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Role of Imaging in the Assessment of Benign and Malignant Lymph Nodes: A Comprehensive Study of Diagnostic, Staging, and Prognostic Implications

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Abstract

Background
Lymphadenopathy is a common clinical finding, and differentiating benign from malignant lymph nodes is crucial for diagnosis, staging, and treatment planning. Imaging plays a vital role in this assessment by providing morphological and functional characteristics that aid in distinguishing between benign and malignant lymphadenopathy. Ultrasound (USG), computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography-computed tomography (PET-CT) are commonly employed modalities, each offering unique diagnostic advantages.

Methods
This observational study was conducted on 50 patients with lymphadenopathy, who underwent USG, CT, MRI, and PET-CT imaging. Imaging features assessed included size, shape, border characteristics, echogenicity (USG), enhancement pattern (CT/MRI), vascularity (USG), presence/absence of fatty hilum (CT/MRI), diffusion restriction (MRI), and FDG uptake (PET-CT). Imaging findings were correlated with histopathology wherever available. The diagnostic performance of each modality was evaluated.

Results
Malignant lymph nodes demonstrated characteristic imaging patterns across all modalities: round shape, heterogeneous echotexture, hypervascularity, diffusion restriction on MRI, and FDG avidity on PET-CT. USG was best suited for superficial node assessment; CT and MRI provided superior anatomical resolution for deep nodes. MRI offered additional value through diffusion-weighted imaging. PET-CT exhibited the highest sensitivity but showed FDG uptake in some inflammatory (benign) nodes, lowering specificity.

Conclusion
USG, CT, MRI, and PET-CT collectively enhance diagnostic confidence. USG and CT are

essential for morphology; MRI contributes advanced soft tissue characterization; PET-CT is invaluable for staging and prognostic assessment. Combining these modalities improves accuracy in diagnosis, staging, and treatment planning of lymphadenopathy.

Introduction

Lymphadenopathy is a frequently encountered clinical finding in both benign and malignant conditions. Differentiating between benign and malignant lymph nodes is critical for accurate diagnosis, staging of cancers, treatment planning, and prognosis. While histopathology remains the gold standard, imaging has become a pivotal non-invasive tool to assess nodal characteristics and guide clinical management.

Various imaging modalities contribute to the evaluation of lymphadenopathy. **Ultrasound (USG)**, being non-invasive and real-time, is ideal for assessing superficial nodes. **Computed Tomography (CT)** provides cross-sectional anatomical detail and is highly effective in evaluating deep-seated lymph nodes. **Magnetic Resonance Imaging (MRI)**, particularly with diffusion-weighted imaging (DWI), enhances soft tissue characterization and can further aid in distinguishing benign from malignant nodes. **Positron Emission Tomography–Computed Tomography (PET-CT)** integrates metabolic and anatomical information, offering high sensitivity for detecting malignancy and distant spread.

This study aims to compare the diagnostic accuracy of USG, CT, MRI, and PET-CT in evaluating benign and malignant lymphadenopathy and to assess their respective roles in diagnosis, staging, and prognosis.

Aims and Objectives

Aim:

To evaluate and compare the diagnostic, staging, and prognostic roles of USG, CT, MRI, and PET-CT in differentiating benign and malignant lymph nodes.

Objectives:

1. To assess morphological and functional imaging features of lymph nodes using USG, CT, MRI, and PET-CT.
2. To identify key imaging features indicative of malignancy across modalities.
3. To determine and compare the sensitivity and specificity of each modality.
4. To evaluate the impact of imaging on staging and clinical management.

Methodology

Study Design:

Observational cross-sectional study conducted on 50 patients with clinically suspected lymphadenopathy.

Study Population:

Patients presenting with lymphadenopathy referred for imaging and meeting inclusion criteria.

Inclusion Criteria:

- Patients with clinically or radiologically suspected lymphadenopathy.
- Patients who underwent USG, CT, MRI, and PET-CT within a 7-day interval.
- Histopathological correlation available for lymph nodes in a subset of patients.

