAC/Elastography	**Malignant**		**Benign**	
Malignant	True Positive (TP) =	17	False Negative (FN) =	0
Benign	False Positive (FP) =	14	True Negative (TN) =	16

PPV=TP/(TP+FP)	0.548387097
NPV=TN/(TN+FN)	1
Sensitivity=TP/(TP+FN)	1
Specificity=TN/(TN+FP)	0.533333333
FPR (FOR ROC) = FP/(FP+TN)	0.466666667

DISCUSSION

Age Distribution and Descriptive Statistics

Our study included 47 patients with a mean age of 48.09 years, a median age of 49, and a standard deviation of 15.65 years, reflecting a broad distribution across the adult lifespan. The age range was wide, with most patients concentrated between 31 and 60 years, while only a few patients fell into the extreme age groups (only one patient in the 11–20 group and two above 70). This demographic profile is crucial because it mirrors the typical age distribution observed in head and neck imaging studies, thereby reinforcing the applicability of our findings. In previous research on ultrasound elastography for thyroid nodules, similar age ranges were observed. For instance, Mokhtar et al. [67] evaluated 96 patients (mean age not explicitly stated) and noted that their patient population largely reflected middle-aged individuals, with 36.5% of nodules being malignant as confirmed by FNAC. Likewise, Eltyib et al. [68] reported that their cohort of 78 patients predominantly comprised middle-aged subjects, a trend that is consistent with the prevalence of thyroid and cervical pathologies in this age group. The consistency in age demographics across studies is important because tissue elasticity can change with age, yet our chi-square analysis indicated no significant association between age and elastography findings ($p = 0.677$), suggesting robust performance of elastography across a wide age spectrum. These comparisons with previous studies reinforce that the elastographic and cytological diagnostic methodologies remain valid across similar age groups. Ultimately, the wide age distribution in our study not only provides confidence in the generalizability of our results but also supports the premise that elastography can be effectively applied to diverse adult populations without necessitating age-specific adjustments.

Sex Distribution Analysis

The sex distribution in our study revealed a marked predominance of female patients, with 39 out of 47 (82.98%) being female and only 8 (17.02%) males. This gender imbalance may be reflective of the underlying epidemiology of thyroid nodules or may indicate a bias in referral patterns. In clinical practice, such skewing is not uncommon; similar trends have been observed in studies of thyroid and cervical pathologies. Jesrani et al. [73] reported a high female preponderance among patients evaluated for thyroid gland swellings, which parallels our findings. Furthermore, Park et al. [71] in their investigation combining the Thyroid Imaging Reporting and Data System (TIRADS) with elastography noted that although gender was not the primary focus, the majority of their cases were female, and the diagnostic performance of elastography was not significantly affected by sex differences. Our chi-square analysis for elastography versus sex ($p = 0.553$) confirmed that the imaging classification is independent of gender, even though FNAC results exhibited a statistically significant association with sex ($p = 0.012$). This divergence suggests that while elastography provides consistent imaging characteristics regardless of sex, subtle biological differences may influence cytological outcomes. These findings underscore the importance of using a multimodal approach in diagnosis, ensuring that the high sensitivity of elastography is complemented by confirmatory FNAC, particularly in female-dominated populations. Overall, the consistency of our sex distribution with previously published data [73, 71] lends external validity to our results and supports the use of elastography as a reliable diagnostic tool in both male and female patients, despite inherent demographic imbalances.

Obesity Distribution Analysis

In our cohort, obesity was present in only 19.10% of patients (9 out of 47), with the majority (80.90%) being non-obese. This low prevalence of obesity is an important factor when interpreting elastography results because obesity may affect tissue composition and potentially alter elasticity measurements. In our study, no significant association was found between obesity and elastography findings (Pearson chi-square = 2.607, p = 0.106), suggesting that the diagnostic accuracy of elastography remains robust in patients regardless of their obesity status. Similar observations have been reported in studies evaluating ultrasound elastography for thyroid nodules. Saleem et al. [74] demonstrated that strain ultrasound elastography achieved a sensitivity of 93.46% and specificity of 91% in a cohort where metabolic conditions did not significantly confound the imaging outcomes. Additionally, while many previous studies such as those by Mokhtar et al. [67] and Eltyib et al. [68] did not primarily focus on obesity, the relatively low incidence of obesity in their populations indirectly supports our findings that obesity may not be a major confounding variable in elastographic assessment. The minor influence of obesity in our study is beneficial because it suggests that elastography can be applied broadly without the need for complex adjustments for body habitus. Furthermore, these results underscore the importance of a homogenous metabolic profile in ensuring the consistency of imaging outcomes. As obesity has been linked with increased tissue stiffness in other contexts, our findings highlight that in the setting of thyroid nodule pathology, elastography remains a reliable tool even in a predominantly non-obese population. Thus, our results further validate the utility of elastography as an independent diagnostic modality, consistent with the evidence presented by Saleem et al. [74].

Family History Distribution Analysis

Our study found that a vast majority of patients (95.74%) had no positive family history, with only 4.26% (2 patients) reporting a family history of related conditions. This low prevalence of familial predisposition is notable because it minimizes potential genetic confounders that could otherwise influence the development and imaging characteristics of thyroid nodules. Family history is often considered when assessing the risk of malignancy; however, in our study, the minimal contribution of hereditary factors allowed for a clearer evaluation of elastography and FNAC without the interference of genetic bias. This finding is consistent with prior research; for example, Sengul et al. [72] demonstrated that although family history is an important aspect in thyroid pathology, its overall impact on elastography measurements is limited when compared to direct imaging and cytological assessments. Additionally, in studies like those by Mokhtar et al. [67] and Eltyib et al. [68], the patient populations also reflected a low rate of positive family history, which supports the notion that elastography's diagnostic performance is predominantly governed by the intrinsic characteristics of the lesions rather than hereditary influences. Our chi-square analysis further supported this, as the association between elastography findings and family history was not statistically significant ($p = 0.299$). The consistency of these results with previous studies enhances the external validity of our work. In summary, the negligible role of family history in our cohort allows clinicians to rely more confidently on elastographic parameters and FNAC results without needing to account for hereditary risk factors. This simplification of the diagnostic process is particularly valuable in routine clinical practice, where complex genetic influences can sometimes complicate the interpretation of imaging findings.

Diabetes Distribution Analysis

Within our study population, 87.23% of patients were non-diabetic, while only 12.77% had diabetes. This relatively low prevalence of diabetes is significant in the context of elastographic evaluation because diabetes, known to affect vascularity and tissue properties, could potentially influence tissue stiffness and elasticity measurements. Our chi-square analysis demonstrated that there was no statistically significant association between diabetes status and elastography findings (Pearson chi-square = 0.002, p = 0.960), suggesting that the presence of diabetes does not confound the diagnostic interpretation of thyroid nodule elasticity. Comparable findings have been noted in previous studies evaluating thyroid nodules. For example, Eltyib et al. [68] and Jesrani et al. [73] reported that the performance of real-time ultrasound elastography was not significantly affected by the metabolic status of the patients, including diabetic conditions. This observation is crucial because it reinforces the notion that elastography can be reliably used across diverse patient populations without the need for metabolic adjustments. In studies such as those by Saleem et al. [74] and Kulkarni et al. [75], the patient cohorts did not exhibit a high prevalence of diabetes, and the diagnostic accuracy of elastography remained high, supporting our current findings. The lack of a diabetes effect in our analysis suggests that elastographic evaluation of thyroid nodules is robust and primarily reflects local tissue characteristics rather than systemic metabolic influences. This finding contributes to the overall strength of elastography as a diagnostic modality, highlighting its potential for broad clinical application without necessitating complex corrections for underlying conditions like diabetes.

