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MULTIPARAMETRIC MRI IN THE DIFFERENTIAL DIAGNOSIS OF ADRENAL TUMORS: CURRENT POSSIBILITIES AND CLINICAL SIGNIFICANCE

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ABSTRACT

Introduction. Adrenal tumors are a significant diagnostic problem in modern oncoendocrinology, especially when it is necessary to differentiate between benign and malignant tumors. Multiparametric magnetic resonance imaging (MP-MRI) is considered as a promising noninvasive imaging method that allows comprehensive assessment of the morphological and functional characteristics of tumor tissue. The

purpose of the study. To systematize modern data on the possibilities of multiparametric MRI in the differential diagnosis of adrenal tumors and to evaluate its clinical significance in distinguishing benign and malignant neoplasms.

Materials and methods. An analytical review of domestic and foreign publications indexed in PubMed, Scopus, Web of Science, and Google Scholar databases for the period 2015-2025 has been conducted. The analysis includes clinical studies, systematic reviews, and meta-analyses on the use of MP-MRI in adrenal tumors. The diagnostic capabilities of chemical shift imaging, diffusion-weighted imaging (DWI), ADC mapping, and dynamic contrast-enhanced MRI (DCE-MRI) sequences, as well as radiomics and artificial intelligence methods, were evaluated.

Results. An analysis of the literature has shown that the use of a multiparametric approach significantly improves the accuracy of the differential diagnosis of adenomas, adrenocortical carcinomas, pheochromocytomas and metastatic lesions of the adrenal glands. The most informative parameters are indicators of lipid saturation, diffusion coefficient (ADC) and characteristics of contrast accumulation. The integration of MP-MRI with radiomics and artificial intelligence technologies helps automate image interpretation, improve reproducibility of results, and create predictive models. In addition, the method has high clinical significance in preoperative planning, monitoring the effectiveness of therapy, and dynamic patient monitoring.

Conclusion. Multiparametric MRI is a highly informative tool for noninvasive diagnosis of adrenal tumors, providing a comprehensive functional and morphological assessment of the formations. The introduction of standardized research protocols and the integration of radiomic technologies open up prospects for the widespread use of MP-MRI in personalized and precision medicine.

KEYWORDS: multiparametric MRI, adrenal tumors, differential diagnosis, adenoma, adrenocortical carcinoma, pheochromocytoma, metastases, radiomics, artificial intelligence, DWI, DCE-MRI.

INTRODUCTION

Adrenal tumors represent one of the most pressing problems of modern endocrinology and oncology, which is due to the steady increase in their detectability due to the widespread introduction of high-tech medical imaging methods [1-3]. According to epidemiological studies, adrenal incidentalomas are found in 3-10% of the adult population, while among patients over 60 years of age, their detection rate reaches 15% [4, 5]. The significant prevalence of adrenal formations, as well as the risk of their hormonal activity and malignant potential, determine the need for timely and maximally accurate diagnosis.

The greatest difficulties in clinical practice are caused by the differential diagnosis of benign adenomas, adrenocortical carcinomas, pheochromocytomas, and metastatic lesions, especially in the presence of lipid-poor formations with similar morphological characteristics [6-10]. Erroneous interpretation of imaging data can lead to both unjustified surgical interventions and late diagnosis of the malignant process, which underscores the need to improve non-invasive methods of radiation diagnosis.

In recent years, multiparametric magnetic resonance imaging (MP-MRI) has become particularly important, allowing a comprehensive assessment of not only anatomical but also functional features of tumor tissue [11-13]. The use of chemical

