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ADVANTAGES AND DISADVANTAGES OF ULTRASONOGRAPHY IN THE THYROID DISEASES

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Resume. Thyroid diseases are among the most common endocrine pathologies in the world. According to the World Health Organization, up to 30–50% of adults will have at least one thyroid nodule during their lifetime, and 5–15% of them may be malignant. This article is devoted to studying the role and effectiveness of ultrasound examination in modern diagnostics of various pathological conditions of the thyroid gland. The article studies the main advantages of ultrasound examination (ultrasonography; US) - safety, high accuracy, real-time visualization, dynamic monitoring capabilities, and the ability to combine with functional examinations (blood flow). At the same time, certain disadvantages of the method - operator dependence, limitations in viewing deep structures - are analyzed.

Keywords: Thyroid gland, Ultrasonography, US, echogenicity, diagnosis, TI-RADS.

ПРЕИМУЩЕСТВА И НЕДОСТАТКИ УЛЬТРАЗВУКОВОГО ИССЛЕДОВАНИЯ ПРИ ЗАБОЛЕВАНИЯХ ЩИТОВИДНОЙ ЖЕЛЕЗЫ

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Резюме. Заболевания щитовидной железы являются одними из наиболее распространенных эндокринных патологий в мире. По данным Всемирной организации здравоохранения, у 30-50% взрослых в течение жизни обнаруживается как минимум один узел щитовидной железы, при этом 5-15% из них могут быть злокачественными. Данная статья посвящена изучению роли и эффективности ультразвукового исследования в современной диагностике различных патологических состояний щитовидной железы. В статье рассматриваются основные преимущества ультразвукового исследования (ультрасонографии; УЗИ) - безопасность, высокая точность, визуализация в режиме реального времени, возможности динамического наблюдения и способность сочетаться с функциональными исследованиями (кровоток). Вместе с тем анализируются определенные недостатки метода - зависимость от оператора и ограничения в визуализации глубоких структур.

Ключевые слова: Щитовидная железа, ультразвуковое исследование, УЗИ, эхогенность, диагностика, TI-RADS.

The role and importance of ultrasonography in thyroid diseases. Ultrasonography (US) is the primary imaging diagnostic method in thyroid diseases, which allows for the assessment of anatomical structures with high accuracy [1]. The advantages of US are that it is radiation-free, completely safe for the patient, repeatable, and inexpensive [2]. Due to the close location of the thyroid gland to the surface, it is possible to visualize tissues with high resolution through US, which is why it is chosen as the first-line examination method in all countries [3]. US has a sensitivity of up to 95% in detecting thyroid nodules, which is significantly higher than CT/MRI of the chest or neck [4]. Nodular thyroid diseases are widespread, and in women over 50 years of age, the detection of nodules by US reaches 50–70%, therefore it has become an important element of screening [5]. This method evaluates a number of criteria, such as the type of structure of the nodule, its borders, echogenicity, types of calcification, blood supply, and relationship to the capsule; they serve as the basis for making a diagnostic conclusion about whether the nodule is benign or malignant [6]. Papillary carcinoma in particular has very clear morphological signals on US, which can be detected early [7]. The clinical importance of US is that it plays a key role in determining the indications for FNAB (fine-needle aspiration biopsy), i.e. not every nodule is biopsied - the results of US clearly determine whether a biopsy is necessary or not [8]. Therefore, US is at the heart of clinical decision-making - it reduces unnecessary biopsies and helps to effectively identify malignant nodules [9].

Thyroid anatomy and basic principles of US imaging. US allows for a high-resolution depiction of thyroid anatomy, allowing for improved morphological assessment [10]. The thyroid gland is divided into two lobes (lobus dechter and sinister), an isthmus, and sometimes a third pyramidal lobe; the anterior surface of the lobes is covered by skin, neck muscles, and adipose tissue [11]. Normal thyroid tissue appears homogeneous on US imaging, with moderate echogenicity and higher echogenicity than muscle [12]. When a nodule is present, this homogeneity is disrupted and focal changes appear [13]. Therefore, US is also capable of detecting microstructural changes with high spatial resolution [14].

