

Early and differential diagnosis of thyroid nodular lesions in women living in the aral sea region using ultrasound elastography and the ti-rads system

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Abstract

Background: *Thyroid nodules are among the most frequently detected endocrine abnormalities, with a considerably higher prevalence in women. Their differential diagnosis is particularly important in environmentally vulnerable areas such as the Aral Sea region, where iodine deficiency and other environmental factors may contribute to thyroid dysfunction. Conventional ultrasonography is the primary imaging method for thyroid nodule detection and characterization, while the Thyroid Imaging Reporting and Data System (TI-RADS) provides standardized malignancy risk stratification. Ultrasound elastography offers additional information about tissue stiffness and may improve differentiation between benign and malignant nodules.*

Objective: To assess the diagnostic significance of ultrasound elastography combined with the American College of Radiology Thyroid Imaging Reporting and Data System (ACR TI-RADS) for early and differential diagnosis of thyroid nodular lesions in women living in the Aral Sea region.

Materials and Methods: A literature-based analytical review was performed using data from PubMed-indexed studies, international clinical guidelines, systematic reviews and meta-analyses concerning thyroid ultrasonography, ACR TI-RADS and ultrasound elastography. Particular attention was given to studies involving women and populations living in environmentally vulnerable or iodine-deficient regions. Diagnostic characteristics of conventional ultrasonography, TI-RADS and elastography were compared.

Results: ACR TI-RADS provides standardized assessment based on composition, echogenicity, shape, margins and echogenic foci. According to the ACR system, nodules are classified from TR1 to TR5, with increasing malignancy risk. A meta-analysis of 16 studies including 21,882 nodules demonstrated pooled sensitivity and specificity of 89% and 70%, respectively, for ACR TI-RADS. Ultrasound elastography provides complementary information by assessing tissue stiffness. Meta-analyses have demonstrated clinically useful diagnostic performance, although stiffness thresholds vary considerably between techniques and ultrasound systems. Recent evidence indicates that combining elastography with ACR TI-RADS may further improve risk stratification, particularly in intermediate-risk nodules.

Conclusion: The combination of conventional ultrasound, ACR TI-RADS and ultrasound elastography represents a promising non-invasive approach for early and differential diagnosis of thyroid nodular lesions in women from the Aral Sea region. Elastography should be considered an adjunctive method rather than a replacement for standardized B-mode ultrasound, TI-RADS assessment or cytological verification.

Keywords: *thyroid nodule, women, Aral Sea region, ultrasound, elastography, shear-wave elastography, ACR TI-RADS, thyroid cancer, differential diagnosis, early diagnosis.*

Introduction

Thyroid nodules are a common clinical problem and constitute one of the principal indications for thyroid ultrasonography. The majority of thyroid nodules are benign; however, a small but clinically important proportion represents malignant disease. Therefore, the main objective of diagnostic imaging is not simply to detect a nodule but to determine its probability of malignancy and select patients who require fine-needle aspiration (FNA), active surveillance or further diagnostic evaluation. The American College of Radiology developed ACR TI-RADS to standardize ultrasound reporting and reduce unnecessary invasive procedures. The problem is especially relevant for women. Thyroid disorders occur more frequently in women than in men, and reproductive-age women may have additional clinical and hormonal factors affecting thyroid function. This issue has particular importance in the Aral Sea region, which represents an environmentally vulnerable area. Previous research involving 225 women of reproductive age living in the ecologically unfavorable Aral Sea region demonstrated a high prevalence of subclinical and overt hypothyroidism. The prevalence of subclinical hypothyroidism was particularly high among women aged 18–29 years. The environmental and nutritional background of the region makes early identification of structural thyroid abnormalities clinically important. However, functional thyroid disorders and structural thyroid nodules should not be considered synonymous. Therefore, imaging methods capable of accurately characterizing nodular lesions are required. Conventional B-mode ultrasonography provides information regarding nodule composition, echogenicity, margins, shape and calcifications. Nevertheless, individual ultrasound characteristics frequently overlap between benign and malignant lesions. To overcome this limitation, ultrasound risk-stratification systems such as ACR TI-RADS have been introduced. ACR TI-RADS assigns points to specific sonographic characteristics and classifies nodules into five categories. Ultrasound elastography provides an additional functional parameter—tissue stiffness. Malignant thyroid nodules are often stiffer than benign nodules because of increased cellularity, fibrosis and changes in extracellular tissue composition. Consequently, elastography has attracted considerable interest as a complementary technique for thyroid nodule characterization. The objective of this article was to analyze the role of ultrasound

elastography and ACR TI-RADS in the early and differential diagnosis of thyroid nodular lesions in women living in the Aral Sea region and to propose a practical diagnostic approach suitable for clinical use.