shift imaging, diffusion-weighted imaging (DWI), ADC mapping, and dynamic contrast-enhanced MRI (DCE-MRI) sequences provides a quantitative assessment of lipid composition, cell density, microcirculation, and perfusion characteristics of adrenal gland formations [14-17]. The combined analysis of these parameters significantly improves the accuracy of differential diagnosis and contributes to the formation of a personalized approach to patient management.
Additional prospects for the development of the method are associated with the introduction of artificial intelligence, radiomics, and machine learning technologies that automate image interpretation and create reproducible diagnostic models [10, 13, 16]. Modern research demonstrates that the integration of quantitative radiomic features with MP-MRI data provides high diagnostic efficiency in distinguishing between benign and malignant tumors of the adrenal glands.
In this regard, the systematization of modern data on the possibilities of multiparametric MRI in the diagnosis of adrenal tumors is of considerable scientific and practical interest.
The aim of the study is to systematize modern data on the possibilities of multiparametric magnetic resonance imaging in the differential diagnosis of adrenal tumors, as well as to evaluate its clinical significance in distinguishing benign and malignant tumors.
To prepare the review, scientific literature was searched in the electronic databases PubMed, Scopus, Web of Science and Google Scholar for the period 2015-2025. Keywords and their combinations were used: adrenal tumors, adrenal adenoma, adrenocortical carcinoma, multiparametric MRI, diffusion-weighted imaging (DWI), chemical shift imaging (CSI), dynamic contrast-enhanced MRI (DCE-MRI), as well as the corresponding Russian-language equivalents.
The review included clinical studies, systematic reviews, and meta-analyses on the diagnostic capabilities of MRI and its multiparametric modes for adrenal neoplasms in adult patients. Publications based solely on computed tomography, PET/CT, or experimental models were excluded. The initial search revealed more than 2,300 publications, and after applying the selection criteria and analyzing full-text sources, 42 scientific papers were included in the final review.

PHYSICAL AND TECHNICAL FUNDAMENTALS OF MULTIPARAMETRIC MRI (MP-MRI)

Multiparametric magnetic resonance imaging (MP-MRI) is a modern imaging method based on a combination of several pulse sequences that allow a comprehensive assessment of the morphological and functional characteristics of the adrenal gland tissues [12, 19, 20]. The use of chemical shift imaging, diffusion-weighted imaging (DWI), ADC mapping, and dynamic contrast-enhanced MRI (DCE-MRI) provides analysis of lipid composition, cell density, and perfusion characteristics of tumors.
The chemical shift imaging method is based on the difference in the precession frequencies of water and fat protons and is one of the key tools for the differential diagnosis of adrenal adenomas and metastatic lesions [42]. Adam et al. [42] showed that a decrease in signal intensity on the opposite-phase images reflects the intracellular lipid content and is characteristic of benign adenomas.
Diffusion-weighted imaging (DWI) and ADC mapping make it possible to quantify the diffusion of water molecules and the cell density of a tumor. Halefoglu et al. [36] demonstrated that a decrease in ADC values is associated with a high malignant potential and promotes the differentiation of adenomas and metastases.
Additional information is provided by dynamic contrast-enhanced MRI (DCE-MRI), which allows analyzing the features of tumor vascularization and contrast accumulation [18, 19]. Combined with DWI and chemical shift imaging, this approach significantly improves diagnostic accuracy.
Modern research also highlights the importance of quantitative image analysis and radiomics. Romeo et al. [38] showed the effectiveness of textural analysis of MR images for automated assessment of structural heterogeneity of tumors, while Lattin and colleagues [35] noted the importance of correlation of radiological and histopathological data for standardization of interpretation of MR signals. Charles et al. [22] demonstrated that T1 and T2 relaxation parameters can serve as additional criteria for tissue heterogeneity.
Kataoka et al. [18] found that combining chemical shift imaging, DWI, and DCE-MRI data into a single analysis model significantly improves the accuracy of classification of adrenal tumors. Barat and colleagues [16, 17] emphasized the importance of standardizing quantitative parameters and implementing artificial intelligence algorithms to improve reproducibility of results.
Thus, multiparametric MRI is based on the synergy of various pulse sequences and quantitative analysis, providing a comprehensive functional and morphological assessment of adrenal tumors and expanding the possibilities of non-invasive diagnosis in oncoendocrinology.

DIFFERENTIAL DIAGNOSIS OF ADRENAL TUMORS USING MP-MRI

Modern studies demonstrate that multiparametric MRI (MP-MRI) plays a key role in the noninvasive differential diagnosis of adrenal tumors, especially when it is necessary to distinguish between adenomas, hyperplasia and metastatic lesions [10, 11, 15]. The use of quantitative biomarkers derived from dynamic (DCE) and diffusion-weighted (DWI) sequences allows an objective assessment of cell density, vascular permeability, and microcirculation, which significantly improves diagnostic accuracy compared with traditional CT [23, 27].
Works by Meucci et al. [28] and Zhao et al. [29] confirmed that the values of the apparent diffusion coefficient (ADC) significantly differ between benign and malignant tumors, which makes this parameter a universal marker of cellular atypia. Dalavia and colleagues [30] have shown the advantages of combining chemical shift and proton MR spectroscopy, providing accurate differentiation of low-lipid adenomas from metastases, while Feng et al. [27] demonstrated the effectiveness of subtraction methods for increasing image contrast and detecting microfocus lesions.

