

Combined Multimodal Clinical And Radiological Model For Classifying Soft Tissue Tumors

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Abstract

Soft tissue tumors (STTs) represent a heterogeneous group of mesenchymal neoplasms ranging from benign lesions to highly aggressive sarcomas. Accurate preoperative classification is essential for guiding biopsy planning, surgical strategy, and systemic therapy. However, conventional diagnostic workflows—based on clinical assessment and imaging interpretation—often face limitations due to overlapping morphological features across tumor subtypes.

A combined multimodal clinical and radiological model aims to improve diagnostic performance by integrating structured clinical data (e.g., age, sex, tumor location, growth rate, symptom duration, laboratory parameters) with advanced radiological features derived from imaging modalities such as MRI, CT, and occasionally PET. Radiological inputs may include conventional imaging characteristics (size, margins, signal intensity, contrast enhancement patterns) as well as quantitative radiomic features capturing tumor texture, shape, and heterogeneity.

Keywords: Soft tissue tumors; Soft tissue sarcoma; Benign and malignant differentiation; Ultrasonography; Magnetic resonance imaging (MRI); Multimodal imaging; Machine learning; Artificial intelligence; Logistic regression; LASSO regression; Predictive modeling; Scoring system; Malignancy index; ROC analysis; Diagnostic accuracy; Sensitivity and specificity; Clinical decision support system; Radiologic risk stratification; Multimodal diagnostic model; Radiation diagnostics.

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1. Introduction

Ultrasonography is the primary visualization modality in the diagnosis of soft tissue tumors. However, its main limitation is operator-dependence, due to which, in traditional recognition based on image characteristics, errors can be made in differentiating benign and malignant MTOs. Moreover, the phenomenon of

overlapping of graphical features is often observed in benign and malignant MTO. Our research has shown that the creation of an ultrasonographic scoring model for MTO classification using the machine learning method significantly improves the differential diagnostic capabilities of ultrasound. However, despite the excellent quality of the model (AUS=0.935), the accuracy was 80%, due to the relatively high number of errors in our

data of 20.0%, which we attribute to the lower resolution of the ultrasonic method in deep-section MTO.

The MRI scoring model proved to be more accurate compared to sonography in the nature of MTO differentiation (AUS= 0933, accuracy 84.5%), which can be explained by the better tissue contrast of magnetic resonance imaging. At the same time, the number of erroneous predictions was 15.5%.

Since both visualization modes were performed in all 121 patients with MTO, initially ultrasonography followed by MRI, it became possible to study the influence of ultrasound and MRI combinations on the effectiveness of predicting the benign or malignant nature of visualized soft tissue formations. For this purpose, using the machine learning method, a combined ultrasound + MRI scoring model for predicting the benign or malignant nature of the visualized MTO was developed. The model was developed based on a database containing 23 features, including one clinical (patient age), 11 ultrasonographic, and 11 MRI features. Of the total number of 23 signs, three were continuous semantic features - the patient's age, maximum diameter of the formation, all remaining 20 signs were semantic features described during visual assessment of ultrasound and MRI images.

During machine learning, LASSO regression was used to reduce the feature space, and a predictive combined model was created using multiple logistic regression. As independent variables predictors of the machine model, 7 of the 23 analyzed signs were selected, including 1 clinical sign - the age of the examined person; two ultrasonographic signs - the type of formation and the degree of vascularization in DIC; four MRI signs - the

contours of the formation, the intensity of the T1VI MRI signal, changes in adjacent soft tissues, and regional lymphadenopathy. Model constructed by the following regression equation.

$$Y = 1 / (1 + \exp (- (-10.51 + 2.92 \times X1 + 2.95 \times X2 + 0.057 \times X3 + 3.99 \times X4 + 0.91 \times X5 - 1.71 \times X6 + 16.64 \times X7))), \text{ where:}$$

Y- malignant neoplasm index

X1 - type of formation;

X2 - degree of vascularization according to CDC data;

X3 - patient's age;

X4 - formation contours;

