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MULTIPARAMETRIC ULTRASONIC DIAGNOSTICS IN THE ASSESSMENT AND PREDICTION OF OUTCOMES OF CHRONIC KIDNEY DISEASE

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Abstract. Renal Doppler ultrasound plays a key role in the comprehensive assessment and diagnosis of kidney diseases, which can be functional, diffuse, and systemic. The use of Doppler imaging techniques allows for an objective assessment of vascular changes and renal hemodynamics. Doppler imaging is widely used to analyze renal artery perfusion, with key quantitative indicators including the resistive index, pulsatility index, and peak systolic blood flow velocity, which reflect the state of intrarenal circulation. Doppler analysis provides clinically significant diagnostic information, enabling the detection of early signs of impaired renal perfusion and the prediction of renal parenchymal damage at the preclinical stage. In recent years, ultrasound elastography, a promising noninvasive method aimed at assessing the mechanical properties of renal tissue, has seen significant development. Elastography expands the capabilities of ultrasound diagnostics, allowing for the quantitative characterization of the degree of fibrotic changes and structural reorganization of the parenchyma. The combined use of Doppler ultrasound and elastography is considered an effective approach to assessing chronic kidney disease, increasing the diagnostic accuracy and prognostic value of ultrasound examination. In the future, the use of elastography may significantly reduce the need for invasive procedures, including renal biopsy, and contribute to the optimization of patient management strategies for chronic kidney disease.

Relevance. Doppler ultrasound occupies a key position in modern medical imaging and is widely used to assess the velocity and direction of blood flow. This method is based on the Doppler effect, which allows for recording changes in the frequency of ultrasound echo signals reflected from moving blood cells. In many clinical situations, Doppler ultrasound successfully replaces radiocontrast angiography due to its non-invasive nature , the absence of ionizing radiation, and the ability to dynamically assess hemodynamics in real time.

In nephrology practice, Doppler ultrasonography is widely used to diagnose and monitor renal and vascular diseases. The most common and clinically significant Doppler parameter is the renal resistive index (RI), used to assess kidney transplant rejection, identify renal artery stenosis in patients with hypertension, and diagnose and predict the course of chronic kidney disease (CKD). Analysis of Doppler parameters provides objective information on the state of intrarenal circulation and vascular resistance.

Along with Doppler ultrasonography, ultrasound elastography, a modern imaging method sensitive to tissue stiffness, has been rapidly developing in recent years. Elastography provides a quantitative assessment of the mechanical properties of the renal parenchyma and allows for the detection of elasticity changes caused by fibrosis and other pathological processes. This method demonstrates potential in the differential diagnosis of benign and malignant kidney tumors and may potentially reduce the need for invasive diagnostic procedures, including biopsy.

Research methodology. The combined use of Doppler ultrasound and elastography significantly expands the diagnostic capabilities of ultrasound examination, providing highly informative data on hemodynamic and structural-mechanical changes in renal tissue. This is essential for the early detection of pathological processes, assessing their severity, and selecting the optimal treatment strategy for patients with kidney disease.

Pulsed-wave Doppler (PWD) is used to record the spectrogram of the blood vessel being examined (artery or vein). This method measures blood flow velocity throughout the entire cardiac cycle and displays the velocity distribution with proper angular correction, improving the accuracy of quantitative analysis.

Doppler ultrasonography is considered more informative than traditional gray-scale echography because it complements morphological assessment with functional and vascular characteristics. This method allows for an objective assessment of renal and extrarenal vascularity and the identification of hemodynamic abnormalities not detectable with B-mode.

Correct performance of a Doppler study is key to obtaining reliable data. This method provides information on the presence, direction, and nature of blood flow in the renal vessels. Diagnosis of renal artery stenosis is based on the analysis of Doppler parameters, including the resistive index (RI), pulsatility index (PI), and systolic -diastolic ratio (S/D). These parameters reflect vascular resistance and have significant prognostic value in various kidney diseases.

Renal artery Doppler ultrasonography begins with the patient in the supine position using a low-frequency transducer (2.5–5.0 MHz) to visualize the abdominal aorta and the renal artery orifices. The anterior abdominal wall is the primary access. The renal arteries arise from the lateral walls of the abdominal aorta at the level of the second lumbar vertebra, approximately 1–2 cm below the origin of the superior mesenteric artery. The right renal artery passes behind the inferior vena cava, which must be taken into account during scanning. In some cases, the patient is positioned on the opposite side to optimize the acoustic window.

A convex transducer with a frequency of approximately 3.5 MHz and an adjustable focal zone is used for the examination . The examination protocol includes an initial assessment of each kidney in B-mode in at least two planes to determine the position, size, echostructure , and echogenicity of the parenchyma. Doppler indices (RI and PI) are measured at the level of the interlobular or arcuate arteries in the upper, middle, and lower segments of the kidney, followed by calculation of average values for each kidney, ensuring representativeness of the hemodynamic parameters obtained.

