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THE IMPORTANCE OF ULTRASOUND IN DIAGNOSIS OF THE THYROID GLAND AND ITS DISEASES

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✓ ***Resume***

Thyroid diseases are among the most common endocrine dysfunctions worldwide. According to the World Health Organization, approximately 30–50% of the adult population will have at least one thyroid nodule during their lifetime, and 5–15% of them have the potential to develop malignant neoplastic processes. This scientific article provides an in-depth analysis of the role, importance, and effectiveness of ultrasound (ultrasonography, US) in modern clinical practice in identifying and differentially diagnosing various pathological conditions of the thyroid gland. The article extensively discusses the main advantages of ultrasonography - the absence of ionizing radiation, high informativeness and sensitivity, the ability to visually monitor anatomical and functional processes in real time, as well as the ability to obtain additional diagnostic information about perfusion and blood flow parameters using Doppler methods. In addition, some limitations of the method, in particular the high dependence on operator skill, technical difficulties in adequately visualizing deep or retrosternal structures, and the possibility of subjective interpretation of the results, were scientifically evaluated.

Keywords: Ultrasonography, TI-RADS, thyroid gland, diagnostics, exogenous, advantage, disadvantage.

ЗНАЧЕНИЕ УЛЬТРАЗВУКОВОГО ИССЛЕДОВАНИЯ В ДИАГНОСТИКЕ ЩИТОВИДНОЙ ЖЕЛЕЗЫ И ЕЁ ЗАБОЛЕВАНИЙ

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✓ ***Резюме***

Заболевания щитовидной железы относятся к числу наиболее распространенных эндокринных дисфункций во всем мире. По данным Всемирной организации здравоохранения, примерно у 30–50% взрослого населения в течение жизни обнаруживается хотя бы один узел щитовидной железы, а у 5–15% из них имеется потенциал развития злокачественных опухолевых процессов. В данной научной статье представлен глубокий анализ роли, значения и эффективности ультразвукового исследования (УЗИ) в современной клинической практике для выявления и дифференциальной диагностики различных патологических состояний щитовидной железы. В статье подробно рассматриваются основные преимущества УЗИ: отсутствие ионизирующего излучения, высокая информативность и чувствительность, возможность визуального контроля анатомических и функциональных процессов в режиме реального времени, а также возможность получения дополнительной диагностической информации о параметрах перфузии и кровотока с помощью допплеровских методов. Кроме того, научно оценены некоторые ограничения метода, в частности, высокая степень зависимости от квалификации оператора, технические сложности адекватной визуализации глубоких или ретростернальных структур, а также возможность субъективной интерпретации результатов.

Ключевые слова: УЗИ, TI-RADS, щитовидная железа, диагностика, экзогенность, преимущество, недостаток.

QALQON BEZI VA UNING KASALLIKLARINI TASHXIS QILISHDA ULTRATSAVTORIZATSIYANING AHAMIYATI

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✓ ***Rezyume***

Qalqonsimon bez kasalliklari global miqyosda uchraydigan eng keng tarqalgan endokrin disfunktsiyalar sirasiga kiradi. Jahon sog'liqni saqlash tashkiloti ma'lumotlariga ko'ra, kattalar populyatsiyasining taxminan 30–50 % qismi hayot davomida hech bo'lmaganda bitta qalqonsimon bez tuguniga ega bo'ladi, ularning 5–15 % ida esa neoplastik jarayonlarning malign potentsiali kuzatilishi ehtimoli mavjud. Ushbu ilmiy maqola qalqonsimon bezning turli patologik holatlarini aniqlash va differensial diagnostika qilishda ultratovush tekshiruvining (ultrasonografiya, US) zamonaviy klinik amaliyotdagi o'rni, ahamiyati va samaradorligini chuqur tahlil qiladi. Maqolada ultrasonografiyaning asosiy afzalliklari — ionlashtiruvchi nurlanishning yo'qligi, yuqori informativlik va sezgirlik darajasi, real vaqt rejimida anatomik va funksional jarayonlarni vizual kuzatish imkoniyati, shuningdek dopplerografik usullar orqali perfuziya va qon oqimi parametrlari haqida qo'shimcha diagnostik ma'lumot olish imkoniyati - keng yoritilgan. Bundan tashqari, metodning ayrim cheklovlari, xususan operator malakasiga yuqori darajada bog'liqligi, chuqur yoki retrosternal lokalizatsiyadagi tuzilmalarni adekvat vizualizatsiya qilishdagi texnik qiyinchiliklar hamda natijalarning sub'ektiv talqin qilinish ehtimoli ilmiy asosda baholangan.