Domestic research in recent years also reflects the growing interest in the use of magnetic resonance imaging in the diagnosis of adrenal tumors. So, Magamedova S.S. et al. [1] demonstrated the high diagnostic value of multiparametric MRI in differentiating between adenomas and metastatic lesions of the adrenal glands, showing the importance of a combination of chemical shift, diffusion-weighted images and dynamic contrast enhancement. In the work of A.V. Arablinsky and Y.V. Sidorova. [2] emphasized the role of MRI as a noninvasive method of clarifying the diagnosis of adrenal diseases, especially in clinically complex and ambiguous cases. The presented domestic data are consistent with the results of foreign studies and confirm the expediency of introducing a multiparametric MR approach into routine clinical practice. Generalized data from modern domestic and foreign studies reflecting the diagnostic significance of various MR parameters are presented in Table 1.

Further research by Delivanis et al. [39] showed that the combination of non-amplified MRI with PET/CT and parametric DWI analysis increases the accuracy of classification of adrenal incidents by up to 94%, and Hekimsoy et al. [37] demonstrated reproducibility of results using high-field tomographs of 3 T. Barat and colleagues [16, 17] focused on the introduction of artificial intelligence and machine learning for automated evaluation of parametric maps, which ensures standardization of analysis and reduction of the subjective factor in data interpretation.

Thus, multiparametric MRI is a key direction in the modern differential diagnosis of adrenal tumors. The combination of chemical shift, DWI, and DCE data makes it possible to quantify the structure, cell density, and perfusion characteristics of the formation, ensuring high differentiation accuracy and forming the basis for a personalized approach in oncoendocrinology. [10, 11, 27, 29].

INTEGRATION OF MULTIPARAMETRIC MRI WITH ARTIFICIAL INTELLIGENCE AND RADIOMICS METHODS

Modern deep learning models, originally developed for natural image analysis, have been modified to integrate with multiparametric MRI (MP-MRI) data, which provided highly accurate identification and localization of adrenal lesions by combining radiomic features and artificial intelligence (AI) algorithms [32, 33].

As shown in the study by Magomedov et al., combining radiomic characteristics with MP-MRI sequences (T1, T2, DWI, and CE) and convolutional neural networks increases the sensitivity of detecting microstructural changes and improves the differentiation of benign and malignant processes compared with traditional imaging methods [1].

A significant contribution of Oloukoi and colleagues is the development of an integrated diagnostic algorithm combining quantitative radiomic analysis and deep learning models, which made it possible to objectify the assessment of tissue heterogeneity and significantly improve the accuracy of the differentiation of adenomas and adrenocortical carcinomas [3].

Architectures based on convolutional neural networks ResNet and VGG, as well as feature pyramid detectors (FPN) integrated with radiomic descriptors of texture and shape, provide increased stability of analysis to variations in scanning protocols and create prerequisites for standardization of visual stratification of adrenal tumors [34].

An additional advantage is demonstrated by the combination of radiomics methods with single-stage detectors such as FCOS and RetinaNet, which perform automatic extraction of quantitative features from areas of interest (ROI), minimizing the subjectivity of manual segmentation and increasing diagnostic reproducibility [35].

According to Barat et al., it is the integration of AI with multiparametric MRI that is the key direction in the evolution of radiation diagnostics, since it provides the formation of explicable radiome maps reflecting the spatial heterogeneity and biophysical properties of tumor tissue [25].

Therefore, the combination of MP-MRI, radiomics, and deep learning technologies forms a new paradigm in adrenal imaging — the transition from descriptive to quantitative and analytical radiology, where the construction of predictive and interpretable models becomes the basis for personalized diagnosis and risk stratification [1, 10, 25].