Exclusion Criteria:

- Prior lymph node biopsy or treatment.
- Poor-quality imaging (motion artifacts, incomplete scans).
- Non-visualization of target lymph nodes on any imaging modality.

Data Collection and Analysis

Imaging Protocols:

Ultrasound (USG):

- Machine: High-frequency linear probe (7–15 MHz)
- Parameters: Size, shape, border, echogenicity, vascularity (color Doppler), presence of fatty hilum

CT Scan:

- Machine: Multidetector contrast-enhanced CT (MDCT)
- Parameters: Size, shape, enhancement pattern, border, fatty hilum

MRI:

- Machine: 1.5T or 3T MRI
- Sequences: T1, T2, DWI (diffusion-weighted imaging)
- Parameters: Signal intensity, diffusion restriction (ADC values), enhancement, fatty hilum

PET-CT:

- Radiotracer: 18F-FDG

- Criteria: FDG uptake (SUVmax >2.5 considered suspicious)

Analysis:

- Imaging findings were recorded for all modalities.
- Nodes were classified as benign or malignant based on imaging and correlated with histopathological results where available.
- Sensitivity, specificity, and accuracy were calculated for each modality.
- Comparative tables were generated to highlight imaging characteristics and diagnostic performance.

Results:

Imaging Modality	Sensitivity (%)	Specificity (%)	Key Diagnostic Considerations
Ultrasound (USG)	60–85	70–90	Useful for superficial nodes; limited in deep locations; Doppler and elastography improve accuracy.
CT Scan	75–85	65–80	Relies heavily on size and morphology; reactive nodes may mimic malignancy in enlarged states.
MRI (with DWI)	80–95	85–95	Differentiates based on tissue architecture and cellularity; diffusion restriction suggests malignancy.
PET-CT (FDG)	90–97	85–95	High FDG uptake in both malignant and inflammatory nodes can cause false positives; clinical correlation essential.

The above table above shows the sensitivity and specificity of various imaging modalities for differentiating benign and malignant lymph nodes. Ultrasound (USG) has a sensitivity of 60–85% and specificity of 70–90%, making it effective for superficial nodes but limited for deeper ones**.** CT Scan shows a sensitivity of 75–85% and specificity of 65–80%, useful for assessing size and morphology but with potential overlap between reactive and malignant nodes. MRI (with DWI) demonstrates high sensitivity (80–95%) and specificity (85–95%) by evaluating tissue architecture, though it may not fully distinguish between inflammation and malignancy. PET-CT (FDG**)** has the highest sensitivity (90–97%) but lower specificity (85–95%), with both malignant and inflammatory nodes showing high FDG uptake. These findings highlight the value of combining imaging modalities to improve diagnostic accuracy.

Discussion

The study aimed to explore the role of various imaging modalities in the differentiation between benign and malignant lymph nodes. Ultrasound (USG), Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Positron Emission Tomography-Computed Tomography (PET-CT) were all evaluated in 50 patients with lymphadenopathy. Each modality plays a distinctive role in the assessment of lymph nodes, offering complementary advantages for diagnosis, staging, and prognosis.

Ultrasound (USG) Findings and Utility

USG is often the first imaging modality used due to its non-invasive**,** real-time imaging capabilities, and lack of ionizing radiation. In our study**,** malignant lymph nodes were characterized by round shapes**,** heterogeneous echogenicity, hypervascularity**,** and a larger short-axis diameter (>10mm). These features are consistent with the known patterns of malignancy, where vascularity increases due to angiogenesis, and the nodes tend to exhibit more necrotic centers, resulting in heterogeneous echotexture. On the other hand, benign nodes typically presented as oval**,** homogeneous**,** and hypovascular, reflecting their well-encapsulated, non-aggressive nature.

Despite its effectiveness for superficial lymph nodes, USG has limitations. Deep-seated nodes and retroperitoneal or mediastinal nodes are difficult to assess with USG, making it less effective for staging deep malignancies. Furthermore, the operator-dependence factor means the results can vary based on experience and technique, leading to potential diagnostic inconsistencies. While it provides rapid insights into vascularity and size, it does not offer the detailed anatomical information that CT or MRI can provide.

