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字数 4882

提交时间 27-6月-2023 11:30上午

论文 ID 100818249

Name of Journal: *World Journal of Radiology*
Manuscript NO: 85238
Manuscript Type: MINIREVIEWS

Progress of magnetic resonance imaging radiomics in preoperative lymph node diagnosis of esophageal cancer

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Abstract

Esophageal cancer, also referred to as esophagus cancer, is a prevalent disease in the cardiothoracic field and is a leading cause of cancer-related mortality in China. Accurately determining the status of lymph nodes is crucial for developing treatment plans, defining the scope of intraoperative lymph node dissection, and ascertaining the prognosis of patients with esophageal cancer. Recent advances in diffusion-weighted imaging and dynamic contrast-enhanced magnetic resonance imaging (MRI) have improved the effectiveness of MRI for assessing lymph node involvement, making it a beneficial tool for guiding personalized treatment plans for patients with esophageal cancer in a clinical setting. Radiomics is a recently developed imaging technique that transforms radiological image data from regions of interest into high-dimensional feature data that can be analyzed. The features, such as shape, texture, and waveform, are associated with the cancer phenotype and tumor microenvironment. When these features correlate with the clinical disease outcomes, they form the basis for specific and reliable clinical evidence. This study aimed to review the potential clinical applications of MRI-based radiomics in studying the lymph nodes affected by esophageal cancer. The combination of MRI and radiomics is a powerful tool for diagnosing and treating esophageal cancer, enabling a more personalized and effectual approach.

Key Words: Esophageal cancer; Diffusion-weighted imaging; Dynamic contrast-enhanced imaging; Radiomics; Lymph nodes

Xu YH, Lu P, Gao MC, Wang R, Li YY, Song JX. Progress of magnetic resonance imaging radiomics in preoperative lymph node diagnosis of esophageal cancer. *World J Radiol* 2023; In press

Core Tip: Precise TNM staging is crucial for developing effective treatment plans for esophageal cancer. Establishing whether esophageal cancer has lymph node metastasis before surgery remains a significant clinical challenge. However, with the continuous advancement of radiomics, high-quality clinical decision support systems have emerged, enabling more accurate determination of preoperative lymph node status in esophageal cancer. This breakthrough may lead to formulating treatment plans that adhere to individualized medical guidelines.

INTRODUCTION

According to statistical studies, esophageal cancer is a prevalent malignant tumor of the digestive system, ranking seventh in incidence and sixth in mortality worldwide[1,2]. Endoscopic therapy, chemotherapy, and surgical resection are the primary treatments for esophageal cancer, with surgery being the leading treatment method for early-stage esophageal cancer[3]. Lymph node metastasis is an important prognostic factor in surgically treatable esophageal cancer[4-6]. While lymphatic spread in esophageal cancer is highly variable, positive lymph nodes should be resected along with the tumor to improve long-term survival[7,8]. However, extended lymph node resection may increase postoperative complications and worsen the prognosis of patients with esophageal cancer. Therefore, accurate lymph node evaluation is essential for developing an appropriate treatment strategy.

Magnetic resonance imaging (MRI) is more definitive than other imaging modalities in detecting positive lymph nodes in cancer and has been increasingly used in studying esophageal squamous cell carcinoma at the T and N stages[9-13]. Additionally, radiomics has gained momentum in cancer research over recent years[14]. Radiomics can quantify inter- and intratumor heterogeneity, accurately determine the status of preoperative lymph nodes in esophageal cancer and provide a better basis for clinical decisions regarding treatment options for esophageal cancer[15]. This paper reviews the research and applications of MRI, radiomics, and combined imaging techniques to determine the status of lymph nodes in esophageal cancer.

METASTATIC FEATURES OF ESOPHAGEAL CANCER LYMPH NODES AND THEIR IMPACT ON TREATMENT

Esophageal cancer commonly metastasizes to the lower neck, upper mediastinum, and perigastric area[16,17]. The lymph node metastasis rate (LNMR) primarily depends on the location and depth of tumor infiltration[18]. Therefore, certain lymph node regions, such as the cervical segmental paraoesophageal LN, the laryngeal recurrent nerve LN, and the LN along the left gastric artery, have a high LNMR[16].

