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CAPABILITIES OF MULTIPARAMETRIC ULTRASONIC EXAMINATION IN DIFFERENTIAL DIAGNOSIS OF SOFT TISSUE TUMORS

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Relevance. The early diagnosis of musculoskeletal and soft tissue tumors remains one of the unsolved challenges in modern oncology and radiation diagnostics. Traditional imaging methods, including various modifications of X-ray examinations, computed tomography, and other imaging techniques, are associated with radiation exposure, high cost, and limitations in the frequency of repeat use. This is especially important for dynamic monitoring, evaluation of treatment effectiveness, and early detection of disease recurrence.

From the first publications on soft tissue ultrasound, it was noted that echography allows for the visualization of structural details inaccessible with standard radiography. Subsequently, numerous studies have confirmed the method's high differential diagnostic accuracy in assessing soft tissue pathologies. It has been demonstrated that ultrasound's ability to detect soft tissue tumors is not only comparable to radiographic methods, including computed tomography, but in some clinical situations, it surpasses them in sensitivity, particularly for superficial tumors and for assessing the structure of the tumor.

Doppler techniques offer fundamentally new diagnostic possibilities, allowing for the assessment of tumor vascularization, the nature of the vascular pattern, and hemodynamic parameters. Analysis of vascular architecture and blood flow intensity improves the accuracy of differentiation between benign and malignant tumors and facilitates more informed treatment decisions.

In this regard, it is important to systematize data on the capabilities of multiparametric ultrasound, including B-mode, Doppler, and, when necessary, elastography, in the diagnosis of soft tissue tumors. Determining the informative value of complex ultrasound imaging in initial diagnosis, assessing treatment effectiveness, and early detection of recurrences is of significant clinical importance and contributes to the optimization of algorithms for the management of patients with soft tissue tumors.

The aim of the study. To improve the accuracy and informativeness of soft tissue tumor diagnostics using a comprehensive multiparametric ultrasound examination, including gray-scale ultrasound scanning, Dopplerography and additional functional ultrasound techniques.

Materials and methods. To clarify the ultrasound semiotics of soft tissue tumors, a retrospective analysis of ultrasound examination results was conducted in 174 patients with soft tissue diseases observed between 2019 and 2023. Malignant neoplasms were detected in 126 patients (72%), benign tumors in 41 (24%), and non-neoplastic changes in 7 (4%).

Modern, expert-class ultrasound systems provide highly detailed images of tissues and structures of the musculoskeletal system. The use of multi-frequency linear transducers with variable operating frequencies in the 5–13.5 MHz range allows for the effective detection of soft tissue pathologies. When examining overweight patients, as well as when localizing pathological processes in large areas of soft tissue (thigh, gluteal region), convex transducers with low scanning frequencies (2–5 MHz) were used, ensuring sufficient ultrasound penetration depth.

It is known that the size of an ultrasound image is limited by the width of the transducer used, which in extensive tumor processes can make it difficult to determine the true boundaries of the tumor and its relationship with surrounding tissues over a distance of up to 60 cm. In these cases, staged scanning with sequential visualization of the entire affected area was particularly important.

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The ultrasound diagnostic search algorithm for examining the musculoskeletal system included a sequential examination of images from the skin to the underlying bone structures to identify or exclude a space-occupying lesion. During visualization of the tumor, its location, shape, size (in three mutually perpendicular planes), number of nodules, contours, internal structure and echogenicity, and the presence and thickness of the capsule were determined. The condition of the surrounding tissues was also assessed, including the presence of edema, infiltration, soft tissue thickening, and signs of disruption or involvement of bone structures. The condition of the main vessels (displacement, deformation, infiltration, and the presence of thrombotic changes) was also analyzed.

Power Doppler imaging was used to assess the degree of tumor vascularization and the condition of major vessels. This technique, a modification of color Doppler mapping, allows for two-dimensional visualization of the vascular bed with high sensitivity to low-velocity blood flow and small-diameter vessels. The advantages of power Doppler imaging include relative independence from the insonation angle, high frame rate, and the absence of spectral ambiguity, making it particularly valuable for assessing tumor neoangiogenesis.

To determine the diagnostic capabilities of Dopplerographic techniques for soft tissue malignancies and to identify tumor blood flow characteristics, color and power Doppler mapping modes, as well as pulsed-wave Dopplerography, were used. The Doppler study results were analyzed in 110 patients. In 16 cases (13%), tumor blood flow was not visualized. Depending on the number of intratumor vessels, all observations were conditionally divided into three blood flow types: Type I — the presence of a single intratumor vessel; Type II — visualization of 2 to 5 vessels; Type III — the presence of more than 5 intratumor vessels, which was regarded as a sign of pronounced vascularization and potential malignancy.

Results and discussion. When comparing the histological type of malignant soft tissue tumors and their sizes, it was found that synovial sarcoma was predominantly characterized by small tumor node sizes (up to 3.0 cm and 3.1–6.0 cm). The greatest number of patients with tumor sizes of 3.1–6.0 cm and more than 15.1 cm was noted in the liposarcoma group . Malignant fibrous histiocytoma (MFH) was observed in all size groups, but was most common with tumor diameters of 6.1–9.0 cm and 12.1–15.0 cm. A similar pattern was observed in the analysis of other, rarer forms of soft tissue sarcomas.

Based on the data obtained, it was established that the tumor size does not allow for a reliable determination of its histological type. However, malignant neoplasms with a diameter greater than 9 cm were statistically significantly more common ($p < 0.001$). The majority of malignant tumors had a single-nodular structure (51.0% of cases), while multinodular forms (three or more nodes) were detected in 35.0% of patients. Solid tumors were significantly more common in synovial sarcomas and rare forms of soft tissue sarcomas ($p < 0.001$). MFG and liposarcomas constituted the most numerous group, both in single-nodular and multinodular growth patterns.