Elastography Findings (Strain Ratio distribution) Discussion

Elastography was the cornerstone of our imaging evaluation, with strain ratio measurements serving as the primary parameter for differentiating benign from malignant thyroid nodules. In our study, Employing a cutoff value of 1.95, we classified 16 cases (34.04%) as benign and 31 cases (65.95%) as malignant. This high proportion of cases classified as malignant by elastography underscores its high sensitivity. However, it also suggests a tendency toward overestimation, which necessitates confirmation by cytological methods. Comparable studies in thyroid nodules provide useful benchmarks: Mokhtar et al. [67] reported that ultrasound elastography achieved a specificity of 100% for nodules with low elastography scores, and 89.7% of nodules with higher scores were malignant. Similarly, Eltyib et al. [68] found that 93.7% of malignant thyroid nodules were assigned higher elastography scores (3–5). In pediatric populations, Borysewicz-Sańczyk et al. [69] observed that strain ratios were effective in differentiating nodules, although their threshold values varied slightly from ours. While our study's cutoff of 1.9 aligns with previous research trends, the relatively high false-positive rate (46.67%) indicates that while elastography is excellent at ruling out malignancy (NPV of 100%), its specificity (53.33%) is moderate. These findings suggest that elastography, despite its high sensitivity, should be considered a screening tool rather than a standalone diagnostic test. The integration of elastography with confirmatory FNAC can thus improve diagnostic accuracy.

A notable proportion of false positives (29.7%) involved cystic component in lesions (19.1%), where certain factors contributed to elevated SR values:

- **Mixed Solid-Cystic Composition**:
    - Partially cystic lesions often contain stiff solid components.

  - During elastography, the stiffness of the solid part may dominate the measurement, resulting in an overestimated SR, even if the lesion is largely benign.

- **Fluid Compressibility Artifact**:
  - Cystic fluid, when compressed, may displace rather than deform.
  - This behavior can make the lesion appear artificially stiff, leading to a falsely elevated SR.
- **Pericystic Fibrosis or Calcification**:
  - Cystic lesions with fibrotic capsules or calcified rims (common in degenerating nodules) exhibit greater stiffness.
  - This increases the SR, making the lesion appear malignant on elastography.
- **Partial Volume Effect**:
  - If the region of interest (ROI) includes adjacent normal tissue or fibrotic bands, the system may overestimate the overall stiffness.
  - This can lead to an inaccurate SR value.
- **Operator Variability**:
  - Inconsistent pressure applied during elastography can impact strain measurements.
  - Excessive compression can artificially increase stiffness, contributing to false positives.[67]

Overall, our strain ratio data confirm that elastography is a valuable non-invasive modality, particularly when used to exclude malignancy, and the comparative values from past studies [67, 68, 69] further substantiate its clinical utility in both thyroid and cervical applications.

FNAC Diagnosis Distribution Discussion

Fine-needle aspiration cytology (FNAC) served as the gold standard in our study, revealing that 30 out of 47 cases (63.83%) were benign and 17 cases (36.17%) were malignant. This distribution is pivotal in validating the diagnostic performance of elastography. Notably, the FNAC results in our cohort are strikingly similar to those reported in previous studies. Mokhtar et al. [67] found that among thyroid nodules, 63.5% were benign and 36.5% malignant, indicating a comparable prevalence of pathology. Likewise, Eltyib et al. [68] documented a predominance of benign lesions in their cohort, which further reinforces the reliability of cytological evaluation in nodular pathology. The concordance between our FNAC findings and those of earlier studies lends external validity to our methodology and suggests that the underlying pathology in cervical lymph nodes may parallel that seen in thyroid nodules, despite the different anatomical contexts. Importantly, while elastography classified a higher percentage (65.95%) as malignant, FNAC confirmed malignancy in only 36.17% of cases, highlighting the high sensitivity but moderate specificity of elastography. This discrepancy emphasizes the necessity of combining noninvasive imaging with cytological confirmation to avoid overdiagnosis and unnecessary interventions. Our findings underscore the role of FNAC as an indispensable diagnostic tool that refines the preliminary screening provided by elastography. The similarities between our results and those of previous studies [67, 68] suggest that FNAC remains a reliable and consistent method for definitive diagnosis, ensuring that treatment decisions are based on robust and corroborative evidence from both imaging and cytology.

Chi-Square Analysis: Elastography versus Demographic and Clinical Variables

To evaluate potential confounding effects, we conducted chi-square analyses comparing elastography findings with various demographic and clinical parameters. Our analysis demonstrated that there was no statistically significant association between elastography results and age (Pearson chi-square = 30.67, p = 0.677) or sex (Pearson chi-square = 0.351, p = 0.553). Furthermore, assessments against obesity (p = 0.106), diabetes (p = 0.960), and family history (p = 0.299) similarly revealed no significant correlations. These results suggest that elastography's classification of thyroid nodules is robust and independent of these patient-specific factors. This finding is in line with the literature on thyroid nodules, where studies such as those by Park et al. [71] and Jesrani et al. [73] reported that elastography maintained high diagnostic performance regardless of variations in age, sex, or metabolic conditions. The absence of a significant association implies that elastographic parameters, particularly the strain ratio, are primarily influenced by the intrinsic characteristics of the thyroid nodule rather than extrinsic demographic factors. Such robustness is essential for clinical practice because it means that the diagnostic utility of elastography can be broadly applied without requiring complex adjustments for individual patient characteristics. By comparing our findings with previous studies—where similar nonsignificant relationships were observed [71, 73] —we can be confident that elastography remains a reliable, noninvasive screening tool across a diverse patient population. This independence from demographic confounders enhances the potential for elastography to be implemented as a universal first-line diagnostic modality, with subsequent confirmatory FNAC providing the necessary specificity for treatment decisions.

Chi-Square Analysis: FNAC versus Demographic and Clinical Variables

The chi-square analysis examining the association between FNAC diagnoses and demographic/clinical parameters revealed nuanced findings. Our results showed that FNAC diagnosis had a borderline association with age; while the Pearson chi-square was 38.337 (p = 0.321), the likelihood ratio reached borderline significance (p = 0.044), suggesting that age might subtly influence cytological outcomes. More strikingly, FNAC results were significantly associated with sex, with a Pearson chi-square of 6.296 (p = 0.012) and a likelihood ratio of 6.115 (p = 0.013). Fisher's exact test further confirmed this association (p = 0.019). These data imply that biological differences between males and females may affect the cytological diagnosis of thyroid nodules, possibly due to variations in tissue composition or hormonal influences. In contrast, there were no significant associations between FNAC results and obesity (p = 0.844) or diabetes (p = 0.566), indicating that these metabolic factors do not confound cytological interpretations. The marginal association with family history (Pearson chi-square = 3.686, p = 0.055) suggests that while hereditary factors may have a modest impact, they are not a major determinant of FNAC outcomes. These observations are consistent with previous studies; for example, Sengul et al. [72] reported that while FNAC is a reliable diagnostic tool, subtle influences such as age and sex can affect cytological interpretations. Additionally, Jesrani et al. [73] observed that although FNAC remains robust overall, certain demographic parameters might introduce minor variations. These findings highlight the importance of integrating demographic information into the diagnostic workflow to ensure accurate interpretation of cytology. Overall, the significant association between FNAC and sex reinforces the need for a tailored approach in the diagnostic evaluation of thyroid nodules, ensuring that potential gender-related variations are taken into account when planning further management.