THE CLINICAL SIGNIFICANCE AND PROSPECTS FOR THE DEVELOPMENT OF the MULTIPARAMETRIC MRI METHOD

Continuing to consider the integration possibilities of multiparametric MRI with artificial intelligence and radiomics methods, it is necessary to emphasize that the practical significance of these technologies is manifested primarily in the clinical context - in preoperative planning, monitoring of therapy and standardization of diagnostic approaches. According to Halefoglu et al., the use of MP-MRI makes it possible to clarify the degree of tumor invasion and topographic relationships with surrounding structures, which significantly increases the accuracy of surgical tactics in adrenal tumors [36].

A study by Hekimsoy et al. It has shown that quantitative indicators of diffusion and perfusion obtained by MP-MRI make it possible to predict the tumor response to drug therapy and radiosurgery, which makes this method indispensable in dynamic monitoring and evaluation of treatment effectiveness [37]. According to the results of Ramamurthy et al., the integration of DWI and DCE functional parameters into a comprehensive analysis model makes it possible to objectively monitor tumor regression without the need for invasive intervention, which is especially important for patients with high surgical risk [38].

The problem of standardization of MP-MRI protocols remains one of the most urgent. Works by Kataoka et al. and Cao et al. They emphasize the need to unify pulse sequences, contrast parameters, and quantitative analysis algorithms to ensure comparability of data between different centers and tomographs [18, 19]. In addition, studies by Huang et al. It is demonstrated that the creation of international classification systems for visual and quantitative signs of adrenal

formations (including radiomic profiles) will make it possible to proceed to the formation of standardized diagnostic scales similar to PI-RADS or LI-RADS [32].
According to Adam et al., the introduction of MP-MRI into routine clinical practice requires not only technical unification, but also interdisciplinary interaction between radiologists, endocrinologists, and surgeons to form a unified algorithm for interpreting and making clinical decisions [42].
Thus, the prospects for the development of the method are associated with the transition from descriptive radiology to a quantitative, analytical and personalized approach, where MP-MRI acts not only as a diagnostic tool, but also as a platform for predictive modeling and therapeutic control [36-42]. Further development of the technology is seen in the integration of multiparametric data with multiomic and clinical indicators, which will allow the formation of complex predictive models for risk stratification and the choice of optimal therapy. Thus, MP-MRI becomes an integral part of the concept of precision medicine, opening up opportunities for individualized management of patients with adrenal tumors and improving the effectiveness of oncoendocrinological care.

CONCLUSION

The analysis of domestic and foreign studies has confirmed that multiparametric magnetic resonance imaging (MP-MRI) occupies a key place in the modern diagnosis of adrenal tumors, providing high accuracy in differentiating benign and malignant tumors. The combination of chemical shift imaging, diffusion-weighted imaging (DWI), and dynamic contrast-enhanced MRI (DCE-MRI) sequences allows not only to detail the morphological structure of a lesion, but also to quantify its functional and molecular-associated characteristics, including cellular density, perfusion, tissue heterogeneity, and lipid saturation.
Quantitative biomarkers such as ADC and contrast accumulation parameters are of particular importance, reflecting the biophysical properties and metabolic activity of the tumor tissue. The use of radiomic analysis and artificial intelligence algorithms contributes to the objectification of image interpretation, automation of diagnostics, and the formation of reproducible risk stratification models.
Due to this, MP-MRI becomes not only a method of visual diagnosis, but also a tool for molecular imaging and prognostic modeling, which is especially important in preoperative planning, monitoring the effectiveness of therapy and dynamic patient monitoring. The possibility of noninvasive assessment of interstitial heterogeneity and potential biological aggressiveness of the tumor expands the prospects for a personalized approach in oncoendocrinology.
At the same time, for the widespread introduction of the method into clinical practice, standardization of research protocols, unification of quantitative parameters and the development of international diagnostic scales are necessary. This will improve the reproducibility of the results and ensure the integration of multiparametric MRI into the concept of precision medicine.
Thus, multiparametric MRI is not only a modern highly informative method for the diagnosis of adrenal tumors, but also a promising platform for the development of personalized and molecular-oriented oncoradiology.

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Contribution of the authors
The authors have made an equal and significant contribution to the collection of empirical data, their processing and the writing of the article.

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