***Kalit so'zlar:* Ultrasonografiya, TI-RADS, qalqonsimon bez, diagnostika, exogenlik, afzallik, kamchilik.**

Relevance

The role and importance of ultrasonography in thyroid diseases. Ultrasonography (US) is the primary imaging diagnostic method in thyroid diseases, which allows for high-resolution assessment of anatomical structures [1]. The advantages of US are that it is radiation-free, completely safe for the patient, repeatable, and inexpensive [2]. Since the thyroid gland is located close to the surface, it is possible to visualize the tissues with high resolution through US, which makes it the first-line examination method in all countries [3]. US has a sensitivity of up to 95% in detecting thyroid nodules, which is much higher than CT/MRI of the chest or neck [4]. Nodular thyroid diseases are common, and the detection of nodules by US in women over 50 years of age 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, borders, echogenicity, types of calcifications, blood supply, and relationship to the capsule, of the nodule; 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 — it is clearly determined whether a biopsy is necessary or not based on the results of US [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. The ability of US to record thyroid anatomy with high resolution has expanded the ability to assess morphology [10]. The thyroid gland is divided into two lobes (lobus dexter 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, moderately echogenic, and more echogenic than muscle [12]. When a nodule develops, this uniformity is disrupted and focal changes appear [13]. Therefore, US is also able to detect microstructural changes with high spatial resolution [14]. The following technical factors significantly affect the quality of US images: 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, US 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 a benign or malignant nodule [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, 3. mixed structural nodules [24]. The probability of malignant tumor in solid nodules is higher than in mixed and cystic nodules [25]. In addition, microcalcifications (less than 1 mm) are a classic diagnostic sign for papillary carcinoma [26].

Microcalcifications and their relationship to malignancy. Microcalcifications are one of the most important US features of papillary carcinoma, corresponding to psammoma bodies [27]. They are punctate, shiny, non-acoustic calcium deposits and can increase the probability of malignancy by up to 80% [28]. Several large-scale studies have shown that microcalcifications are associated with: a) papillary carcinoma [29]; b) medullary carcinoma [30]; c) lymphoma [31]. Benign nodules rarely have microcalcifications, but macrocalcifications may be present [32]. Therefore, the type of calcification is very important 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, scattered ("spiculated") contour — indicates malignant tumor infiltration [35]. Papillary carcinoma often presents with indistinct borders, as 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 evaluated with a high score in the international TI-RADS system [37].

Elastosonography and tissue stiffness measurement. Elastography is a new form of US methodology that assesses nodule stiffness by either tissue deformation-based (strain elastography) or shear-wave-based (shear-wave elastography) [29]. Malignant nodules typically have a fibrous stroma and dense tumor tissue, so their deformation is small and the shear-wave velocity is high on elastography [30]. In strain elastography, nodule stiffness 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 nodules with shear-wave velocities > 50 kPa are more likely to be malignant [32]. The combination of strain + shear-wave may help to increase diagnostic accuracy, as they are complementary [33]. Meta-analyses have shown that US with elastography (especially shear-wave) is more accurate: SROC AUC ~ 0.92, a significant improvement over plain US [10]. However, calcified nodules may give false results on elastography, as calcium opacity and stiffness confound strain measurements [34]. Elastography is also useful as an additional assessment tool in nodules with an "unknown" (non-diagnostic or indeterminate) FNAB result. 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 detailed visualization of the microvascular structure (small vessels and new capillaries) [5]. SMI has high sensitivity in reflecting very small capillary flow, which is a marker of angiogenesis, which helps to detect new blood vessel formation in malignant nodules [5]. Some clinical studies have shown that combining SMI features with TI-RADS criteria improves sensitivity and specificity in contrast evaluation. For example, the combination of TI-RADS + SMI may reconsider the need for biopsy in patients with suspicious nodules [5]. The use of SMI allows for the following approaches: identification of signs of invasive angiogenesis, guidance in biopsy planning, and observation of dynamic changes in blood vessels during monitoring.