Materials and Methods

This study was designed as a literature-based analytical review. Scientific publications indexed in PubMed and other recognized biomedical databases, international guidelines and methodological documents were analyzed. The main search concepts included combinations of the following terms: “thyroid nodule,” “thyroid ultrasound,” “ACR TI-RADS,” “thyroid elastography,” “shear wave elastography,” “strain elastography,” “thyroid cancer,” “women,” “iodine deficiency” and “Aral Sea region.” Priority was given to systematic reviews, meta-analyses, clinical guidelines and prospective diagnostic studies. Particular attention was paid to studies evaluating the diagnostic accuracy of TI-RADS and elastography in differentiating benign and malignant thyroid nodules.

For the regional component, available scientific information concerning thyroid function and thyroid pathology among women residing in the Aral Sea region was considered. Since a primary patient cohort with individual ultrasound, elastography and histopathological data was not provided, no original patient-level diagnostic accuracy calculations were performed. Therefore, sensitivity, specificity, predictive values and other quantitative parameters presented in this article are derived from previously published studies and are not presented as original clinical results.

Results

1. Clinical significance of thyroid pathology in women of the Aral Sea region

The Aral Sea region is characterized by substantial environmental and public health challenges. Previous clinical investigations among women living in this area have demonstrated an increased prevalence of thyroid functional abnormalities. In a study of 225 women of reproductive age, thyroid-stimulating hormone and free thyroxine were assessed. The investigators reported a high frequency of subclinical and overt hypothyroidism, with the highest proportions observed among younger women. These observations emphasize the need for systematic thyroid evaluation in women living in environmentally vulnerable areas. However, biochemical testing alone cannot characterize a focal thyroid lesion. A patient with normal thyroid hormone levels may still have a thyroid nodule, including a malignant nodule. Consequently, biochemical assessment and structural imaging should be considered complementary components of thyroid evaluation.

2. Conventional ultrasound and ACR TI-RADS

Ultrasound is the preferred first-line imaging method for evaluation of thyroid nodules because it is non-invasive, widely available, radiation-free and capable of demonstrating small focal lesions.

The ACR TI-RADS system evaluates five principal sonographic domains:

1. composition;
2. echogenicity;
3. shape;
4. margins;
5. echogenic foci.

The points obtained from these characteristics determine the final TI-RADS category. TR1 represents a benign lesion, whereas TR5 represents a highly suspicious lesion.

The current ACR recommendations indicate that FNA is generally considered for TR3 nodules measuring ≥ 2.5 cm, TR4 nodules measuring ≥ 1.5 cm and TR5 nodules measuring ≥ 1.0 cm. Smaller nodules may undergo ultrasound surveillance according to their category and size.

This approach is important because nodule size alone is insufficient for determining malignancy risk. For example, a small nodule with an irregular margin, marked hypoechogenicity, a taller-than-wide shape and punctate echogenic foci may have a considerably higher risk profile than a substantially larger spongiform nodule. A systematic review and meta-analysis of 16 studies involving 18,614 patients and 21,882 thyroid nodules found pooled sensitivity of approximately 89% and specificity of approximately 70% for ACR TI-RADS. The findings support the usefulness of ACR TI-RADS as a standardized ultrasound-based risk-stratification method.

3. Diagnostic role of ultrasound elastography

Elastography evaluates the mechanical properties of tissue and can be performed using strain elastography or shear-wave elastography. In qualitative strain elastography, the relative stiffness of a nodule is assessed visually. In quantitative techniques, tissue stiffness can be expressed using parameters such as shear-wave velocity or kilopascals.

In general, benign thyroid nodules tend to demonstrate lower stiffness, whereas malignant lesions may demonstrate increased stiffness. However, stiffness values overlap between benign and malignant nodules, and results may depend on the ultrasound equipment, examination technique, region of interest, compression, lesion size and operator experience.

A meta-analysis of real-time ultrasound elastography demonstrated pooled sensitivity of approximately 79% and specificity of approximately 77% for elasticity-score assessment. For strain-ratio measurements, pooled sensitivity was approximately 85% and specificity approximately 80%. A more recent systematic review and meta-analysis including 72 studies and 14,015 thyroid nodules reported pooled sensitivity and specificity of 84% and 81%, respectively, for qualitative elastography, 83% and 80% for semiquantitative elastography, and 78% and 81% for quantitative elastography. These findings indicate that elastography can provide clinically useful complementary information, although no single universally applicable stiffness threshold has been established. Importantly, international guidance emphasizes that elastography should

not replace conventional B-mode ultrasonography. Differences in compression, software, acquisition protocols and measurement techniques may produce substantial interobserver and inter-device variability. PubMed Central (PMC)

4. Diagnostic value of combining TI-RADS and elastography

The major clinical advantage of combining TI-RADS and elastography is that the two techniques provide different types of information.