Diagnostic Performance Metrics and Correlation Between Elastography and FNAC

A critical component of our study was the evaluation of the diagnostic performance of elastography in comparison with FNAC. Our data revealed that elastography achieved a sensitivity of 100% successfully identifying all 17 malignant cases as determined by FNAC while its specificity was only 53.33%, with 16 true negatives and 14 false positives. Consequently, the positive predictive value (PPV) was calculated at 54.84%, and the negative predictive value (NPV) reached 100%, with a false positive rate (FPR) of 46.67%. These performance metrics indicate that while elastography is excellent for ruling out malignancy (given its perfect NPV), its moderate specificity necessitates confirmatory FNAC for positive cases. Comparatively, similar studies in thyroid pathology have demonstrated high sensitivity and variable specificity. Jesrani et al. [73] reported a sensitivity of 100% and a specificity of 80.2% using strain elastography, while Saleem et al. [74] noted a sensitivity of 93.46% and specificity of 91% in a larger cohort. Moreover, Kulkarni et al. [75] observed sensitivity and specificity values of 88.9% and 88.3%, respectively, suggesting that elastography's performance can vary based on the studied population and the cutoff values employed. Our results, although indicating a lower specificity, still underscore the utility of elastography as a robust screening modality, particularly when its high NPV is leveraged to exclude malignancy. The strong correlation between elastography and FNAC, demonstrated by a Pearson chi-square value of 13.746 ($p = 0.000$), further validates the complementary use of these modalities in clinical practice. Integrating elastography as a preliminary screening tool, followed by FNAC for positive cases, could optimize patient management by reducing unnecessary invasive procedures while ensuring that malignant lesions are accurately identified.

References: [73] Jesrani et al. (2021); [74] Saleem et al. (2022); [75] Kulkarni et al. (2023).

Individual Case Data Analysis, Implications, and Future Directions

An in-depth review of individual case data offers critical insight into the diagnostic nuances of elastography when correlated with FNAC. Our dataset reveals that cases with strain ratios exceeding the 1.95 cutoff were predominantly classified as malignant by both elastography and FNAC, affirming the method's sensitivity. However, a subset of cases with high strain ratios exhibited benign FNAC results, highlighting a potential for false positive outcomes. Such discrepancies are not uncommon and have been reported in the literature. Borysewicz-Sańczyk et al. [69] demonstrated that while strain elastography is a valuable adjunct, certain cases may yield indeterminate results due to factors such as lesion heterogeneity. Magri et al. [70] further explored advanced parameters like the maximal stiffness percentage index, which showed promise in enhancing diagnostic accuracy over the conventional strain index, particularly in nodules under 1 cm. These findings suggest that integrating additional imaging modalities such as diffusion-weighted imaging (DWI) and ADC mapping could further refine the specificity of elastography, reducing the reliance on FNAC for borderline cases. The individual case analysis in our study underscores the importance of a multimodal approach: while elastography reliably identifies malignant lesions (as evidenced by a 100% NPV), its moderate specificity requires that positive findings be confirmed via FNAC or histopathology to guide clinical decision-making. Future research should focus on multicentric studies with larger cohorts to validate these preliminary findings and explore the incorporation of complementary imaging parameters. Such efforts could pave the way for more precise, noninvasive diagnostic protocols that balance high sensitivity with improved specificity, ultimately enhancing patient outcomes while minimizing unnecessary invasive procedures.

References: [69] Borysewicz-Sańczyk et al. (2015); [70] Magri et al. (2015).

Strength of the Study

This study exhibits several notable strengths that enhance its overall validity and clinical relevance. First, the study design integrated both noninvasive imaging via elastography and confirmatory cytological evaluation using FNAC, allowing for a comprehensive assessment of thyroid nodule pathology. The combination of these modalities provided a dual-layer diagnostic approach that not only improved the sensitivity of detecting malignant lesions but also ensured that false positives were identified through cytological confirmation. The detailed statistical analyses, including chi-square tests for multiple demographic and clinical variables, reinforced the robustness of the findings by demonstrating that the imaging parameters remained consistent across diverse subgroups. Moreover, the inclusion of a wide age range and a relatively homogeneous population in terms of comorbid conditions such as obesity, diabetes, and family history helped isolate the effect of elastography on thyroid nodule evaluation. The meticulous data collection and systematic evaluation of individual cases further contributed to the study’s credibility. Additionally, the clear demonstration of high sensitivity and negative predictive value underscores the potential of elastography as an effective screening tool, thereby reducing the need for invasive procedures in patients with benign findings. The strength of the study also lies in its practical application; by providing detailed descriptive statistics and diagnostic performance metrics, it offers clinicians concrete evidence to support the use of elastography in routine practice. Overall, the rigorous methodology, comprehensive data analysis, and integration of imaging with cytological results collectively contribute to the study’s strength and set a solid foundation for future research and clinical application in the field of head and neck pathology.

Implication

The implications of this study are far-reaching in the realm of diagnostic imaging and clinical management of thyroid nodules. By demonstrating that elastography offers a 100% sensitivity and negative predictive value, the findings suggest that this noninvasive modality can effectively rule out malignancy in thyroid nodules, thereby sparing patients from unnecessary invasive procedures such as FNAC when elastography yields negative results. This has significant clinical impact, as it means that a reliable screening tool is available to promptly identify patients who require further intervention, optimizing patient management and resource allocation. Furthermore, the strong correlation between elastography and FNAC underscores the complementary role of these diagnostic techniques, facilitating early and accurate detection of malignant lesions. Clinicians can use elastography as an initial, rapid assessment tool, with FNAC reserved for cases that test positive on elastographic evaluation. The study's findings also emphasize that factors such as age, sex, obesity, diabetes, and family history do not significantly affect elastography outcomes, reinforcing its utility across diverse patient populations. In a broader context, the adoption of elastography could lead to a paradigm shift in diagnostic protocols, where noninvasive imaging becomes the first line of investigation, thus reducing patient anxiety, procedural risks, and healthcare costs associated with invasive diagnostic methods. The study's results further imply that standardizing elastography protocols and integrating them into routine clinical workflows could enhance diagnostic accuracy and improve patient outcomes. Overall, these implications are poised to influence both clinical practice and future research, driving advancements in diagnostic imaging and individualized patient care.

Recommendation

Based on the findings of this study, several key recommendations can be made to enhance the clinical application of elastography in the evaluation of thyroid nodules. First, it is advisable that elastography be adopted as a frontline screening tool in clinical settings, given its high sensitivity and negative predictive value. Patients with negative elastography findings could potentially avoid unnecessary FNAC procedures, thereby reducing both procedural risks and patient discomfort. For cases with positive elastographic results, confirmatory FNAC should be routinely performed to ensure diagnostic accuracy and prevent overtreatment. It is also recommended that standardized protocols for elastography be developed, including clearly defined cutoff values for strain ratios, to ensure consistency across different clinical centers. This standardization will help mitigate variability and improve interobserver reliability in elastographic assessments. Furthermore, clinical guidelines could incorporate elastography as a complementary modality alongside traditional imaging techniques, providing a more holistic diagnostic approach. Regular quality assurance and interdepartmental reviews can help maintain high diagnostic standards and facilitate continuous improvement. The study also suggests that further research should explore the integration of elastography with other advanced imaging modalities, such as diffusion-weighted imaging and ADC mapping, to potentially enhance specificity. By combining multiple imaging techniques, clinicians may develop more robust diagnostic algorithms that optimize both sensitivity and specificity. Overall, implementing these recommendations will not only streamline patient management but also foster a more efficient, cost-effective, and patient-centered approach in the evaluation and treatment of thyroid nodule.