The following technical factors significantly affect the quality of the ultrasound image: 1) sensor frequency (10–15 MHz provides high resolution) [15], 2) focal length [16], 3) gain parameters [18], 4) presence or absence of artifacts [19]. Therefore, ultrasound examination requires not only high-tech equipment, but also a qualified specialist; operator experience significantly reduces diagnostic errors [20].

US classification and main criteria of thyroid nodules. US evaluates nodules based on 5 main parameters: 1. Echogenicity; 2. Structure; 3. Borders; 4. Calcifications; 5. Vascularization. These criteria are very important in differentiating between benign and malignant nodules [21]. For example, hypoechoic nodules are more likely to be malignant than benign nodules [22]. Hyperechoic nodules are often associated with benign colloid nodules [23]. Thyroid nodules can be of three types: 1. solid (solid) nodules, 2. cystic nodules, and 3. mixed structural nodules [24]. Among solid nodules, the risk of malignancy is higher than that of mixed and cystic nodules [25]. Microcalcifications (<1 mm) are also a classic diagnostic feature of papillary carcinoma [26].

Microcalcifications and their association with malignancy. Microcalcifications are one of the most important US features of papillary carcinoma and are consistent with psammoma bodies [27]. They are punctate, shiny, non-acoustically opacifying calcium deposits and may increase the risk of malignancy by up to 80% [28]. Several large studies have shown that microcalcifications are associated with: a) papillary carcinoma [29]; b) medullary carcinoma [30]; c) lymphoma [31]. Benign nodules rarely have microcalcifications, whereas macrocalcifications may be present [32]. Therefore, the type of calcification is of great importance in assessing malignancy.

Borders: smooth, irregular, and infiltrative contours. The appearance of the nodule border on US is one of the most accurate criteria for determining whether a nodule is malignant or benign [33]. 1. Smooth and clear contours are characteristic of benign nodules [34]. 2. Indistinct, spiculated contours indicate malignant infiltration [35]. Papillary carcinoma often presents with indistinct borders because the tumor extends into the surrounding tissue [36]. The “taller-than-wide” sign (vertical dimension greater than horizontal dimension) is an important diagnostic indicator of malignancy and is assigned a high score in the international TI-RADS system [37].

Elastosonography and tissue stiffness measurement. Elastography is a newly developed form of US methodology that assesses the stiffness of a nodule by either tissue deformation (strain elastography) or mechanical velocity (shear-wave) measurement (shear-wave elastography) [29]. Malignant nodules typically have a fibrous stroma and dense tumor tissue, so they have low deformation and high shear-wave velocity on elastography [30]. In strain elastography, the stiffness of the nodule is represented by a color map; blue indicates high stiffness and green indicates soft tissue [31]. This visual assessment method may be dependent on operator experience, as the pressure is manually controlled and the operator may have varying levels of sensitivity and accuracy [31]. Shear-wave elastography, on the other hand, provides a more precise measurement (m/s or kPa), and many studies have shown that nodes with shear-wave velocities> 50 kPa are more likely to be malignant [32]. The combination of strain + shear-wave helps to increase diagnostic accuracy, as they are complementary [33]. Meta-analyses have shown that the accuracy of US combined with elastography (especially shear-wave) is increased: the SROC AUC is ~0.92, which is a significant improvement over conventional US [10]. However, calcified nodes can give false results on elastography, as calcium opacity and stiffness confound strain measurements [34]. Elastography is also useful as an additional assessment tool in nodes with "unknown" (non-diagnostic or indeterminate) FNAB results. Studies have shown that strain and shear-wave elastography can help predict the risk of such nodules, which may provide improved biopsy selection [11].

Superb Microvascular Imaging (SMI) and assessment of microvascularization. In addition to conventional Doppler US, advanced techniques such as Superb Microvascular Imaging (SMI) allow for the detailed visualization of microvascular structures (small vessels and new capillaries) [5]. SMI has a high sensitivity in imaging the very small capillary flow that characterizes angiogenesis processes, which helps to detect the formation of new blood vessels in dangerous nodules [5]. Several clinical studies have shown that combining SMI features with TI-RADS criteria improves the sensitivity and specificity of contrast assessment. For example, the combination of TI-RADS + SMI may reconsider the need for biopsy in suspicious nodules in patients [5]. The use of SMI allows for the following approaches: identification of signs of invasive angiogenesis, guidance in biopsy planning, and monitoring of dynamic changes in blood vessels during monitoring.