An analysis of the ultrasound semiotics of malignant tumors showed that they are significantly more often characterized by an irregular shape (61%, $p < 0.05$), uneven contours (78%, $p < 0.01$), heterogeneous internal structure (84%, $p < 0.01$), and a predominantly solid structure (95%, $p < 0.01$). Reduced echogenicity of tumor tissue was detected in 75% of cases ($p < 0.05$). The sign of clear or unclear contours did not have statistically significant differences and occurred with almost the same frequency (56% and 44%, respectively). Solid-cystic and cystic structure is uncharacteristic for malignant tumors of soft tissues and was observed only in 3% of patients with MFG and myogenic sarcoma.

Areas of increased echogenicity were detected in 17% of cases and, upon morphological examination, were consistent with connective tissue proliferation. Calcifications were visualized in 14% of cases as hyperechoic inclusions with acoustic shadowing. Overall, no pathognomonic ultrasound features were identified when analyzing the ultrasound images of various histological variants of malignant soft tissue tumors. Liposarcoma was an exception, for which increased echogenicity of the tumor structure was characteristic in 60% of cases .

Ultrasound tomography also allowed us to assess the spread of the tumor process to surrounding tissues, bone structures, and the relationship of the tumor with major vessels. In three cases, ultrasound revealed bone involvement, which was subsequently confirmed by morphological examination of the surgical material. When analyzing the nature of tumor vascularization, it was found that a single intratumoral vessel was detected in 7.3% of cases. Most often, 2 to 5 vessels were visualized (63.6%), while pronounced vascularization with the presence of more than 5 vessels was observed in 29.1% of patients. Type II blood flow was detected in all histological variants of tumors, reaching 100% in the group of neurogenic sarcomas. Type III blood flow was less common; its predominance in patients with lymphosarcomas was explained by the significant size of the tumor nodes (9.1–12.0 cm). In general, types II and III blood flow were significantly more frequently detected in malignant tumors of soft tissues ($p < 0.001$).

Pulsed-wave Doppler ultrasonography was used to analyze blood flow velocity parameters and peripheral resistance indices. A significant range of absolute hemodynamic parameters was observed for all histological types of malignant tumors, preventing a clear correlation between the tumor morphological type and the tumor's morphological type. However, malignant tumors were characterized by high peripheral resistance indices, likely due to the structural features of tumor vessels—their tortuosity, multiple stenoses, and occlusions. The highest linear blood flow velocities were observed in neurogenic and angiogenic sarcomas, reaching 68 and 60 cm/s, respectively.

An analysis of the ultrasound semiotics of benign soft tissue tumors in B-mode (41 patients) revealed that they were characterized by relatively small sizes—up to 3 cm (34.3%)—most frequently observed in neurofibromas, myxomas, and giant cell tumors ($p < 0.001$). Large sizes (15 cm or more) were observed primarily in desmoids and lipomas. A single-nodular structure was detected in 85.4% of patients, while a multinodular form was observed exclusively in desmoids .

The differential diagnosis of tumor and non-neoplastic soft tissue lesions requires special attention. The group of non-neoplastic lesions included patients with ossifying myositis, hygroma, and villonodular Tenosynovitis and organized hematomas. Inflammatory processes were characterized by the absence of a clearly defined tumor nodule, soft tissue swelling, and minimal vascularization . Ossifying myositis was visualized as an irregularly shaped area of chronic inflammation with a heterogeneous structure and isolated vessels. Hygromas had a cystic nature with septa and isolated vessels in the capsule. Villonodular Tenosynovitis was defined as a solid, irregularly shaped mass with irregular contours and a heterogeneous structure, localized in the joint area. Organized hematomas were formations with clear, smooth contours, a cellular structure, and an absence of blood flow.

Overall, in 98% of cases, ultrasound examination correctly identified the presence of a space-occupying lesion and its tumor or non-neoplastic nature. True-positive results were 96%, and true-negative results were 2%. False-positive results (2%) were associated with atypical ultrasound imaging of non-neoplastic processes. There were no false-negative results in the initial detection of space-occupying lesions.

The sensitivity of ultrasound imaging in diagnosing soft tissue neoplasms was 100%, specificity was 57%, and overall accuracy was 98%. Using a combination of ultrasound features, correct diagnostic conclusions were made in 85% of patients with benign and malignant tumors.

Furthermore, the diagnostic performance of ultrasound in detecting malignant soft tissue tumors was as follows: sensitivity of 92%, specificity of 65%, and accuracy of 85%.

Conclusions. Comprehensive multiparametric ultrasound is a highly informative method for diagnosing soft tissue lesions in the neck, trunk, and extremities. This method allows for the identification of tumor nodules, their size, location, and relationship to surrounding anatomical structures, as well as assessment of the extent of invasion into adjacent tissues.

The use of Doppler ultrasonography and elastography significantly expands the diagnostic capabilities of ultrasound. Analysis of vascularization patterns and quantitative assessment of tissue stiffness allow for a high degree of differentiation between benign and malignant lesions and, in some cases, closer morphological characterization of the tumor.

The most significant ultrasound signs of malignant extraorgan soft tissue tumors include: decreased echogenicity of the formation, the presence of a false capsule, pronounced heterogeneity of the echostructure, uneven bumpy contours, intense intratumor Vascularization, elevated stiffness values based on elastography, and deep localization of the pathological process. These criteria, taken together, can be considered a set of signs characteristic of malignant growth and serve as the basis for a more in-depth examination and early oncological treatment of the patient.

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