Future Aspects

Future research should focus on addressing the limitations identified in this study and further refining the use of elastography in the diagnostic evaluation of thyroid nodules. One promising area for future exploration is the expansion of sample sizes and the inclusion of multicentric trials. By incorporating larger and more diverse populations, future studies can enhance the generalizability of findings and ensure that the diagnostic performance of elastography is validated across various demographic and clinical settings. In addition, prospective longitudinal studies are needed to assess the long-term prognostic value of elastography findings, including its role in predicting patient outcomes and guiding treatment decisions over time. Integrating additional advanced imaging techniques, such as diffusion-weighted imaging, ADC mapping, and shear wave elastography, may further improve specificity and reduce false-positive rates. Combining these modalities into a multimodal imaging protocol could yield a more comprehensive diagnostic framework that leverages the strengths of each technique. Furthermore, research should focus on developing and validating standardized protocols and cutoff values for elastography to minimize interobserver variability and ensure consistent interpretation of results. Future studies may also explore the potential of artificial intelligence and machine learning algorithms in analyzing elastographic images to provide automated, objective assessments that could further enhance diagnostic accuracy. Investigations into the cost-effectiveness of incorporating elastography into routine clinical practice, as well as its impact on patient management and healthcare resource utilization, are also warranted. By addressing these areas, future research can build upon the current findings and pave the way for more precise, efficient, and patient-centered diagnostic strategies in the evaluation of thyroid nodules.

CONCLUSION

The findings of this study underscore the potential of elastography as a highly sensitive screening tool for the evaluation of thyroid nodules while simultaneously highlighting the necessity for confirmatory cytological analysis via FNAC. The integration of elastography in clinical practice is supported by the fact that it demonstrated a perfect sensitivity of 100%, effectively detecting all malignant cases as confirmed by FNAC. This high sensitivity, coupled with an outstanding negative predictive value (NPV) of 100%, indicates that a negative elastographic result reliably excludes malignancy, thereby sparing patients from unnecessary invasive procedures and reducing the overall diagnostic burden. However, the study also revealed that elastography's specificity was only moderate at 53.33%, with a false positive rate of 46.67%, meaning that nearly half of the patients classified as malignant by elastography might actually have benign pathology as determined by FNAC. This discrepancy highlights the importance of a multimodal diagnostic approach, where elastography serves as an initial screening modality and positive findings are further validated with FNAC to ensure diagnostic accuracy. The detailed demographic analysis revealed a predominance of middle-aged females, with the majority of patients exhibiting non-obese, non-diabetic profiles and a negligible positive family history, thus minimizing potential confounding factors that could affect tissue elasticity. The consistency of these demographic factors with those reported in related imaging studies adds robustness to our findings and enhances the generalizability of the study. Chi-square analyses further confirmed that elastography findings were not significantly influenced by variables such as age, sex, obesity, diabetes, or family history, thereby establishing the reliability of elastographic measurements across diverse patient populations. In contrast, FNAC outcomes demonstrated a significant association with sex and borderline associations with age and family history, suggesting that while elastography provides uniform imaging parameters, certain biological factors might influence cytological interpretations. The strong correlation between elastography and FNAC results, as evidenced by a Pearson chi-square value of 13.746 (p = 0.000), reinforces the complementary nature of these diagnostic modalities and suggests that integrating both methods can substantially improve the accuracy of thyroid nodule evaluation. In clinical settings, the implementation of elastography as an initial screening tool has the potential to streamline patient management by rapidly ruling out malignancy in cases with negative imaging findings, while ensuring that those with positive elastographic results undergo further confirmatory testing. This approach could lead to more efficient use of healthcare resources, reduced patient anxiety, and lower procedural risks associated with invasive diagnostic techniques. Moreover, the study's detailed analysis of individual case data provides additional insight into the diagnostic nuances of elastography, showing that although most cases with strain ratios above the threshold of 1.9 are correctly identified as malignant, there remains a subset of cases that yield false positive results. Such findings underscore the ongoing need for refinement in elastographic techniques and suggest that future research should focus on optimizing cutoff values and integrating additional imaging parameters to enhance specificity without compromising sensitivity. Overall, while elastography represents a promising noninvasive modality that can significantly contribute to the early detection and management of thyroid nodules, its optimal utility lies in its combined use with FNAC, ensuring that the strengths of both modalities are harnessed to achieve a balanced, accurate, and patient-centered diagnostic strategy.

SUMMARY

- **Age Distribution**

The study included 47 patients with a mean age of 48.09 years, a median age of 49 years, and a standard deviation of 15.65 years, indicating a broad age range with the majority falling between 31 and 60 years.

- **Sex Distribution**

Out of 47 patients, 39 (82.98%) were female and 8 (17.02%) were male, reflecting a marked female predominance in the study population.

- **Obesity Distribution**

A total of 38 patients (80.90%) were non-obese, while 9 patients (19.10%) were classified as obese, demonstrating a low prevalence of obesity.

- **Family History**

The majority of patients (45, 95.74%) reported no family history of related conditions, with only 2 patients (4.26%) having a positive family history.

- **Diabetes Distribution**

Among the patients, 41 (87.23%) were non-diabetic and 6 (12.77%) had diabetes, indicating that diabetes was relatively uncommon in the cohort.

- **Elastography Findings (Strain Ratio)**

Using a cutoff value of 1.95, 16 cases (34.04%) were classified as benign and 31 cases (65.95%) as malignant.

- **FNAC Diagnosis**

Fine-needle aspiration cytology (FNAC) results indicated that 30 cases (63.83%) were benign while 17 cases (36.17%) were malignant.

- **Diagnostic Performance Metrics**

Elastography demonstrated a sensitivity of 100%, specificity of 53.33%, positive predictive value (PPV) of 54.84%, negative predictive value (NPV) of 100%, and a false positive rate of 46.67%.

- **Chi-Square Analyses (Elastography)**

There was no significant association between elastography findings and age ($p = 0.677$), sex ($p = 0.553$), obesity ($p = 0.106$), diabetes ($p = 0.960$), or family history ($p = 0.299$).

- **Chi-Square Analyses (FNAC)**

FNAC outcomes showed a statistically significant association with sex ($p = 0.012$) and a borderline association with age (likelihood ratio $p = 0.044$) and family history (likelihood ratio $p = 0.040$).

- **Correlation Between Elastography and FNAC:**

A strong correlation was observed between elastography and FNAC diagnoses, with a Pearson chi-square value of 13.746 ($p = 0.000$), confirming the complementary role of these diagnostic modalities.

❖ Individual Case Data

Analysis of individual cases revealed that cases with strain ratios greater than 1.9 were predominantly classified as malignant by both elastography and FNAC, however some false-positive results were noted.