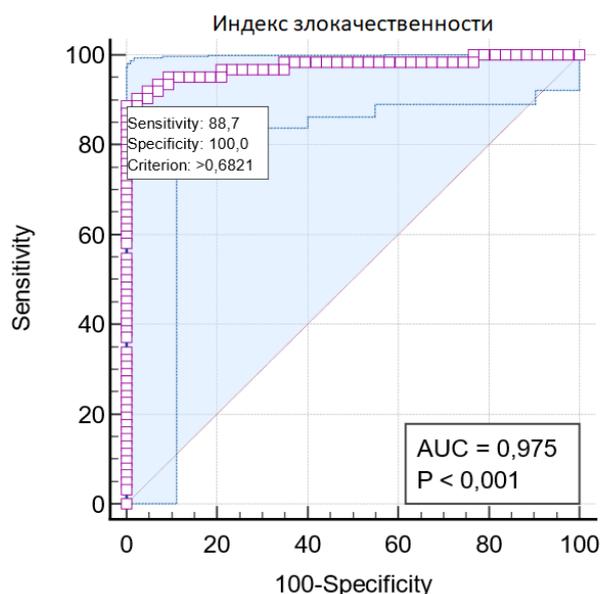
X5 - state of regional lymph nodes;

X6 - signal characteristics on T1,VI;

X7 - presence of muscle invasion.

Each predictor trait was presented with its own coefficient corresponding to the degree of significance of the trait.

To quantitatively analyze the diagnostic effectiveness of the constructed prognostic model, a ROC analysis (Receiver Operating Characteristic) was conducted, which allows for assessing the balance between sensitivity (true positive rate) and specificity (true negative rate) at different values of the probability threshold. The ROC curve reflects the model's ability to distinguish between two classes - in this case, benign and malignant tumors.



On the ROC curve graph, the combined model demonstrates a confident approach to the upper left corner, reflecting the simultaneous achievement of high sensitivity (88.7%) and absolute specificity (100%) at the optimal threshold > 0.6821. This behavior of the curve confirms the excellent discriminatory ability of the model, which is especially valuable in clinical oncology, where a mistake towards a false positive result can lead to unnecessary invasive interventions, and a false negative result can delay treatment.

The conducted research has shown that the potential capabilities of the multi-mode method for diagnosing soft tissue tumors, which has many advantages, have not yet been fully revealed. The involvement of machine learning with artificial intelligence algorithms has significantly improved the diagnostic and prognostic capabilities of the ultrasound method, reducing the influence of the subjective factor on the final research result.

A significant advantage of the machine learning method for developing multimodal scoring models is their easy integration into practice, as the predictors of the model are sonographic and MRI signs, which are part of the standard description protocols used by radiation diagnostics physicians in their daily practice.

ROC analysis demonstrated the high accuracy of the proposed model, confirming its suitability for practical application and potential use as a semi-automated clinical decision support system.

Comparison of the effectiveness of differentiation between benign and malignant MTOs using the machine learning method, ultrasonographic, MRI, and combined (ultrasound + MRI) semantic models is presented in the following table (Table 5.1).

Indicators of the effectiveness of predicting the nature of visualized soft tissue tumors using machine learning, semantic predictive ultrasonographic, MRI, and combined models