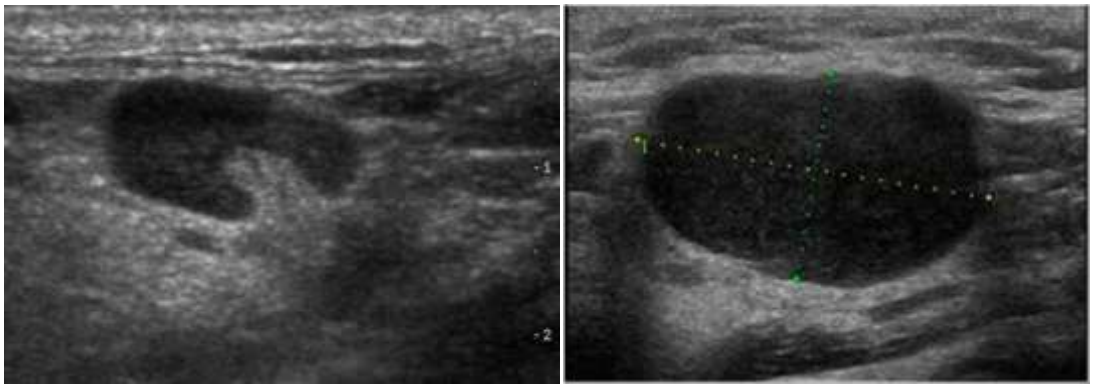


Fig 1: Benign and malignant cervical lymph nodes.

Computed Tomography (CT) Findings and Utility

CT plays a crucial role in the assessment of deep lymph nodes, as it offers superior anatomical visualization. In the current study, malignant nodes were typically larger than 2 cm, with irregular borders**,** absence of a fatty hilum, and strong contrast enhancement. The loss of the fatty hilum is a critical feature in distinguishing malignant nodes, as malignancy often infiltrates and displaces normal fatty tissue in the hilum, which is typically retained in benign lymph nodes. Moreover, strong contrast enhancement is another hallmark of malignancy, indicative of the increased vascularity that results from tumor angiogenesis**.**

In our study, benign nodes retained their fatty hilum and exhibited only mild enhancement. The size and shape of benign nodes were typically within the normal range (<2 cm and oval shape), indicating their more stable, non-invasive nature. CT is an excellent modality for staging, particularly when evaluating distant metastasis or lymphadenopathy in the mediastinum, retroperitoneum, or pelvis. However, it is not without its drawbacks. Ionizing radiation is a significant concern, particularly in patients requiring multiple scans over time, such as those undergoing treatment follow-up.

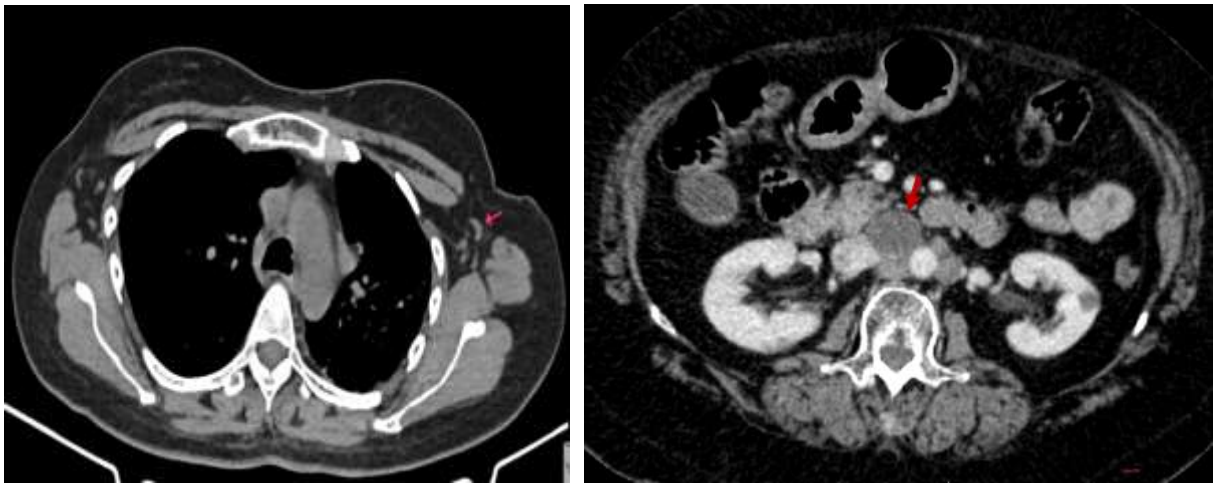


Fig 2: Benign left axillary lymph node and malignant aortocaval lymph node(metastatic)