LIMITATIONS

Despite its many strengths, this study is not without limitations, which should be carefully considered when interpreting the findings. One of the primary limitations is the relatively small sample size, which may restrict the generalizability of the results across larger and more diverse populations. A limited number of cases may also reduce the statistical power to detect subtle associations between demographic variables and imaging outcomes. Another limitation is the potential for selection bias, as the study population was drawn from a single clinical center, possibly reflecting unique referral patterns and demographic characteristics that may not be representative of broader patient populations. The reliance on a single cutoff value for strain ratios, although supported by the data, may not account for individual variations in tissue elasticity due to factors not captured in the study, such as prior treatments or concurrent inflammatory conditions. Another limitation is solid cystic lesions in this study may have resulted in False positive strain ratios (SR) likely due to fluid displacement artifacts, pericystic fibrosis, partial volume effects, and operator variability. Moreover, while FNAC was used as the reference standard, it is important to acknowledge that cytological evaluation itself has inherent limitations, including sampling error and interpretative variability. These limitations might influence the perceived accuracy of elastography and contribute to the observed false-positive rates. Lastly, the study did not incorporate additional imaging modalities, such as diffusion-weighted imaging or shear wave elastography, which could have provided complementary insights and potentially enhanced diagnostic accuracy. Recognizing these limitations is essential for guiding future research and ensuring that subsequent studies address these gaps to further validate and refine the role of elastography in clinical practice.

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ANNEXURE - I

INFORMED CONSENT FORM

"ASSESSMENT OF THYROID NODULES USING STRAIN ULTRASOUND ELASTOGRAPHY AND ITS COMPARISON WITH FINE NEEDLE ASPIRATION CYTOLOGY – A ONE YEAR HOSPITAL BASED CROSS SECTIONAL STUDY"

Principal Investigator: REGISTRATION NO: BS0122010

Introduction: You are being invited in the study to assess the thyroid nodules using strain ultrasound elastography and its comparison with fine needle aspiration cytology.

Explanation of procedure: If you agree to be part of my research study, you will be asked the relevant history and you will be subjected to relevant clinical examination and investigations.

Withdrawal from participation in the study: Participation in this study is voluntary. You will be free to decide whether to participate in this study or continue participation once enrolled. In case you decide to withdraw your participation, you are free to do so. However, please convey the decision to the principal investigator.

Possible benefits from participating in the study: You will not get any benefits by participating in this study. The data gathered will help population at large.

Possible risks from participating in the study: There are no risks involved in participating in this study.

Privacy and confidentiality: The information collected from you will be coded, to prevent any person to identify you. Your identity will never be revealed. The data collected from you will be kept confidential and only processed or aggregated data will be used for publication.

Financial incentives: You will not receive any payment for participating in this study. Cost of investigations done during the course of study will be paid by the principal investigator.

Authorization for publication of aggregated data: Results obtained after processing of the aggregated data will be published for scientific purpose and or presented to scientific groups. However, your identity will never be revealed.

Questions: In case of any questions with regard to this study, you are free to contact:

REG NO. BS0122010 post-graduate, Department of Radio-Diagnosis. J.N. Medical College, Belagavi	**DR.________________** Guide, Professor, Department of Radio-Diagnosis J.N. Medical College, Belagavi	**DR. HARSHA HEGDE**, CHAIRPERSON, JNMC, IEC & SCIENTIST D, ICMR, NATIONAL INSTITUTE OF TRADITIONAL MEDICINE, BELAGAVI

Legal rights: By signing this consent form, we are not waving any of your legal rights

CONSENT STATEMENT

I am making a voluntary decision to participate in the **study "ASSESSMENT OF THYROID NODULES USING STRAIN ULTRASOUND ELASTOGRAPHY AND ITS COMPARISON WITH FINE NEEDLE ASPIRATION CYTOLOGY – A ONE YEAR HOSPITAL BASED CROSS SECTIONAL STUDY".** My signature below indicates that I have decided to participate and I have read the information provided above or the information provided above has been read to me in the language that I understand best. I was given the opportunity to ask questions and that they have been answered to my satisfaction.

Name of the participant:

Signature or left thumb impression of the participant:

Name of the witness:

Signature or left thumb impression of the witness:

Name of the investigator:

Signature of the investigator:

ANNEXURE - II

PROFORMA FOR DATA COLLECTION

A) Biodata

1. Name
2. Age
3. Sex
4. Phone Number
5. Address
6. Occupation
7. Height
8. Weight

B) Risk Factors

1. Iodine Intake
2. Autoimmune
3. Diabetes
4. Insulin Resistance
5. Drugs
6. Obesity

7. Family History

8. Medical Radiation

9. Dietary Habits

C) Elastography Findings

D) FNAC Result

ANNEXURE - III: PHOTOGRAPHS

MACHINE USED FOR STUDY: MINDRAY RESONA I9

LINEAR TRANSDUCER PROBE USED FOR THE STUDY

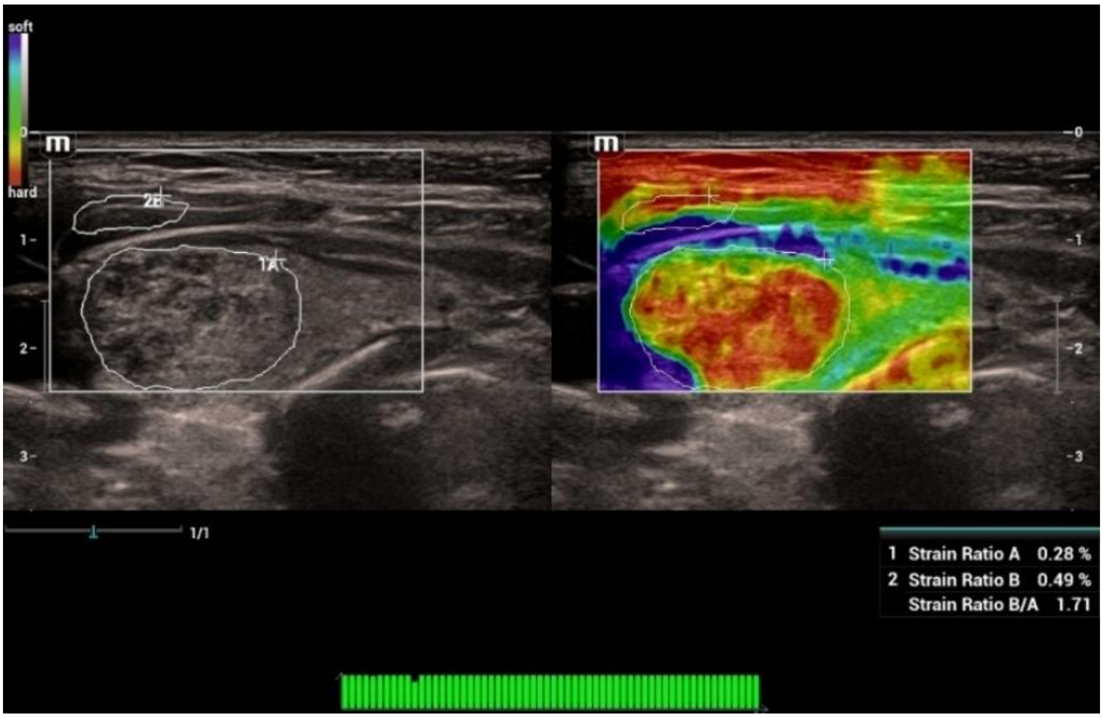

Fig 1a

HISTOPATHOLOGY

Sample Type : **ASPIRATION**	
CYTO NO:	Cy 1660/24
SITE:	Thyroid lesion (FNAC USG -Guided)
NUMBER OF ASPIRATES	01
NATURE OF ASPIRATES	Bloody material
MICROSCOPY:	Smears studied show pauci cellular aspirate showing few thyroid follicular cells in a hemorrhagic and colloid mixed background.
IMPRESSION *	Features are suggestive colloid nodule. The Bethesda system for thyroid FNA reporting- Category II

Fig 1b

Figure 1: (a) Ultrasound strain elastography image showing a strain ratio (B/A) of 1.7, which is below the cutoff value of 1.95, indicating a benign nodule. (b) FNAC results confirm the diagnosis as a colloid nodule (benign).