Since the prognosis of patients with esophageal cancer mainly depends on the extent of the primary tumor and the lymphatic spread of the disease, lymph node status is a crucial prognostic factor[19,20]. Thus, clarifying the extent of lymph node dissection during surgical treatment is important for the prognosis of esophageal cancer. Tong and Kim et al. have demonstrated that patients with esophageal cancer with lymph node metastasis have a lower 5-year survival rate[19,21-23]. The lymph node ratio (absolute number of lymph nodes removed compared to the number of lymph nodes involved) in postoperative patients was an independent predictor of overall survival. Similar studies have indicated that residual lymph node metastasis after treatment is a critical indicator for assessing survival[24]. Therefore, an accurate assessment of the extent of lymph node metastasis in esophageal cancer provides an objective basis for clinical treatment planning and a reference value for patient regression after treatment.

The treatment options for esophageal cancer primarily depend on the TNM stage of the patient. According to Mönig *et al*[17] endoscopic resection is the recommended treatment for early superficial submucosal invasive carcinoma without histologic risk factors such as lymphatic or vascular infiltration. However, the rate of lymph node metastasis in submucosal carcinoma increases with the depth of infiltration. Therefore, the current gold standard of treatment for esophageal cancer is transthoracic subtotal esophagectomy and double field lymph node dissection[25].

The extent of lymph node dissection in esophageal cancer remains controversial[26]. A randomized study found no significant improvement in long-term survival with expanded transthoracic surgery in esophageal adenocarcinoma[27,28]. Meanwhile, Lordick *et al*[29] concluded in their discussion of early management of esophageal cancer that surgery is considered standard of care for disease without suspected lymph node involvement (T1-2 N0 M0), and if lymph node involvement of disease is suspected (T1-2 N1-3 M0), patients are recommended to undergo preoperative treatment. Only after evaluation without involvement of lymph nodes should surgery be considered. Therefore, accurately diagnosing preoperative lymph nodes remains a challenge to be addressed.

RESEARCH PROGRESS OF MRI IN LYMPH NODES OF ESOPHAGEAL CANCER

After the diagnosis of esophageal cancer is confirmed by endoscopy and biopsy, staging is crucial for treatment and prognosis. Traditional examination methods, including endoscopic ultrasound (EUS) and CT, play an important role in determining T stage, invasiveness of surrounding structures, and detecting distant metastases[30,31]. Recent studies have shown that 18F-fluoro-2-deoxyglucose positron emission tomography (FDG-PET/CT) examination is also valuable in detecting distant metastases[32]. However, EUS, CT, and FDG-PET(/CT) have limitations in detecting lymph node involvement, which is an important independent predictor of long-term survival in patients[33].

CT scans are commonly used as a non-invasive method to assess metastatic infiltration of esophageal cancer lymph nodes. In CT diagnosis, intra-thoracic lymph nodes with a short diameter greater than 10 mm are considered metastatic lymph nodes. However, some studies have shown that only a small percentage of metastatic lymph nodes in esophageal cancer have a short diameter greater than 10 mm[33,34].

Furthermore, a related study found that although the sensitivity of CT was 59% in detecting lymph nodes larger than 10 mm in the conventional lymph node region of esophageal cancer, the diagnostic value of lymph nodes with metastasis was still insufficient[35]. Measuring the long and short axis diameters of lymph nodes in each region of esophageal cancer in CT images and calculating the axis ratio could improve the sensitivity of CT detection of lymph node metastasis in esophageal cancer. However, the sensitivity, specificity, and accuracy of this approach are still insufficient to provide high-quality clinical decision support systems[36].