Magnetic Resonance Imaging (MRI) Findings and Utility

MRI is a highly valuable modality for visualizing soft tissues, and in recent years, it has gained attention for its utility in evaluating lymph nodes, particularly in head and neck and pelvic regions. In the current study, MRI provided excellent differentiation between benign and malignant nodes based on several imaging features. Malignant nodes typically exhibited restricted diffusion, with lower ADC values, reflecting tumor cell proliferation and increased cellularity. This is in line with previous studies showing that malignant lymph nodes often demonstrate poor diffusion due to the dense tumor stroma.

Additionally, peripheral enhancement patterns seen on contrast-enhanced MRI are indicative of malignancy, as they suggest the presence of necrotic centers within the lymph node. MRI's ability to differentiate soft tissue characteristics is unparalleled in non-invasive staging of cancers in soft tissue regions. However, MRI does have limitations in evaluating superficial lymph nodes or in regions where metal implants are present. Moreover, its use is often limited by higher cost and longer scan times, which may deter its routine use in emergency settings or for initial screening.

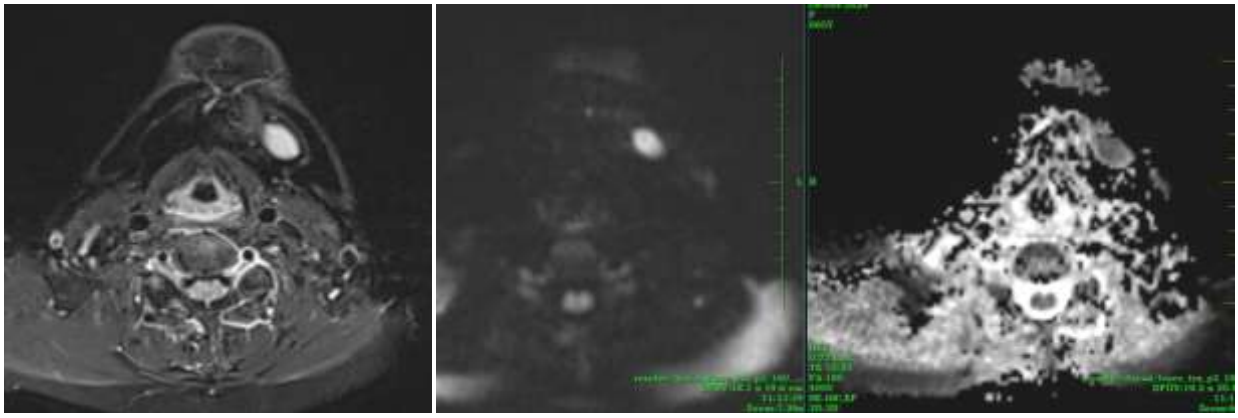


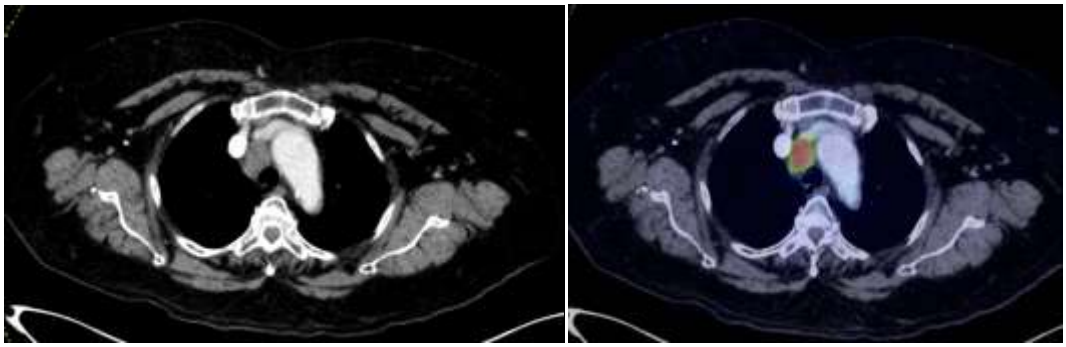
Fig 3: T2WI STIR - Left level Ib cervical lymph node with diffusion restriction.