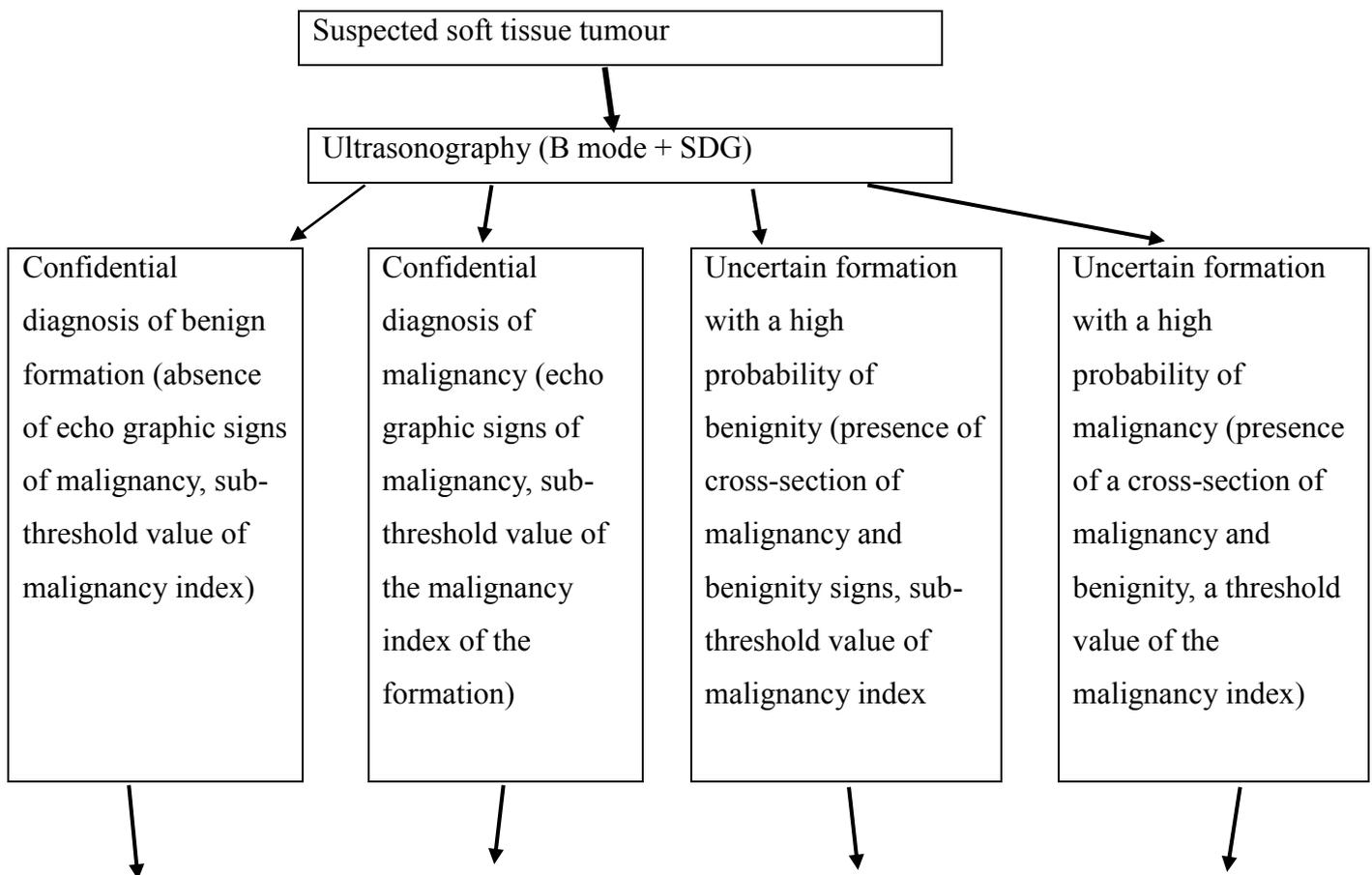
Predictive model	AUS (M±m) 95% confidence interval	Sensitivity (%)	Specificity (%)	Accuracy (%)
ultrasound	0.905 ± 0.027 (0.832 - 0.953)	72.3	92.5	80.0
MRI	0.933 ± 0.023 (0.864 - 0.973)	84.2	85.7	84.5

Combined ultrasound + MRI	0.975 ± 0.014 (0.924 - 0.996)	88.7	100.0	93.3
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From the data presented in the table, it can be seen that the effectiveness of modality visualization increases significantly when predictive models for the differentiation of benign and malignant MTOs are created based on subjectively assessed image features. With the use of the developed ultrasonographic model, the number of patients with a confidential diagnosis of benign or malignant MTO increases from 64% to 80%; with MRI modeling - from 66% to 84.5%. The predictive model, created on the basis of a combination of ultrasonographic and MRI signs, including the clinical process of the examined person's age, allows for a very high accuracy in predicting the nature of the visualized formation - 93.5%, comparable to those achieved with

classification models created by in-depth learning with convolutional neural networks.

The developed ultrasonographic, MRI, and combined models significantly increase the effectiveness of risk stratification for malignant soft tissue tumors, optimize the tactics of using visualization methods at the stages of patient examination. For example, the use of multimodal radiation diagnostics is justified for malignant or undetermined MTO, whereas in most cases, in benign tumors, it is possible to limit oneself only to ultrasonography with the determination of the malignancy screening index along with the assessment of the visualized signs (Fig. 5.1)