MRI is superior to CT in terms of soft tissue resolution and can accurately detect differences in water content in tissues. Its images are unique in their ability to discriminate between masses, lymph nodes, and vascular structures from each other. MRI has multi-sequence imaging and multiple image types, and can generate images from multiple levels (cross-sectional, sagittal, coronal, and various oblique views) at will, reducing the artifacts of soft tissue boundaries in the images and providing richer imaging information to clarify the nature of the lesion. Although MR imaging modalities primarily focus on morphologic changes and provide less functional information about the tumor and are not the preferred method for staging, recent studies have shown that with the technical development of diffusion-weighted imaging (DWI), dynamic contrast-enhanced (DCE)-MRI, and IVIM, MR is progressively more accurate than CT in determining resectability, mediastinal invasion, and especially lymph node involvement[37].

DWI can provide information on tissue structure and cell density by reflecting the measured apparent diffusion coefficient (ADC) of water molecule mobility, and this quantitative metric is considered a meaningful imaging biomarker in esophageal

studies[38]. Since its introduction into clinical practice, DWI has been widely used to detect lymph node metastasis in various primary malignancies and is a successful method[39]. In a prognostic study of esophageal cancer treatment, Giganti *et al*[38] found that pathological ADC could be considered a prognostic factor in esophageal cancer, and DWI may become a promising and reliable diagnostic technique for esophageal cancer. Sakurada et al. also found that the DWI-MRI imaging technique is important in determining the lymph node status of patients with esophageal cancer by visualizing lymph nodes and performing ADC value measurement[40]. In a quantitative analysis study by Alper *et al*[34] it was found that the STIR sequence improved the detection of metastatic lymph nodes with a sensitivity of 81.3% and a specificity of 98.3%, which is consistent with the findings of the group. While the diagnostic performance of DWI and PET for lymph nodes is controversial, the study by Shuto *et al*[39] concluded that DWI showed a higher sensitivity than PET in terms of diagnostic performance of lymph nodes. Given the association between lymph node status and prognosis in esophageal cancer, we believe that DWI is a predictive modality for survival after surgery in patients with esophageal cancer.

DCE-MRI has proven useful as a functional MRI modality in assessing vascular perfusion for monitoring and predicting response to radiotherapy. The histogram analysis established in DCE-MRI is a means of extracting heterogeneous parameters from significant regions (ROI) and whole-tumor analysis of samples from the entire tumor parenchyma and interstitium that can provide a more accurate quantitative assessment of tumor biology[41]. This technique has improved the diagnostic capability of MRI. In the study by Sun *et al*[42] on radiotherapy for esophageal cancer, the results of different histogram parameters (median, mean, standard deviation, mode, skewness, kurtosis, minimum, maximum, percentile, and entropy) derived from DCE-MRI were compared and found to be useful for the assessment of tumor heterogeneity and monitoring the response to radiotherapy for esophageal cancer. Regarding lymph node status analysis, the findings of Chen *et al*[41] suggest that whole-tumor cumulative histogram analysis obtained from DCE-MRI with pharmacokinetics as a parameter may

be useful for T-staging and regional lymph node status determination in esophageal squamous cell carcinoma. Although the study of lymph node status in esophageal cancer by DCE-MRI is still in its infancy, the available data and results show that DCE-MRI has a high accuracy in determining lymph node status, which is important for developing individualized treatment plans for esophageal cancer.

Recently, the StarVIBE sequence on MRI has been utilized in cases where patients are unable to hold their breath and has gradually been incorporated into studies on esophageal cancer[12,43]. Qu *et al*[44] conducted a study where MRI was shown to better predict lymph node status in patients with preoperative esophageal cancer by extracting the ROI of esophageal cancer lesions. This method demonstrated significantly improved diagnostic accuracy over CT and could facilitate better treatment planning for esophageal cancer. Therefore, MRI shows promise in aiding lymph node assessment in esophageal cancer patients, particularly when CT scans yield inconclusive results. Nevertheless, further research is required to confirm its effectiveness in clinical practice.