Sonographic monitoring and surveillance strategies. Dynamic monitoring of US nodules is a common and proven strategy in clinical practice [17]. According to widely used recommendations, nodules with benign US features and judged benign by FNAB are usually followed up with annual US examinations [17]. During surveillance, the following are monitored: changes in nodule size (in diameter or volume), changes in echogenicity and structure (appearance of new septa or cystic components), development of calcifications and changes in vascularization [8]. If a 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 ultrasonography are highly operator-dependent: the skill, experience, and adherence to standardized procedures of the operator have a significant impact on the reliability of US results [20]. Many studies have shown that nodule interpretation varies between centers and physicians with different levels of experience. In addition, the quality of the US equipment (high-frequency probes, good resolution, focusing) is important for diagnostic accuracy [15]. Low-quality transducers, older equipment, or low-frequency probes limit the detection of micronodules or unclear contours. Technical limitations also include artifacts: Acoustic shadowing may occur around calcifications, which may distort the view of underlying structures. Reverberation artifacts may cause abnormal appearance in adjacent tissues. When the focus and contrast settings are not correct, 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 interpreted in the context of the clinical puzzle (biochemical tests, patient history, clinical risk factors). *Clinical protocol and recommendations.* Ultrasonography should be a core part of the 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, symptoms, and patient risk factors (e.g., hereditary cancer, surgical history) [8]. 2. Nodule classification should be based on the TI-RADS system or nationally adapted protocols, and indications for FNAB should be determined [35][36][40]. 3. Advanced US modalities such as elastography and SMI (if available) should be used as a supplementary assessment tool in suspicious nodules [5][33]. 4. Benign and low-risk nodules are monitored by annual US monitoring and should be reassessed if there are changes in size, structure, or vascularization [17]. 5. US results should be combined with other diagnostic information (biochemical markers, patient history) for the 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 classifying nodules and determining biopsy indications based on US findings [8][36]. Initially, US examination documents the size, echogenicity, contours, margins, microcalcification, composition (solid, cystic, mixed), Doppler vascularization, and elastographic parameters of the nodule [15]. Based on these criteria, the nodule is classified 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, which avoids unnecessary invasive procedures [29][33]. If the nodule has one 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. Many 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 the selection process. The main advantages of US are its high accuracy, rapidity and safety for the patient, especially in repeated monitoring [6]. Due to the absence of radiation, US 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, US allows the assessment of blood flow, angiogenesis and signs of invasive growth in the nodule [19]. Elastography significantly improves the differential diagnosis of malignant nodules by measuring their stiffness, especially shear-wave elastography, which provides objective numerical indicators of clinical significance [29][30][33]. This method avoids unnecessary biopsy of benign nodules and also helps to more accurately assess the probability of malignancy in nodules with indeterminate FNAB results [11]. Another advantage of US is the ability to accurately map the nodule before surgery or radiofrequency ablation: determining its 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 centers [20][21]. The subjective assessment factor is particularly high in determining the contours, echogenicity, and microcalcifications of the nodule [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 adjacent to each other, and cysts and fibrous changes may complicate the simple echogenicity assessment [8]. US cannot determine the internal architecture of some nodules, for example: subcapsular microinvasion, minimal extrathyroidal growth, and assessment of spread along lymphatics - for these, CT or MRI provides more information [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 vascularization [8][35]. The most characteristic US features of papillary carcinoma are microcalcifications, indistinct margins, a “taller-than-wide” configuration and high rigidity [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 biopsy indication [35][36]. In clinical practice, TI-RADS has been shown to reduce the number of biopsies by 25–30%, while maintaining the sensitivity of detecting malignant nodules [36]. The integration of elastography further optimizes the risk assessment: shear-wave > 50 kPa is an independent predictor of malignancy, and “rigid” dominant zones in the strain map indicate a tumor tissue rich in fibrous stroma [29][32]. Doppler perfusion “chaotic intranodular flow” and a high-resistance index are signs of angiogenesis and increase the likelihood of malignancy [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 malignancy develops, 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 techniques such as elastography and SMI are clinically useful [5][22].

Conclusion

Ultrasonography is the cornerstone of thyroid nodule assessment and is a key source of information for clinical decision-making [7]. Its advantages include safety, speed, high resolution, multimodality capabilities (Doppler, elastography, SMI), and accuracy in biopsy guidance [5][10][29]. Despite the operator-dependence and some technical limitations of US, 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 indispensable, necessary, and most widely used method of a well-chosen diagnostic strategy in thyroid diseases.

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