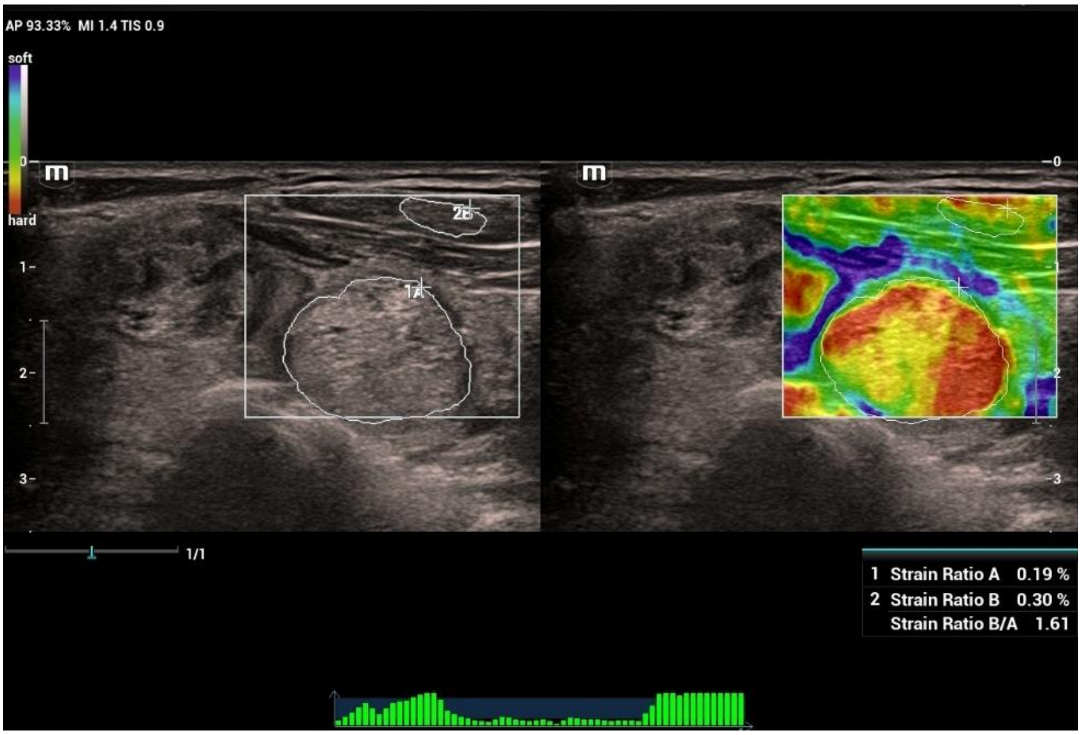

Fig 2a

HISTOPATHOLOGY

Sample Type : ASPIRATION

CYTO NO:	1116/24
SITE:	USG guided FNAC - Thyroid
NUMBER OF ASPIRATES	Two
NATURE OF ASPIRATES	Bloody
MICROSCOPY:	Smears studied show few clusters of benign thyroid follicular cells in background of colloid.
IMPRESSION *	Features are that of Colloid nodule. The Bethesda system for Thyroid FNA, Reporting category II.

Fig 2b

Figure 2: (a) Ultrasound strain elastography image showing a strain ratio (B/A) of 1.6, which is below the cutoff value of 1.95, indicating a benign nodule. (b) FNAC results confirm the diagnosis as a colloid nodule (benign).

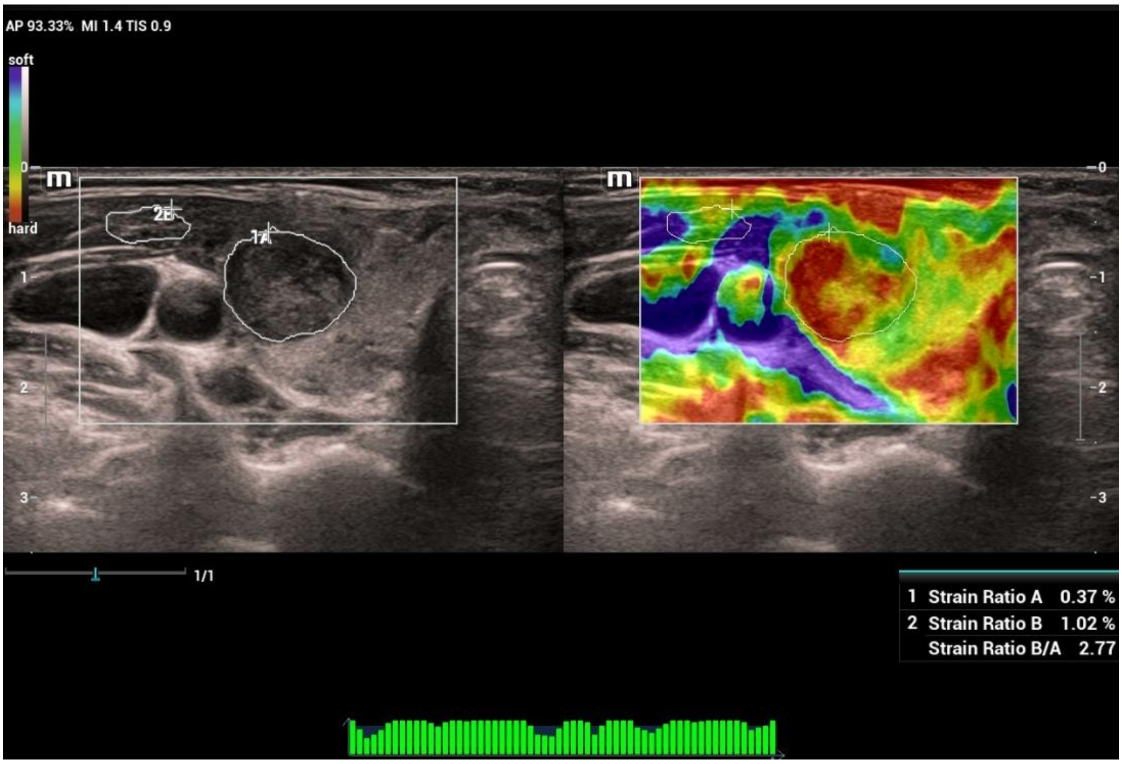

Fig 3a

HISTOPATHOLOGY

Sample Type : ASPIRATION

CYTO NO:	Cy-1223/24
SITE:	Neck - Right side
NUMBER OF ASPIRATES	02
NATURE OF ASPIRATES	Hemorrhagic material
MICROSCOPY:	Smears studied show cellular aspirate showing thyroid follicular cells arranged in follicular pattern and in sheets .
IMPRESSION *	Right lobe of Thyroid (FNAC) - Features are that of Follicular Neoplasm Bethesda system of thyroid reporting - Category IV

-----End Of Report-----

Fig 3b

Figure 3: (a) Ultrasound strain elastography image showing a strain ratio (B/A) of 2.7, which is above the cutoff value of 1.95, suggesting a high likelihood of malignancy. (b) FNAC results indicate follicular neoplasm.

