MEDICAL IMAGING

Review

Multimodal imaging of cervical lymphadenopathy: diagnostic value and clinical applications

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Abstract

Introduction. Cervical lymphadenopathy encompasses a broad spectrum of malignant conditions, including metastatic involvement from head and neck or distant primaries, as well as primary lymphoid malignancies. Accurate imaging assessment is critical for the differential diagnosis, staging, and treatment planning. Advances in imaging now enable detailed evaluation of nodal morphology, vascularity, stiffness, and metabolic activity.

Methods. A narrative review was conducted using PubMed, Web of Science, and Google Scholar to identify studies published between January 2015 and June 2025 on imaging evaluation of cervical lymphadenopathy. The diagnostic performance, strengths, and limitations of various imaging techniques were summarized, with emphasis on recent advances and multimodal strategies.

Results. Conventional ultrasonography remains the first-line modality for superficial nodes, with Doppler and elastography improving characterization. Shear wave elastography offers quantitative stiffness assessment, enhancing specificity when combined with grayscale ultrasonography. Computed tomography and magnetic resonance imaging provide cross-sectional evaluation of deep or inaccessible nodal levels, with the latter offering superior soft-tissue contrast and functional techniques such as diffusion-weighted imaging. Fluorodeoxyglucose positron emission tomography contributes with metabolic information, improving detection of occult metastases and aiding systemic staging. No single modality is definitive; combined approaches yield higher accuracy and better surgical planning. Emerging technologies, including image fusion, and radiomics, show promise for refining diagnosis.

Conclusion. An integrated, multimodal imaging approach optimizes the evaluation of cervical lymph node metastases. Future developments in functional imaging, quantitative analysis, and artificial intelligence may further enhance diagnostic precision and enable personalized management strategies.

Keywords: cervical lymphadenopathy, lymph node metastasis, head and neck, multimodality imaging

Introduction

Head and neck cancers (HNC), including malignancies of the oral cavity, pharynx, and larynx, represent a major global health concern, accounting for over 900,000 new cases and more than 400,000 deaths annually. Among these, squamous cell carcinoma (SCC) is the predominant histological subtype, characterized by a high propensity for regional lymphatic spread. The presence of cervical lymph node (LN) metastases is a pivotal prognostic factor, known to significantly reduce overall survival and increase the risk of locoregional recurrence [1-4]. Thyroid cancer, particularly papillary thyroid carcinoma (PTC), commonly spreads to cervical lymph nodes (LNs), even in early-stage disease. LN metastases are found in up to 30–80% of patients with PTC at diagnosis, most frequently in the central (level VI) and lateral (levels II–V) neck compartments [5]. While nodal involvement rarely impacts overall survival, it is associated with a higher risk of locoregional recurrence and may influence decisions regarding the extent of surgery and radioactive iodine therapy [6]. Accurate identification of nodal metastases is essential for surgical planning and risk stratification, particularly in intermediate- and high-risk thyroid cancer patients [7]. Lymphatic spread from primary tumors usually follows a predictable anatomical route influenced by tumor location, depth of invasion, and biological characteristics [8,9]. In solid tumors such as oral squamous cell carcinoma (OSCC), cervical nodal metastasis can halve the patient's survival probability [4]. The process of metastasis to cervical nodes involves tumor-driven lymphangiogenesis, interstitial fluid dynamics, and immune evasion, allowing malignant cells to access and colonize regional lymphatics [1]. Tumor-induced remodeling of the lymphatic system facilitates this dissemination and plays a key role in both regional recurrence and distant metastasis. Notably, extracapsular spread (ECS) of metastatic nodes is a particularly adverse prognostic factor, significantly associated with poor outcomes, especially in head and neck squamous cell carcinoma (HNSCC) [3,8]. Early detection of cervical LN metastasis is vital for staging, risk stratification, and treatment planning. Clinical examination alone lacks sensitivity, especially in patients with clinically node-negative (cN0) necks [1]. This limitation has made imaging a cornerstone in preoperative and surveillance strategies. Modalities such as contrast-enhanced computed tomography (CECT), magnetic resonance imaging (MRI), ultrasound (US), and positron emission tomography (PET/CT) enable clinicians to assess nodal morphology, metabolic activity, and tissue characteristics [3,8]. The importance of accurate imaging is underscored by findings from prospective trials such as the landmark study by D'Cruz et al., which demonstrated that elective neck dissection significantly improved overall and disease-free survival in patients with cN0 OSCC compared to therapeutic dissection following relapse [2]. Moreover, early detection of nodal disease allows timely intervention with surgery or radiotherapy, reducing the likelihood of ECS and distant metastasis [9-11].