While the clinical value of MRI in lymph node diagnosis, treatment evaluation, and prognosis prediction has been gradually recognized, false-positive lymph nodes can also occur on MRI due to interference from cardiac motion and gastric peristaltic artifacts. Moreover, false-negative lymph nodes can also be observed in smokers and patients with pneumoconiosis or silicosis with esophageal cancer[45]. Despite advancements in radiological examination methods, further improvement in the sensitivity of lymph node metastasis determination may still be possible. For instance, the development of new imaging techniques or the integration of multiple imaging modalities could potentially improve the accuracy of lymph node metastasis detection in esophageal cancer patients. Additionally, further studies focusing on the optimization of imaging protocols and the standardization of image interpretation criteria may lead to more accurate and reliable diagnosis of lymph node metastasis.

Process steps of radiomics

Radiomics is the application of computerized mathematical tools to image processing, transforming image data from ROI in radiological images into mineable high-dimensional feature data. The radiological features (*e.g.*, shape, texture, or waveform) extracted from them can provide information about the cancer phenotype as well as the tumor microenvironment[14]. This information is distinct and complementary to other disease-related information, including clinical features, treatment-related decision information, or genomic data[46]. When radiomics-derived data are combined with other relevant data and correlated or extrapolated to clinical disease outcomes, they can produce accurate and reliable clinical decision support systems (CDSS). These CDSS can assist clinicians in making more informed decisions regarding diagnosis, treatment planning, and prognosis prediction for patients with esophageal cancer.

Radiomics refers to the quantitative mapping of medical images, involving the extraction and analysis of numerous image features that are relevant to the study objectives, including clinical treatment decisions and genomic features. Radiomics studies typically encompass five phases, namely data selection, medical imaging, feature extraction, exploratory analysis, and modeling. The analysis of radiomics can be localized in the primary tumor foci, metastatic lesions, or normal tissues or can be applied to any image generated in the clinical setting. Radiomics analysis can provide valuable insights into tumor heterogeneity and microenvironment, which can aid in identifying potential biomarkers for prognosis and treatment response prediction in patients with esophageal cancer. However, further research is necessary to validate the clinical utility of radiomics in esophageal cancer and to establish standardized protocols for radiomics analysis.

Regarding image feature extraction in radiomics, it involves extracting quantitative features from images that represent the volume of interest (VOI), which are eigenvalues of an image that depend on factors such as image preprocessing (*e.g.*, filtering or intensity discretization) and reconstruction (*e.g.*, filtered backprojection or iterative reconstruction)[14]. Delineating the ROI or VOI is a critical first step in any radiomics method. However, manual, and semi-automatic segmentation methods often introduce

observer bias and can be time-consuming. Additionally, inter-, and intra-observer variation in ROI/VOI delineation can affect the reproducibility and stability of radiomics features. Therefore, studies using manual or semi-automatic segmentation with manual correction should evaluate the internal and external reproducibility of derived radiomics features. To ensure result reproducibility, it is advisable to exclude irreproducible features from further analysis. Automating the segmentation process using deep learning techniques has also shown promise in improving the reproducibility and efficiency of ROI/VOI delineation in radiomics studies.

The second step in image processing is a crucial intermediary between image segmentation and feature extraction. Its objective is to standardize the images for radiomics feature extraction, including pixel spacing, grayscale intensities, and gray histogram binning, among other factors. The reliability of test-retest of extracted radiomics features depends on the image processing settings used in this step. Therefore, it is critical to carefully select and optimize the image processing settings to ensure the robustness and reproducibility of radiomics features. The pyRadiomics package, which is one of the most widely used packages for radiomics analysis, allows various image processing steps to be defined through a parameter file in YAML or JSON structured text format. This file can then be loaded into 3D Slicer or integrated into a Python framework to facilitate feature calculation.

After image segmentation and processing, the third step of radiomics feature extraction can be performed. Feature extraction involves calculating feature descriptors to quantify the gray-level features within the ROI/VOI. As there are many ways and formulas to calculate these features, it is recommended to follow the Image Biomarker Standardization Initiative (IBSI) guidelines[47].