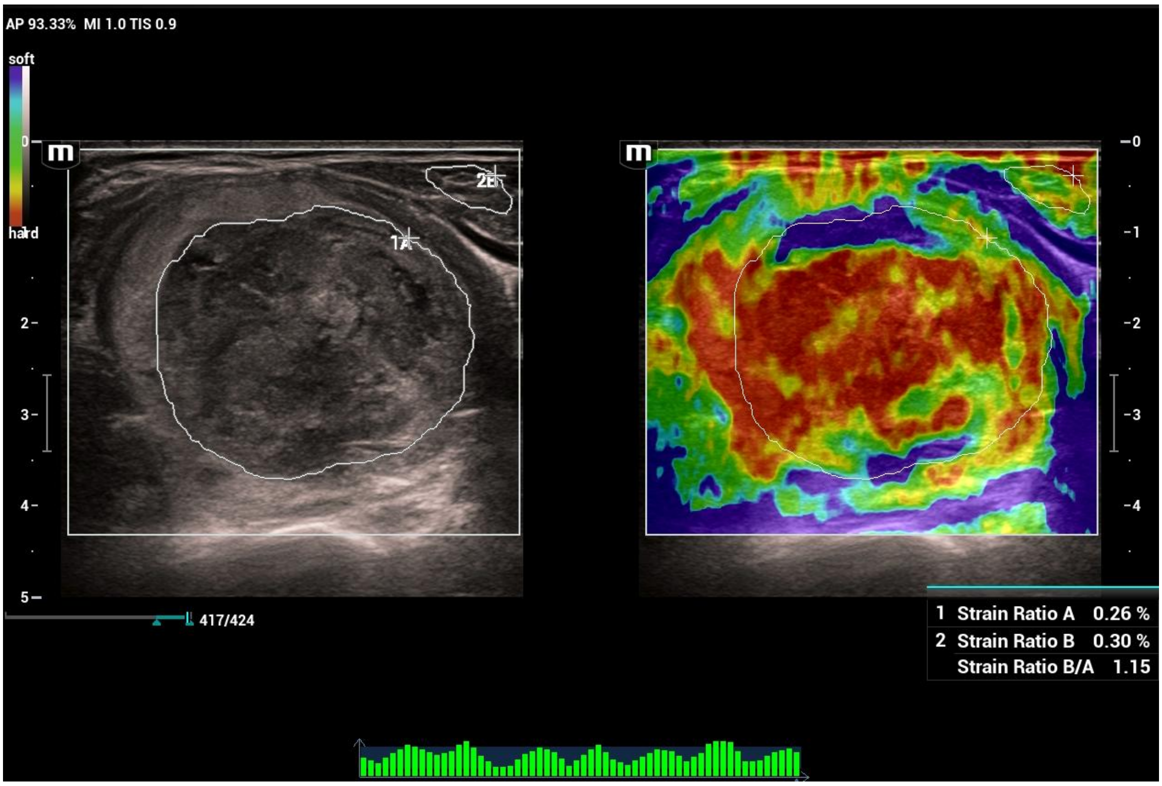

Fig 4a

HISTOPATHOLOGY

Sample Type : ASPIRATION

CYTO NO:	288/24
SITE:	FNAC - Thyroid lobe swelling
NUMBER OF ASPIRATES	One
NATURE OF ASPIRATES	Bloody material
MICROSCOPY:	Smears studied show paucicellular aspirate showing few thyroid follicular cells and inflammatory cells in a hemorrhagic background.
IMPRESSION *	Features are suggestive of Benign thyroid lesion.
	NOTE: Kindly correlate clinicoradiologically.

-----End Of Report-----

Fig 4b

Figure 4: (a) Ultrasound strain elastography image showing a strain ratio (B/A) of 1.15, which is below the cutoff value of 1.9, indicating a benign nodule. (b) FNAC results confirm the diagnosis as benign thyroid lesion.

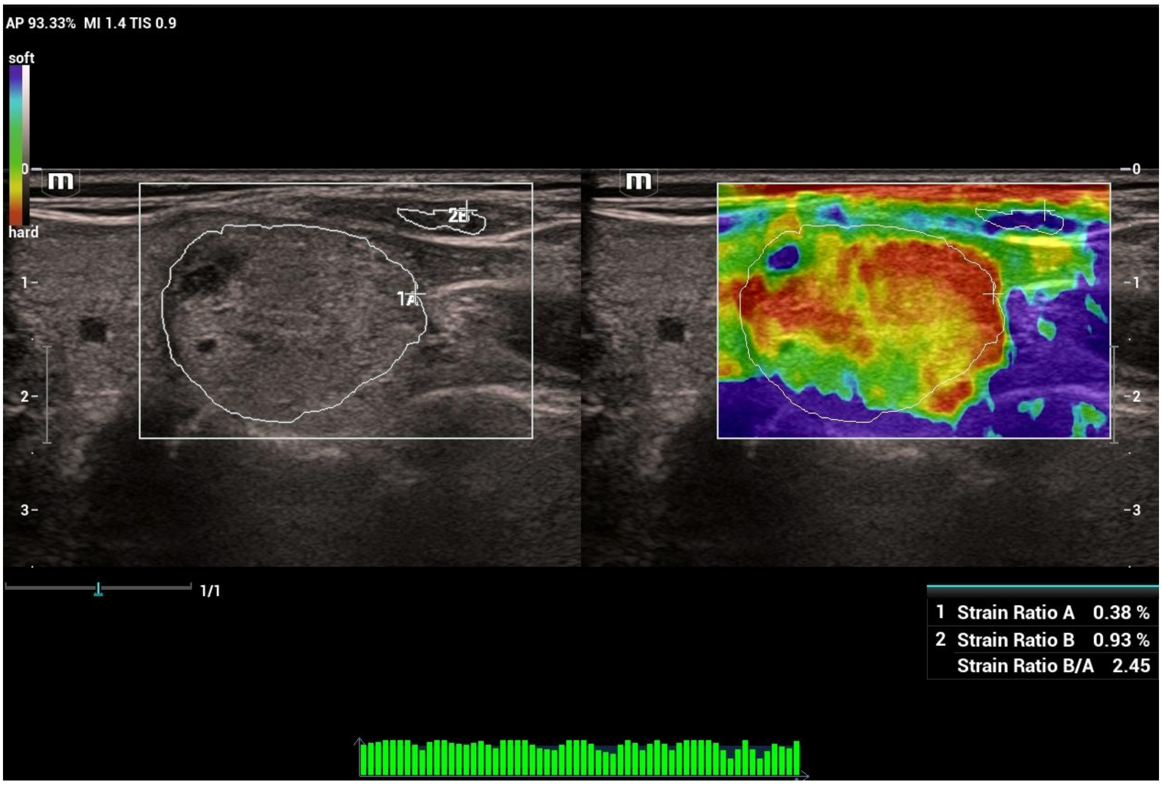

Fig 5a

HISTOPATHOLOGY

Sample Type : ASPIRATION

CYTO NO:	1342/24
SITE:	FNAC - Neck swelling
NUMBER OF ASPIRATES	Three
NATURE OF ASPIRATES	Brownish material
MICROSCOPY:	Smears studied show numerous cyst macrophages and benign follicular cells in background of colloid.
IMPRESSION *	FNAC - Neck swelling - Features are that of colloid material with cystic change. Bethesda system of Thyroid FNA Reporting category - II.