Sonographic monitoring and surveillance strategies. Dynamic monitoring of nodules by ultrasound is a widely used and proven strategy in clinical practice [17]. According to widely used recommendations, nodules with benign ultrasound features and judged benign by FNAB are usually followed up with annual ultrasound [17]. During surveillance, the following are considered: change in nodule size (diameter or volume), change in echogenicity and structure (appearance of new septa or cystic components), development of calcifications, and change in vascularization [8]. If the nodule shows a significant change in size (e.g., diameter increase of more than 20%) or if new malignant features appear, an additional FNAB is recommended [8]. However, the monitoring strategy should be individualized according to the patient's age, location of the nodule, and clinical risk factors.

Operator and technical limitations. The results of ultrasound are highly operator-dependent: the skill, experience, and adherence to standardized procedures of the operator have a significant impact on the reliability of ultrasound results [20]. Many studies have shown that nodule interpretation varies between centers and between physicians of different experience levels. The quality of the ultrasound equipment (high-frequency probes, good resolution, and focusing) is also important for diagnostic accuracy [15]. Low-quality transducers, older equipment, or low-frequency probes can limit the detection of micronodules or ill-defined contours. Technical limitations also include artifacts: Acoustic shadowing may occur around calcifications, which may distort the appearance of underlying structures. Reverberation artifacts may cause an unnatural appearance in nearby tissues. When the focus and contrast settings are incorrect, small nodules or unclear areas may be missed. These limitations increase the risk of diagnostic error in US evaluation, and therefore, US findings should always be evaluated in the context of the clinical picture (biochemical tests, patient history, clinical risk factors).

Clinical protocol and recommendations. Ultrasonography should be an integral part of diagnostic and management protocols in clinical practice. The following recommendations are used in many clinical guidelines: 1. Each nodule should be assessed on US for its initial appearance, size, characteristics, and patient risk factors (e.g., hereditary cancer, surgical history)

[8]. 2. Nodule classification should be performed using the TI-RADS system or nationally adapted protocols, and indications for FNAB should be determined [35][36][40]. 3. Advanced US techniques such as elastography and SMI (if available) should be used as a supplementary assessment tool in suspicious nodules [5][33]. 4. Safe and low-risk nodules should be followed up with annual US monitoring and re-evaluated if there is any change in size, structure, or vascularity [17]. 5. Ultrasound results should be combined with other diagnostic information (biochemical markers, patient history) to make a final clinical decision (biopsy, surgery, or observation).

General clinical algorithms for ultrasonography. Ultrasonography (US) is the first-line diagnostic tool in the evaluation of thyroid nodules and guides clinical decision-making [7]. Current international clinical guidelines (ATA, AACE, eTA) have developed clear algorithms for the classification of nodules and the determination of biopsy indications based on US findings [8][36]. In the initial stage, US examination documents the size, echogenicity, contours, margins, microcalcifications, composition (solid, cystic, mixed), Doppler vascularization, and elastographic parameters of the nodule [15]. Based on these criteria, the nodule is divided into 5 risk groups according to the TI-RADS or ATA system [35]. In the next step, intermediate and high-risk nodules are selected for FNAB, while low-risk nodules are referred for observation [14][36]. If the nodule has benign US features or is soft on elastography, biopsy is not required, thus avoiding unnecessary invasive procedures [29][33]. If the nodule has any of the high-risk features (microcalcifications, irregular contour, vertical orientation, hardness, intra-nodal chaotic vascularization), FNAB is recommended, even if the nodule is small (<10 mm) [9][10]. This approach allows for early detection of papillary carcinoma. Several clinical studies have shown that the combination of US + elastography + Doppler in the diagnostic process provides significantly higher accuracy in predicting risk than US alone, especially when used with the TI-RADS system [10][33]. Therefore, multimodal sonographic assessment has become an integral part of modern clinical algorithms.