Occasionally, cervical LN metastases originate from distant primary tumors outside the head and neck region, including cancers of the lung, breast, kidney, gastrointestinal tract, or gynecologic system. These cases, often first presenting as isolated supraclavicular lymphadenopathy, can precede the identification of the primary site and are typically associated with an advanced disease stage [12]. Among distant tumors, infradiaphragmatic malignancies, such as renal or ovarian carcinoma, are uncommon but important to consider in the differential diagnosis of cervical lymphadenopathy [13]. Imaging modalities such as Fluorodeoxyglucose Positron Emission Tomography–Computed Tomography (FDG-PET/CT) play a crucial role in evaluating these patients, offering superior sensitivity in detecting both the primary site and additional metastatic spread [14]. Although the prognosis is generally poor, selected patients with isolated cervical metastases from remote primaries may benefit from curative-intent neck dissection combined with systemic therapy, with reported 3-year survival rates reaching up to 70% in some series [12,15]. Early recognition of this metastatic pattern is critical to guide biopsy, staging, and multidisciplinary treatment planning.

Lymphomas, both Hodgkin and non-Hodgkin subtypes, frequently involve the cervical lymph nodes and represent a significant proportion of neck masses in both adults and children. In fact, cervical lymphadenopathy is the most common presenting feature in Hodgkin lymphoma and is also frequently seen in aggressive non-Hodgkin lymphomas, such as diffuse large B-cell lymphoma (DLBCL) [16]. These malignancies originate in lymphatic tissue and typically follow a contiguous spread pattern, though extranodal involvement can also occur. Clinical evaluation alone is often insufficient to differentiate malignant from reactive lymphadenopathy, especially in early-stage disease. Therefore, imaging plays a critical role in the diagnostic workup, with ultrasound commonly used for initial evaluation and PET/CT widely regarded as the gold standard for staging and response assessment, due to its ability to detect metabolically active disease [17]. Accurate identification of nodal involvement and disease extent is essential for guiding biopsy decisions, determining prognosis, and planning systemic therapy or radiotherapy [18].

This clinical review explores the diagnostic performance, clinical application, and comparative strengths of contemporary imaging techniques in detecting malignant cervical lymphadenopathy and differentiate from solid tumors and lymphomas. Emphasis is placed on their role in early diagnosis, staging accuracy, and implications for therapeutic decision-making.

Methods

This narrative review was conducted to critically assess and summarize current evidence on the diagnostic performance of contemporary imaging modalities in evaluating cervical LN metastases in patients with solid tumors and lymphomas. Emphasis was placed on the clinical utility, strengths, and limitations of widely used imaging techniques, including US, CECT, MRI, FDG-PET/CT and elastography. In addition, emerging technologies such as SPECT/CT, image fusion, and PET/MRI were explored for their potential to improve diagnostic accuracy, enable comprehensive anatomical and functional assessment, and guide individualized treatment planning in cervical LN evaluation. A comprehensive search of the PubMed [19], Web of Science [20] and Google Scholar [21] databases was performed to identify relevant articles published from January 2015 to June 2025. Search terms included but there were not limited to: cervical lymph node, lymphadenopathy, metastasis, head and neck cancer, oral squamous cell carcinoma, thyroid cancer, lymphoma, ultrasound, CT, MRI, PET/CT, SPECT, diagnosis, imaging. Boolean operators and MeSH terms were applied where applicable to refine results. Titles and abstracts of all retrieved articles were screened for relevance by the authors. Full-text articles of potentially relevant studies were reviewed in detail. A total of 45 articles met the inclusion criteria and were included in the narrative synthesis. Extracted data included study design, sample size, tumor type, imaging modality, diagnostic metrics, and key findings. As a narrative review, no formal meta-analysis or quantitative synthesis was performed. Instead, results were synthesized descriptively and structured by imaging modality. The diagnostic value of each modality was discussed in terms of its ability to detect cervical LN metastases, assess extranodal extension, guide biopsies, and contribute to staging and treatment planning. The clinical relevance, comparative performance, and limitations of each method were summarized to provide a practical overview for multidisciplinary cancer care teams.