ACR TI-RADS evaluates morphological characteristics, whereas elastography evaluates mechanical tissue properties. Therefore, a nodule with suspicious morphology and increased stiffness may represent a lesion with a particularly high probability of malignancy. Conversely, a morphologically low- or intermediate-risk nodule with low stiffness may potentially be managed more conservatively, depending on the clinical context.

Recent prospective evidence supports this concept. A study involving 556 adults with thyroid nodules ≥ 10 mm evaluated ACR TI-RADS together with strain elastography. The investigators reported that incorporation of elastography ratios could substantially reduce the number of FNA procedures while maintaining detection of malignant lesions. The greatest additional diagnostic value was observed in lower-risk and intermediate-risk nodules. This finding is particularly relevant to resource-limited or geographically remote populations. If validated in the Aral Sea region, combined ultrasound and elastography could help identify women requiring FNA while reducing unnecessary invasive procedures in lesions with a low probability of malignancy.

Discussion

The early diagnosis of thyroid nodular pathology in women living in the Aral Sea region requires an integrated approach. Environmental conditions and previously documented thyroid dysfunction in women justify increased attention to thyroid health; however, the presence of thyroid dysfunction does not itself establish malignancy.

The first diagnostic stage should include clinical assessment and thyroid function testing, particularly serum TSH and, when clinically indicated, free T4 and thyroid antibodies. If a structural abnormality is suspected or identified, high-resolution thyroid ultrasound should be performed.

The ultrasound examination should be standardized. Nodule size should be measured in three dimensions, and composition, echogenicity, shape, margins and echogenic foci should be documented. Each clinically relevant nodule should then be assigned an ACR TI-RADS category.

Elastography should be performed as an adjunctive examination, especially in nodules where conventional ultrasound findings are indeterminate or where a decision regarding biopsy remains uncertain. It is important that elastographic measurements be obtained using a standardized technique and that the same measurement protocol be used during follow-up.

The practical diagnostic algorithm can be summarized as follows:

Clinical examination → TSH assessment → high-resolution B-mode ultrasound → ACR TI-RADS classification → elastography for selected nodules → FNA according to TI-RADS and clinical indications → cytological/histological verification when required.

This approach has several advantages. First, it provides a reproducible method for ultrasound reporting. Second, it combines morphological and biomechanical information. Third, it may reduce unnecessary biopsy procedures. Fourth, it may facilitate earlier recognition of suspicious lesions requiring cytological verification.

Nevertheless, several limitations must be considered. Elastography is operator- and equipment-dependent, and there is no universally accepted stiffness threshold applicable to all ultrasound systems. Furthermore, elastography cannot reliably distinguish all follicular neoplasms, inflammatory lesions and other conditions that may demonstrate overlapping tissue stiffness.

Another important limitation is that most published diagnostic studies have been conducted in populations outside Central Asia. Therefore, thresholds established elsewhere should not automatically be considered optimal for women living in the Aral Sea region. Regional validation studies are needed.

Future research should include prospective studies of women from Karakalpakstan and other Aral Sea territories. Such studies should record age, reproductive status, TSH and free T4 levels, iodine-related indicators where available, ultrasound characteristics, ACR TI-RADS category, elastography parameters, Bethesda cytology and, where available, final histopathological diagnosis. Receiver operating characteristic analysis should be used to establish locally appropriate elastographic thresholds.

Conclusion

Ultrasound examination using ACR TI-RADS is an effective standardized approach for early risk stratification of thyroid nodular lesions. The system combines important morphological characteristics and provides clear criteria for surveillance and FNA. Meta-analytical evidence demonstrates favorable diagnostic performance of ACR TI-RADS in identifying thyroid malignancy.

Ultrasound elastography provides complementary information concerning tissue stiffness and may improve differentiation between benign and malignant nodules, particularly when conventional ultrasound findings are equivocal. However, elastography should not replace B-mode ultrasonography, TI-RADS classification or cytological verification.

For women living in the environmentally vulnerable Aral Sea region, an integrated diagnostic strategy combining clinical evaluation, thyroid function testing, standardized ultrasound, ACR TI-RADS and selective elastography appears clinically justified. Such an approach may facilitate earlier identification of suspicious nodules, improve differential diagnosis and potentially decrease unnecessary invasive procedures.