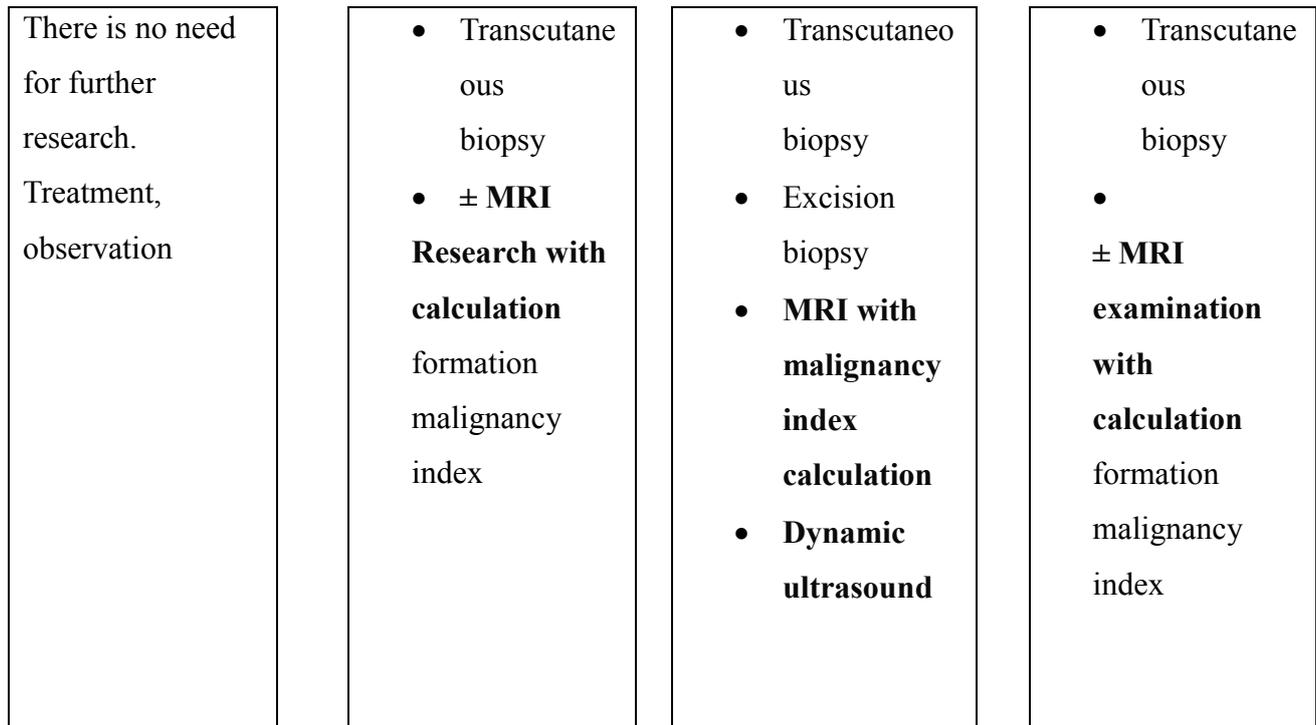


Figure 5.1. Radiation diagnostics algorithm for soft tissue tumors

2. Conclusion

Soft tissue tumors are a heterogeneous group of benign and malignant neoplasms of mesenchymal origin, characterized by a significant diversity of histological forms. This pathology is more common in men, and its prevalence increases with age. At the same time, benign tumors predominate, with a frequency of about 300 cases per 100,000 population, while malignant tumors are detected in approximately 50 cases per 100,000 people annually, which corresponds to only 1% of all malignant neoplasms [4, 5, 123].

Malignant OMT is characterized by high aggressiveness, unfavorable clinical course, and prognosis. Soft tissue sarcomas are characterized by a persistent tendency to recurrence and rapid hematogenous metastasis, which significantly worsens treatment outcomes and often leads to a fatal outcome.

A key factor in the successful treatment of OMT is the timeliness and accuracy of diagnostics, which ensures earlier detection of the tumor and allows for the initiation of optimal therapy [149].

Ultrasound examination (US) plays an important role in the diagnosis of soft tissue formations due to its accessibility, cost-effectiveness, non-invasiveness, speed

of execution, and applicability in children (Hurg, Griffin, 2014). The method is effective for the primary detection of neoplasms, assessment of their localization, shape, size, structure, presence of liquid components, and characteristics of the vascular bed. A number of studies have demonstrated the diagnostic significance of such features as large size, invasion into surrounding tissues, heterogeneous signal amplification, and changes in vascularization in the differentiation of benign and malignant tumors (Veimadian, Pchelin, 2014; Frolova et al., 2015; Nagano et al., 2015; de Marchi et al., 2015). Works by Morii et al. (2018), Schmit et al. (2024) confirmed the potential of ultrasound and MRI in differentiating sarcomas of low and high malignancy. However, in real clinical practice, conventional ultrasound is still rarely used to determine the nature of the tumor and its malignancy.

The ultrasound method allows for a detailed assessment of the characteristics of the formation - its size, contours, echogenicity, depth of location, degree of vascularization, as well as the condition of adjacent soft tissues and bone structures. Nevertheless, there are three main problems that limit its accuracy. Firstly, a number of benign and malignant tumors can have a similar ultrasound picture, making it difficult even for experienced specialists to differentiate between them.