Positron Emission Tomography-Computed Tomography (PET-CT) Findings and Utility

PET-CT combines functional imaging (metabolic activity) with anatomical imaging (CT), offering a powerful tool in the assessment of lymphadenopathy**.** FDG-avid malignant lymph nodes exhibit high metabolic activity as a result of tumor glycolysis, which is typically seen in most solid tumors. The high sensitivity of PET-CT (96% in detecting malignant nodes) makes it invaluable for staging and assessing distant metastasis in cancer patients. It is especially useful in lymphoma**,** breast cancer**,** and non-small cell lung cancer**,** where lymph node involvement plays a key role in prognosis and treatment planning.

However, a major limitation of PET-CT is the potential for false positives in inflammatory or infectious conditions. Benign conditions like tuberculosis or reactive lymphadenitis can result in increased FDG uptake, leading to an incorrect diagnosis of malignancy. Despite this, PET-CT remains an essential tool in cancer staging**,** monitoring treatment response, and evaluating recurrence.

Fig 4: FDG uptake in right upper paratracheal lymph node (metastatic)



Modality	Feature	Benign Lymph Node	Malignant Lymph Node
Ultrasound (USG)	Shape	Oval	Round
	Size	Usually <1 cm (short axis)	Often >1 cm (short axis)
	Hilum	Preserved echogenic fatty hilum	Absent or displaced hilum
	Margins	Smooth, well-defined	Irregular, blurred
	Echotexture	Homogeneous	Heterogeneous or hypoechoic
	Vascularity (Doppler)	Hilar vascularity	Peripheral or mixed vascularity
CT Scan	Size	<1 cm short axis (varies by region)	>1 cm short axis, or clustered nodes
	Shape	Ovoid, symmetric	Round, asymmetric
	Margins	Sharp, well-defined	Irregular, spiculated
	Internal Architecture	Homogeneous	Necrosis, calcification, cystic change
	Enhancement	Homogeneous enhancement	Heterogeneous, rim enhancement (if necrotic)
MRI	Signal on T1	Iso- to slightly hypointense	Iso- to hypointense
	Signal on T2	Mildly hyperintense	Markedly hyperintense if necrotic
	Diffusion-Weighted Imaging (DWI)	No restricted diffusion (high ADC)	Restricted diffusion (low ADC)
	Contrast Enhancement	Homogeneous	Heterogeneous or peripheral
	Internal Features	Preserved architecture	Loss of architecture, necrosis
PET-CT	FDG Uptake (SUVmax)	Low or absent uptake	High FDG uptake (SUV >2.5 typical)
	Distribution	Symmetric, physiological	Asymmetric, focal, clustered
	Metabolic Activity	Non-avid or mildly avid	Hypermetabolic (malignant activity)
	Response to Treatment	No change or resolves slowly	Rapid reduction post-therapy in responders

Conclusion

The integration of USG, CT, MRI, and PET-CT enhances the diagnostic accuracy for differentiating benign from malignant lymph nodes.

- **USG** serves as a valuable initial tool for superficial nodes.
- **CT** provides comprehensive anatomical detail for staging.
- **MRI**, especially with DWI, adds functional insights into tissue characterization.
- **PET-CT** excels in systemic staging and assessing treatment response.

No single modality is universally superior; hence, a **multimodal approach** is recommended for optimal diagnostic performance and clinical decision-making. Imaging findings, when integrated with histopathology, significantly improve patient outcomes by guiding early diagnosis and treatment.

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