The IBSI guidelines provide a consensus for standardized feature calculations from a matrix of all radiomics features. Different types of radiomics features exist, including intensity-based (histogram) features, shape features, texture features, transform-based features, and radial features, with different types of filters (*e.g.*, wavelet or Gaussian filters) usually applied in the feature extraction step. After feature selection/deviation is

performed, subsequent statistical analysis and machine learning will be used to identify the important features that support image analysis. Dimensionality reduction is a multi-step process to exclude irreducible, redundant, and irrelevant features from the dataset. The first step involves excluding non-replicated features, as a feature that has high intra- or inter-observer variability may be less likely to be useful. The second step is to select the most relevant variables for the corresponding task. Various methods that often rely on machine learning techniques can be used for this initial feature selection step, such as elimination filters, recursive feature elimination methods, or random forest algorithms. As these algorithms often cannot account for covariance and correlation in the data, constructing correlation clusters is the logical next step in the dimensionality reduction workflow. In some cases, this step may be combined with the previous (second) step, as few machine learning techniques can handle correlations in the data. Correlation clustering allows the visualization of highly correlated features in the data and the selection of only one representative feature per correlation cluster.

Selecting the variable with the highest bio-clinical variability in the dataset is crucial as it is likely to be the most representative of the variation within a given patient population. Once the dimensionality of the data has been reduced, the importance of the data visualization step increases. Therefore, reducing the number of features used to build statistical and machine learning models through a step called feature selection or dimensionality reduction is critical to generating valid and generalizable results. The remaining uncorrelated and highly correlated features can be used to train models for the corresponding classification tasks, and the constructed radiomics models are evaluated according to the radiomics quality score. These key steps form the basis for ensuring that the imaging histology produces high-quality CDSS.

Progress of CT radiomics in esophageal cancer lymph nodes

When radiomics is involved in tumor exploration, it provides a new approach in the study of cancer patients by developing and validating an imaging-based radiomic columnar map that combines radiomic features and clinical factors in the development

of cancer patients. In the esophageal cancer study discussed in this article, there have been many researchers, in recent years, who have applied radiomics to the study of esophageal cancer, thus showing that radiomics is not a novel technique.

Li *et al*[48] extracted radiomic features from FDG-PET images of 152 patients with esophageal cancer and successfully predicted those patients who would not benefit from preoperative radiotherapy. Qiu *et al*[49] developed and validated a CT-based radiomic columnar map that combined radiomic features and clinical factors to predict the risk of recurrence in patients who underwent surgery after neoadjuvant chemotherapy and achieved a pathologic complete response in patients with esophageal cancer at risk of recurrence. Meanwhile, in terms of lymph nodes, which are the focus of this article, Gu et al. studied 129 sets of lymph nodes from 77 patients in the cohort (trial cohort: 102 lymph nodes from 59 patients; validation cohort: 27 lymph nodes from 18 patients) based on the radiomic features of CT to predict the treatment response and the ability of local control of locally recurrent lymph nodes after radiotherapy esophagectomy[50]. A scoring model based on the location and length of the cancer focus and the size and status of the corresponding lymph node region as revealed by CT allowed for accurate assessment of the status of the lymph nodes, which helped in the development of the surgical approach and accurate intraoperative clearance of the corresponding lymph nodes. Meanwhile, in a case-control study of esophageal cancer, Qu *et al*[44] extracted radiomic features from CT data of 152 patients with esophageal cancer without lymph node metastases and 182 patients with lymph node metastases and found that CT radiologic features could help predict the lymph node status of patients with advanced esophageal cancer and effectively distinguish whether there were regional lymph node metastases in esophageal cancer. Moreover, Tan et al. retrospectively analyzed 230 patients with esophageal cancer who had CT examinations and found that radiomics could help reveal intra-tumor heterogeneity and could be used as a new biomarker to determine LN status in patients with resectable esophageal cancer by using a radiomic column line graph containing 5 features in combination with CT-reported LN status (*i.e.*, size criteria)[51]. This shows

that the CT radiomics model can be applied clinically to assess the lymph node status in patients with esophageal cancer prior to treatment.