Secondly, ultrasound is a highly operator-dependent method, which can lead to data variability and errors. Thirdly, assessment is primarily based on subjective visual analysis and recognition of image patterns. Similar difficulties, although less pronounced, are observed when performing MRI.

Significant progress in data analysis and artificial intelligence technologies opens up new possibilities for diagnosing soft tissue tumors, including the creation of classification models based on both quantitative and qualitative image parameters. However, the use of such approaches in ultrasound and MRI diagnostics of OMT is still at an early stage of development (Long et al., 2023; Zhang et al., 2024).

The limitation of ultrasound in the differentiation of malignant and benign tumors is associated with frequent overlap of sonographic features characteristic of both groups (Wu, Hochman, 2009). In such cases, MRI, having a higher soft tissue resolution, allows for better assessment of the formation structure and its relationship with surrounding tissues and bone elements (Gjyal et al., 2023). Nevertheless, according to Griffin (2023), MRI does not always improve diagnostic accuracy with uncertain ultrasound data and should primarily be used to solve specific tasks that are not available for ultrasound, such as assessing the involvement of vascular-nervous structures or excluding bone destruction. At the same time, comparative studies of the diagnostic effectiveness of ultrasound and MRI on the same clinical material remain rare (Ormen et al., 2015; Jacobson et al., 2012; Shu et al., 2022).

The task of developing clear quantitative criteria for differentiating malignant and benign soft tissue tumors, as well as dividing sarcomas by malignancy degree based on ultrasound and MRI data, remains unresolved. In a few studies, scoring systems based on scoring for significant traits have been proposed, however, the used logistic regression models include a fixed set of indicators and do not consider the problem of their mutual collinearity. Ignoring the dependence of characteristics reduces the reliability and generalizability of the model, increasing the risk of its overstimulation.

A potentially more effective approach is the application of machine learning methods that allow for the automatic selection of not only relevant but also independent parameters, as well as the formation of sustainable predictive models. However, such developments in the diagnosis of soft tissue tumors based on ultrasound and

MRI are still extremely rare and are presented only in individual studies (Hu & Zhou, 2021; Ghanium & Alneamy, 2023; Log et al., 2023).

In connection with the above, the purpose of this dissertation research is to increase the effectiveness of radiation diagnostics of soft tissue tumors by creating and implementing ultrasonographic and MRI scoring models developed based on machine learning algorithms.

At the same time, the following tasks were solved:

1. Study the possibilities of conventional ultrasonography and MRI in differentiating benign and malignant soft tissue tumors.
2. Develop ultrasound models using machine learning and artificial intelligence algorithms to predict the benign and malignant nature of soft tissue formations.
3. Develop scoring models for predicting the benign and malignant nature of soft tissue formations using machine learning and MRI artificial intelligence algorithms.
4. Provide a comparative assessment of the diagnostic effectiveness of ultrasound and MRI in soft tissue sarcomas.

To implement the first task, we conducted a comprehensive analysis of the diagnostic informativeness of routine visual signs, assessed according to ultrasound and MRI data. In the process of visual assessment of 12 echographic parameters, it was established that most traditional ultrasound criteria, including size, depth of location, type of formation, contours, echogenicity, and degree of vascularization, occur with varying frequency in both benign and malignant tumors. Significant overlap in sonographic characteristics did not allow for the use of these features as reliable independent diagnostic criteria and made it difficult to form a definitive conclusion about the nature of the soft tissue formation based on the visual picture.

At the same time, the analysis of MRI data confirmed that, despite the high soft tissue contrast, this method also does not provide full confidence in the differentiation of uncertain formations detected during ultrasound examination, which agrees with literature data. Thus, it was confirmed that the possibilities of conventional ultrasonography and MRI in independent differential diagnostics are limited and require increased accuracy through the use of quantitative and formalized analysis methods.

To overcome these limitations, ultrasound and MRI predictive models based on machine learning using a reverse selection algorithm for traits were developed. For the ultrasound predictive model, a comprehensive analysis of 12 echographic parameters was conducted, which allowed for the identification of two statistically independent and clinically significant predictors - the type of formation and the degree of vascularization according to CDH data. Based on them, a logistic scoring model for determining the malignancy index of soft tissue tumors was created.