-----End Of Report-----

Fig 5b

Figure 5: (a) An ultrasound strain elastography image shows a strain ratio (B/A) of 2.4, which is above the cutoff value of 1.95, indicating a malignant nodule. (b) However, fine-needle aspiration cytology (FNAC) reveals colloid material with cystic changes.

ANNEXURE IV: KEY TO MASTERCHART

F	**Female**
M	**Male**
Ht	**Height**
Wt	**Weight**
Adq	**Adequate**
Reg	**Regular**
N	**No**
Y	**Yes**
DM	**Diabetes Mellitus**
AI	**Auto Immune**
Meds	**Medication history**
FHx	**Family History**
Rad	**Medical Radiation History**
Elast.SR	**Elastography Findings(Strain ratio)**
Elast Concl.	**Elastography Conclusion**
FNAC Concl.	**FNAC Conclusion**

S.NO	Age	Sex	Ht (cm)	Wt (Kg)	Diet	Obesity	DM	Meds	FHx	Rad	Elast. SR	Elast Concl	FNAC Result	FNAC Concl.
1	54	F	168	68	Reg	N	N	N	N	N	1.7	Benign	Colloid nodule	Benign
2	48	F	160	62	Reg	N	N	N	N	N	5	Malignant	Follicular neoplasm	Malignant
3	46	F	158	62	Reg	N	Y	N	N	N	0.7	Benign	Colloid goiter	Benign
4	55	F	158	68	Reg	**Y**	**Y**	N	N	N	4.1	Malignant	Hurthle cell adenoma	Benign
5	27	F	168	65	Reg	N	N	N	N	N	1.6	Benign	Colloid nodule	Benign
6	56	F	157	60	Reg	N	N	N	N	N	8.6	Malignant	Colloid goiter with hurthle cell change	Benign
7	42	F	164	70	Reg	Y	N	N	N	N	2.4	Malignant	Colloid nodule with cystic change	Benign
8	57	F	160	54	Reg	N	N	N	N	N	3.5	Malignant	Follicular carcinoma	Malignant
9	57	F	162	68	Reg	N	N	N	N	N	1	Benign	Lymphocytic thyroiditis	Benign
10	39	F	165	64	Reg	N	N	N	N	N	3.1	Malignant	Colloid nodule with cystic change	Benign
11	22	M	178	80	Reg	N	N	N	**Y**	N	2.5	Malignant	Papillary carcinoma	Malignant
12	61	M	170	85	Reg	**Y**	**Y**	N	N	N	8.6	Malignant	Papillary carcinoma	Malignant
13	76	M	174	82	Reg	N	**Y**	N	N	N	2.9	Malignant	Papillary carcinoma	Malignant
14	91	M	165	65	Reg	N	N	N	N	N	4.1	Malignant	Papillary carcinoma	Malignant
15	25	F	160	56	Reg	N	N	N	**Y**	N	2.7	Malignant	Medullary carcinoma	Malignant
16	60	F	158	66	Reg	**Y**	**Y**	N	N	N	1.5	Benign	Colloid nodule	Benign
17	33	F	170	63	Reg	N	N	N	N	N	1.1	Benign	Benign thyroid lesion	Benign
18	69	M	177	80	Reg	N	N	N	N	N	4.7	Malignant	Papillary carcinoma	Malignant
19	53	F	156	52	Reg	N	N	N	N	N	2.7	Malignant	Follicular neoplasm	Malignant
20	35	F	166	74	Reg	**Y**	N	N	N	N	3.5	Malignant	Cystic colloid goiter	Benign
21	66	F	156	50	Reg	N	N	N	N	N	5.3	Malignant	Colloid nodule	Benign
22	33	F	164	60	Reg	N	N	N	N	N	3.5	Malignant	Colloid goiter with cystic degenration	Benign
23	41	F	162	65	Reg	N	N	N	N	N	3.1	Malignant	Medullary carcinoma	Malignant
24	38	F	157	60	Reg	N	N	N	N	N	4.2	Malignant	Hashimotos throiditis	Benign
25	60	F	155	55	Reg	N	**Y**	N	N	N	4.2	Malignant	Malignancy	Malignant

26	47	F	161	59	Reg	N	N	N	N	N	0.7	Benign	Benign thyroid nodule	Benign
27	39	F	156	63	Reg	N	N	N	N	N	3.2	Malignant	Colloid nodule with cystic change	Benign
28	63	F	153	50	Reg	N	N	N	N	N	1.2	Benign	Benign thyroid lesion	Benign
29	51	F	156	68	Reg	**Y**	N	N	N	N	2.5	Malignant	Goitre with cystic degenration	Benign
30	49	F	163	55	Reg	N	**Y**	N	N	N	5	Malignant	Follicular neoplasm	Malignant
31	35	F	169	65	Reg	N	N	N	N	N	1.2	Benign	Colloid nodule	Benign
32	35	F	167	70	Reg	Y	N	N	N	N	3	Malignant	Benign thyroid follicular lesion	Benign
33	20	F	166	62	Reg	N	N	N	N	N	1.7	Benign	Colloid nodule with cystic degenration	Benign
34	65	F	160	54	Reg	N	N	N	N	N	1.2	Benign	Colloid nodule	Benign
35	32	F	165	68	Reg	N	N	N	N	N	0.7	Benign	Colloid nodule	Benign
36	34	M	176	74	Reg	N	N	N	N	N	3.9	Malignant	Suspicious for malignancy	Malignant
37	38	F	158	55	Reg	N	**Y**	N	N	N	4	Malignant	Lymphocystic thyroiditis in colloid nod	Benign
38	24	F	167	58	Reg	N	N	N	N	N	6	Malignant	Papillary carcinoma	Malignant
39	64	M	182	85	Reg	N	N	N	N	N	1.2	Benign	Goitre	Benign
40	56	M	177	82	Reg	N	N	N	N	N	1.5	Benign	Hurthle cell adenoma	Benign
41	45	F	162	72	Reg	**Y**	N	N	N	N	4.2	Malignant	Papillary carcinoma	Malignant
42	54	F	156	60	Reg	N	N	N	N	N	3.2	Malignant	Colloid goitre with cystic degenration	Benign
43	66	F	153	60	Reg	N	N	N	N	N	3.9	Malignant	Papillary carcinoma	Malignant
44	70	F	157	64	Reg	N	N	N	N	N	3	Malignant	Colloid goitre with cystic degenration	Benign
45	26	F	160	52	Reg	N	N	N	N	N	1.5	Benign	Colloid nodule	Benign
46	53	F	162	55	Reg	N	**Y**	N	N	N	1.7	Benign	Colloid nodule	Benign
47	50	F	155	69	Reg	**Y**	N	N	N	N	4.2	Malignant	Malignant	Malignant