Although most current radiomic studies of ESCC are based on CT and PET, preoperative MRI radiologic features are more valuable because MRI is noninvasive and has higher tissue resolution. Qu *et al*[44] 50 of 181 patients with pathologically confirmed esophageal cancer with lymph node metastases, based on T2-TSE-BLADE and StarVIBE enhancement sequences in MRI images. Nine radiographic features were selected to create radiographic features significantly associated with LN metastasis, and the model was found to distinguish well between metastatic and non-metastatic lymph nodes.

Development of MRI radiomics in tumor research

Although most of the current radiomic studies of ESCC are based on CT and PET, with the advancement of MRI techniques such as DWI, DCE-MRI, and IVIM, and the availability of high-quality imaging sequences such as the related StarVIBE and T2_BLADE, MRI has excellent soft-tissue resolution and is more conducive to the mutual discrimination between lesions, lymph nodes, and vascular structures. MRI findings such as the size, morphology, and shape of cancer foci are important for their identification in the study of tumor subtypes[52,53]. In some studies, it has been found that some specific MRI sequences can better detect lesions and aid in treatment selection[53]. The ROI generated from MRI images can be analyzed by imaging histology to extract superior imaging features. These features can be combined with clinically relevant patient information to generate high-quality CDSS to guide treatment planning.

ROI analysis of the primary tumor lesion not only yields key information about the relevant pathology but also has value for the prognostic analysis of patient survival. Shin et al. applied an MRI radiomic model to assess the pathological remission response in rectal cancer patients receiving neoadjuvant radiotherapy and found that the diagnostic value was superior to visual assessment by an experienced radiologist[54].

Meanwhile, Li *et al*[48] extracted radiomic features from T2-weighted MRI images and combined them with clinical data for deep machine learning, which stably predicted the survival of glioma patients and helped to preoperatively assess the extent of macrophage infiltration in glioma tumors[55].

Although there is increasing interest in MRI radiomics in various areas of oncology across studies, most of the studies have focused almost exclusively on the histological and radiomic features associated with the primary tumor. It is well-known that histopathological data of the primary tumor, such as lymph-vascular invasion, histological grading, and tumor markers, are important factors used to guide or determine clinical treatment decisions. Meanwhile, when MRI radiomics is focused on the diagnosis of preoperative lymph node status, its high-quality diagnostic results can further guide treatment decisions in the clinical setting. In a study by Domiziana et al., they found 3T MRI radiomics combined with histological data could predict preoperative lymph node metastasis in breast cancer patients and guide treatment planning. The results suggest that accurate prediction of lymph node status can avoid invasive surgery, such as lymph node dissection or biopsy[56]. Similar conclusions were reached in studies on the prediction of preoperative lymph node status in breast cancer, suggesting that the influential features of MRI radiomics are important for the determination of lymph node status[57-59].

It is worth noting that while the image features derived solely from the ROI of cancer foci can be used to analyze the status of lymph nodes, the CDSS obtained from both the ROI of lymph nodes and cancer foci is more clinically valuable when combined for imaging histological analysis. In Li et al.'s study, they combined the ROIs of both primary colon cancer lesions and lymph node lesions for imaging histological analysis, and their findings were even more convincing because they required the analysis of both cancer lesion features and lymph node features in their derived nomogram features[60].

While various high-quality MRI sequences have been studied, the analysis of optimal imaging sequences is still rare. Qu *et al*[44] selected 9 radiographic features based

on the T2-TSE-BLADE and Star-VIBE enhancement sequences in MRI images to create radiographic features that are significantly associated with LN metastasis in 181 patients with pathologically confirmed lymph node metastasis. They found that the model based on this sequence effectively distinguished between metastatic and non-metastatic lymph nodes[44].