Advantages of ultrasound in selection. The main advantages of ultrasound are its high accuracy, speed, and safety for the patient, especially during repeated monitoring [6]. Due to the lack of radiation, ultrasound is used as the first-choice diagnostic tool in children, pregnant women, and elderly patients [15]. Modern sensor technology (high-resolution linear probes) allows the detection of micronodes (2–3 mm), which helps to plan clinical decisions at an early stage [5]. In combination with Doppler technology, ultrasound allows the assessment of blood flow in the nodule, angiogenesis, and signs of invasive growth [19]. Elastography significantly improves the differential diagnosis by measuring the stiffness of malignant nodules, and shear-wave elastography in particular provides objective numerical indicators of clinical significance [29][30][33]. This technique avoids unnecessary biopsy of benign nodules and also helps to more accurately assess the malignancy risk in nodules with indeterminate FNAB results [11]. Another advantage of US is the ability to provide precise topographic mapping before surgery or radiofrequency ablation: determining the nodule's relationship to the trachea, esophagus, recurrent nerves, and blood vessels [12].

Limitations of ultrasonography (factors affecting diagnostic quality). Although US is the leading method for diagnosing thyroid nodules, it has a number of limitations. The most important limitation is the high dependence on operator skill, which leads to significant differences in US interpretation between different centers [20][21]. The subjective assessment factor is particularly high in determining the contours of the nodule, echogenicity, and microcalcifications [34]. In patients with high obesity, thick neck muscles, or very deep-seated nodules, ultrasound penetration is reduced, which reduces the result [15]. Calcified nodules do not show the underlying structure due to acoustic shadowing, which makes it difficult to determine the true boundary of the nodule [19][34]. In multinodular goiter, nodules may be confluent, and cysts and fibrous changes may complicate the assessment of simple echogenicity [8]. US may not be able to determine the internal architecture of some nodules, such as subcapsular microinvasion, minimal extrathyroidal growth, or lymphatic spread, for which CT or MRI is more informative [43].

Algorithms for risk assessment using US. The main principle in assessing the risk of a nodule is the general combination of echogenicity, calcifications, contour and vascularity [8] [35]. The most characteristic US features of papillary carcinoma are microcalcifications, indistinct margins, a "taller-than-wide" configuration and high hardness [10]. The TI-RADS system converts the risk of malignancy into a numerical score (0–3 points low, 4 points moderate, 5 points high risk), which helps the physician to accurately indicate the indication for biopsy [35][36]. In clinical practice, TI-RADS has been shown to reduce the number of biopsies by 25–30%, while maintaining the sensitivity for detecting malignant nodules [36]. Integration of elastography further optimizes risk assessment: shear wave> 50 kPa is an independent predictor of risk, and "stiff" dominant zones in the strain map indicate a tumor tissue rich in fibrous stroma [29][32]. On Doppler perfusion, "chaotic intranodular flow" and a high-resistance index are signs of angiogenesis, increasing the likelihood of risk [19].

Monitoring and reassessment criteria. The monitoring interval for benign nodules is annual US, which is considered sufficient, especially in young, asymptomatic patients without significant risk factors [17]. If the nodule diameter increases by more than 20% or new malignant features appear, a repeat FNAB is recommended [8][14]. In multinodular glands, each nodule should be evaluated individually, as malignancy may not always be present in the largest nodule but may also be present in small micronodules [12]. In autoimmune thyroiditis, it may be difficult to distinguish benign from malignant nodules due to the heterogeneity of the parenchyma, and additional methods such as elastography and SMI are clinically useful [5][22].

Conclusions: Ultrasonography is the cornerstone of thyroid nodule assessment and is a primary source of information for clinical decision-making [7]. Its advantages include safety, speed, high resolution, multimodality (Doppler, elastography, SMI), and accuracy in biopsy guidance [5][10][29]. Despite the operator-dependence of US and some technical limitations, the diagnostic accuracy has increased significantly with the introduction of modern TI-RADS systems, elastography protocols, and contrast-enhanced US technologies [36][40]. Today, US is the first and most important link in the multimodal diagnostic chain, and its results are integrated with CT, MRI, PET, and FNAB to create a complete clinical picture [43]. Thus, ultrasonography is an integral, necessary, and most widely used method of a correctly selected diagnostic strategy in thyroid diseases.

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