Several studies have demonstrated that the normal mean renal resistive index (RI) is approximately 0.60. In individuals without preexisting renal disease, the mean RI ranges from 0.58 to 0.64, with most authors reporting values of 0.60 ± 0.01 as representative of the healthy population. In clinical practice, the upper limit of normal RI in adults is considered to be 0.70.

Spectral Doppler analysis of renal artery waveforms is widely used to characterize hemodynamic disturbances. Despite the high prognostic value of RI in a number of renal diseases, factors influencing the arterial waveform, including systemic vascular resistance, vascular elasticity, and heart rate, should be considered. However, an increased RI has been shown to correlate with the severity of histological changes in chronic kidney disease (CKD) and an unfavorable renal prognosis. RI values ≥ 0.65 are associated with atherosclerotic changes, severe interstitial fibrosis, and decreased renal function. Thus, RI is considered a significant Doppler marker for risk stratification of CKD progression to end-stage renal disease.

Chronic kidney disease is a global public health problem. According to international epidemiological studies, the prevalence and mortality associated with CKD have increased significantly in recent decades, highlighting the need for early diagnosis and prognosis.

In gray-scale ultrasound, CKD assessment is based on measuring kidney length and analyzing the echogenicity of the cortex. A decrease in kidney size combined with increased cortical echogenicity is the primary ultrasound criterion for chronic kidney disease. Normal kidney length in young adults averages 11–12 cm (the left kidney is usually 2–3 mm longer than the right), with a tendency to gradually decrease with age-related atrophy. Normally, the echogenicity of the renal parenchyma is comparable to that of the liver or spleen. Increased cortical echogenicity , exceeding that of the liver or spleen, reflects inflammatory and fibrotic changes, including glomerulosclerosis and interstitial fibrosis, which are characteristic of chronic kidney disease.

However, it should be noted that a number of inflammatory diseases, such as glomerulonephritis and acute interstitial nephritis, are also accompanied by increased echogenicity of the renal parenchyma. In clinical practice, the combination of reduced kidney size and marked parenchymal hyperechogenicity in most cases indicates chronic kidney disease (CKD) rather than acute kidney injury.

Doppler ultrasound plays a significant role in the diagnosis of CKD and the assessment of its progression to end-stage renal failure. Renal resistive index (RI) has been shown to correlate more strongly with arteriosclerosis, glomerulosclerosis , and tubulointerstitial lesions than morphological parameters such as kidney length and cortical area. In general, elevated RI values (> 0.70) reflect more pronounced atherosclerotic changes compared to normal (< 0.65) or high-normal values ($0.65 \leq RI < 0.70$). Patients with high-normal RI have been shown to demonstrate a more favorable response to steroid therapy compared to those with RI exceeding 0.70. Moreover, in patients with late stages of CKD, RI values are significantly higher than in early stages of the disease, which emphasizes its prognostic significance.

Ultrasound elastography, as an imaging method sensitive to tissue stiffness, was first described in the 1990s and has undergone significant development in recent years, focusing on quantitative assessment of tissue mechanical properties. Elastography allows for the detection of changes in soft tissue elasticity caused by pathological and physiological processes. It is known that solid tumor tissue and fibrously altered parenchyma exhibit greater stiffness compared to normal tissue, which underlies the diagnostic value of this method.

Renal elastography is considered a promising imaging tool and a potential clinical biomarker of the disease. Several studies have shown that renal transplant cortex elastography parameters, as well as corticomedullary strain coefficients, significantly correlate with the degree of cortical fibrosis. Shear wave elastography wave Electroradiography (SWE), including technologies using acoustic radiation force impulse (ARFI), has demonstrated successful clinical application in the assessment of various organs. In nephrology, SWE has shown encouraging results in the assessment of chronic kidney disease, renal transplant function, and vascular complications, including renal vein thrombosis.

Conclusions. Thus, Doppler ultrasound and elastography are highly effective renal imaging techniques that complement each other in assessing structural and functional changes in renal tissue. Doppler ultrasound allows for an objective assessment of renal vascularization and intrarenal hemodynamics, while elastography provides a quantitative characterization of the mechanical properties and elasticity of the parenchyma.

Ultrasound elastography is a promising and rapidly developing technique that can be effectively used to assess the severity of corticomedullary fibrosis and stratify the risk of chronic kidney disease progression. The combined use of Doppler ultrasonography and elastography enhances the diagnostic and prognostic value of ultrasound examinations and potentially reduces the need for invasive diagnostic procedures, including renal biopsy, thereby improving patient safety and quality of care.

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