It is important to note that MRI examinations typically have a long examination time, and tumors that originate in the chest may be affected by the patient's respiratory movements, making artifacts unavoidable. While imaging histology can help reduce the impact of artifacts, it may also be beneficial to minimize examination time and extract established imaging histological features from optimal sequences to improve CDSS quality.

In oncology patients, accurately diagnosing lymph node status is critical for determining appropriate treatment options. While existing MRI radiomics studies have demonstrated its effectiveness in determining lymph node status, studies targeting focal radiomic features that link tumor features with lymph node status remain relatively uncommon. Analyzing various MRI sequences to identify sequences that yield high-quality imaging histological features may be an important area for future research.

Radiomics has garnered significant attention from researchers worldwide for its non-invasive, quantitative, and low-cost approach in diagnosing tissue characteristics, tumor staging, and treatment response. The current focus of radiomics research for esophageal cancer is on evaluating patient response and survival prognosis after different treatments. While predicting preoperative lymph node status using radiomics remains relatively rare, the numerous studies exploring various aspects of radiomics in esophageal cancer offer optimism for future research into using radiomics more widely to evaluate lymph nodes.

CONCLUSION

Although MRI has shown a trend toward superiority over other imaging methods for determining the lymph node status of esophageal cancer, the interference of respiratory

motion and heartbeat specific to the chest and the presence of artifacts in imaging can affect the diagnosis of the lymph node status of esophageal cancer. Radiomics techniques use a combined medical-mathematical tool approach to convert conventional images into digital quantitative features, which have the potential to tap into the underlying biological features and heterogeneity of tumor images and have been widely used for diagnosis, differential diagnosis, and disease assessment. Radiomics can significantly improve the diagnostic specificity of lymph nodes.

However, MRI-based radiomics has not been extensively studied in esophageal cancer lymph nodes. Although some studies have found that MRI-based radiomic features are associated with lymph node metastasis, most were relatively small-sample and single-center studies, and the applicability and generalizability of the findings require further validation. The specificity of various MRI sequences and techniques for diagnosing lymph node status in esophageal cancer needs to be compared, and the quality of the images formed by the selected MRI sequences needs to be validated against histological data. Furthermore, a multicenter study should be conducted to increase the sample size and validate our findings. Successful completion of these essential steps can lead to the development of a valuable clinical decision support systems (CDSS) for esophageal cancer.

It is important to note that while radiomics analysis can be performed on medical images from different modalities, integrating cross-modality approaches using the potential information extracted from MRI, computed tomography, and PET can provide added value compared to evaluating each modality separately. However, the level of research sophistication still has low stability and generalizability, and specific study conditions and author selection can strongly influence the results.

In addition, most radiomic studies are based on retrospective data, resulting in a low evidence level. Therefore, prospective studies for validation in external cohorts or confirmatory studies, besides larger patient cohorts, are necessary to provide more reliable and generalizable results. Future studies should focus on developing standardized radiomics protocols and establishing open-access radiomics databases to

promote the reproducibility and transparency of radiomics research. Radiomics has great overall potential for aiding clinical decision-making and improving patient outcomes; however, further validation and standardization are needed to ensure clinical utility.

It is essential to ensure that the imaging histology study is of high quality, addresses actual clinical needs, and can be implemented clinically to increase the likelihood of clinically relevant and valuable radiomics studies. Obtaining all relevant non-imaging data, such as demographics and bioinformatics, is critical. Standardizing the acquired images before performing radiomics analysis is essential to minimize the impact of different settings on the modeling. Implementing these key steps can lead to the formation of a valuable CDSS.

Furthermore, we believe that combining various MRI techniques and radiomics studies on esophageal cancer lymph nodes can introduce new quantitative imaging markers for medical imaging. With the precise determination of lymph node status using different MRI techniques and high-quality CDSS provided by radiomics findings, this approach may lead to significant breakthroughs in clinical studies. Preoperative personalized clinical characterization and precise treatment planning for esophageal cancer are possible with the introduction of new quantitative imaging markers.

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