The high diagnostic effectiveness of the developed model was confirmed by ROC analysis: AUC was 0.926 ± 0.022 , sensitivity - 77.1%, specificity - 94.1%, total prediction accuracy - 84.3%, which indicates a significant advantage of the model over simple visual assessment.

The practical simplicity of the developed model gives it special value: both included predictors are easily evaluated in standard ultrasound studies and do not require special programs or additional equipment.

The obtained results show that conventional ultrasonography using a machine-learned scoring model has significantly higher diagnostic value in differentiating benign and malignant soft tissue tumors. This indicates the expediency of integrating predictive analysis and machine learning methods into the standard algorithm for radiation diagnostics of OMT.

A similar machine learning algorithm was also used to construct an MRI predictive model based on visualized features of conventional MRI research. At the first stage, all key MRI characteristics of soft tissue tumors were categorized and included in the multidimensional analysis process, which allowed us to assess their contribution to the differentiation of benign and malignant neoplasms. Using selection methods that minimize redundancy and collinearity of variables, an optimal combination of independent predictors was formed.

As a result of machine selection, the most significant MRI parameters with high discriminatory ability were identified: the nature of tumor contours, edge type, presence or absence of enlarged regional lymph nodes, features of the MR signal in T1- and T2-weighted images, tumor structure, as well as its shape. Based on these seven independent predictors, a logistic regression model for calculating the malignancy index of soft tissue

formation was constructed. The obtained model allows for the calculation of an integral indicator - the malignancy index, which reflects the probability of the visualized formation belonging to the group of malignant soft tissue tumors. The predictor values in the equation reflect the strength and direction of influence of each trait: for example, the presence of uneven or infiltrative contours, pronounced structural heterogeneity, as well as an incorrect form of formation significantly increased the malignancy index. Conversely, hyperintensity in T1- or T2-weighted images and uniform edges of the formation were associated with a decrease in the likelihood of the malignant process, which corresponds to the characteristic MR signs of benign soft tissue tumors.

The constructed model underwent a comprehensive performance evaluation using ROC analysis, which allowed for the quantitative determination of its diagnostic significance. The high AUC value, along with favorable sensitivity, specificity, and predictive accuracy indicators, confirmed the reliability of the developed instrument as a non-invasive preoperative differentiation method for soft tissue neoplasms.

Thus, the application of machine learning algorithms to the analysis of conventional MRI signs allowed for the creation of a diagnostic model that surpassed subjective visual assessment in effectiveness. The developed MRI scoring system is a logical complement to the ultrasound model and makes a significant contribution to increasing the reliability of radiation diagnostics of soft tissue tumors, opening up prospects for standardization and personalization of the diagnostic process.

One of the important tasks of our research was to provide a comparative assessment of the diagnostic effectiveness of ultrasound and magnetic resonance imaging in soft tissue sarcomas. The analysis showed that each of the methods has a certain informativeness, however, their diagnostic value increases significantly when using a comprehensive approach that combines the visual features of ultrasound and MRI into a single predictive system.

Within the framework of this study, an integrated model for calculating the malignancy index of soft tissue tumors was formed, including the most significant predictors identified both during ultrasound examination and MRI. The obtained set of parameters allowed for the creation of a unified diagnostic tool that surpassed each methodology individually in accuracy. The effectiveness of the combined approach is confirmed by the results of

ROC analysis.

According to the obtained data, the integrative model demonstrated exceptionally high diagnostic effectiveness, which is reflected by the area under the ROC curve $AUC = 0.975$, $p < 0.001$. This indicator indicates a practically optimal ability of the combined malignancy index to distinguish between benign and malignant soft tissue tumors.

The optimal classification threshold was > 0.6821 , where the model's sensitivity reached 88.7%, and the specificity reached 100%. Such a level of specificity indicates that the combined approach completely excluded false-positive results, which has important clinical significance for choosing treatment tactics and preventing excessive interventions.

The obtained results demonstrate that combining echographic and MR-tomographic predictors into a single logistical model allows for a significant increase in diagnostic accuracy compared to subjective visual assessment of images or the separate use of ultrasound or MRI. High sensitivity is ensured by a comprehensive characterization of the morphological features of tumors, and high specificity is provided by the consistency and complementarity of features determined by various methods of radiation imaging.

Thus, the comparative assessment showed that the combined use of ultrasound and MRI with the calculation of the combined malignancy index provides the highest level of diagnostic reliability. The integrative model is an effective tool for improving the accuracy of differentiation between benign and malignant soft tissue tumors, making it promising for widespread implementation in clinical practice.

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