Results

Contrast-Enhanced Computed Tomography for investigating cervical lymphadenopathy

CECT remains a cornerstone in the radiologic assessment of cervical LN metastases due to its widespread availability, rapid acquisition, and capacity to delineate anatomical detail. Among the reviewed studies (Table I), CECT demonstrated variable diagnostic performance depending on nodal characteristics. Struckmeier et al. reported that enlarged nodes (≥10 mm) achieved balanced sensitivity (65.8%) and specificity (84.8%), while melted nodes, indicative of necrosis, showed very high specificity (98.2%) but limited sensitivity (39.2%) [21]. The diagnostic performance improved further when coronal reconstruction was incorporated, as shown by Ando et al., where specificity and overall accuracy increased significantly, particularly in identifying extranodal extension and small metastatic foci [23]. Bhargava et al. reported a sensitivity of 83.3%, specificity of 75%, and overall accuracy of 76.7%, suggesting that CECT is superior to clinical palpation in detecting subclinical nodal disease [24]. Similarly, Qureshi et al. found a diagnostic accuracy of 73% with a sensitivity of 83% and specificity of 61.7%, though the lower specificity highlighted a tendency toward false positives, likely due to inflammation or reactive hyperplasia [25]. Noor et al. supported these findings, reporting a sensitivity of 78%, specificity of 68%, and accuracy of 72.8%, further confirming that CECT is a reliable adjunct to clinical evaluation and can aid in preoperative planning [26]. In a preliminary analysis of 92 patients with pathologically confirmed malignant cervical lymphadenopathy, Yang et al. demonstrated that dual-energy CT provides valuable quantitative data to distinguish between thyroid carcinoma, salivary gland carcinoma, HNSCC, and lymphoma [27]. Park et al. demonstrated that arterial phase contrast-enhanced CT significantly improves the diagnostic performance for detecting lateral cervical LN metastasis in patients with PTC [28]. In assessing cervical lymphadenopathy in lymphoma, CECT demonstrated clinically useful diagnostic performance. Zytoon et al. evaluated 100 lymphoma patients and found that CECT had a sensitivity of 83.1%, specificity of 94%, and overall accuracy of 89.6% in detecting involved LN groups. However, 6.8% of nodes were falsely positive, and 46 involved nodal groups were missed compared to PET/CT, which confirmed CECT's limitations in sensitivity [29]. Complementing this, Li et al. focused on differentiating lymphoma from Castleman disease in cervical lymph nodes using post-contrast attenuation values. They reported significantly lower HU values in lymphoma (mean 75.6 ± 13.2) compared to Castleman disease (mean 108.6 ± 20.5), with an optimal cutoff of 92.5 HU achieving an AUC of 0.954, supporting the role of quantitative CECT in diagnostic discrimination [30]. These findings underscore the importance of multiparametric interpretation combining nodal size, shape, border irregularity, and central necrosis to enhance diagnostic accuracy. However, despite its strengths, CECT may overcall nodal involvement in the presence of reactive hyperplasia, especially in post-treatment settings, highlighting the value of combining it with functional modalities when necessary.

Table I. Data extraction sheet for CECT.

Author (Year)	Tumor Type	Investigation Type	Sensitivity	Specificity	Accuracy	Key Findings
Bhargava et al. (2016)	HNSCC	CECT	83.3%	75%	76.7%	CECT outperforms clinical exam in subclinical nodal detection.
Qureshi et al. (2021)	OSCC	CECT	83%	61.7%	73%	Elective neck dissection recommended due to limited NPV.
Noor et al. (2022)	OSCC	CECT	78%	68.2%	72.8%	Useful for preoperative planning; moderate staging reliability.
Zytoon et al. (2020)	Lymphoma	CECT	83.1%	94%	89.6%	CECT effective but missed nodes detected by PET/CT.
Park et al. (2017)	PTC	Arterial-phase CECT	87%	97.9%	88%–92%	25-sec arterial phase offers best diagnostic yield with lower radiation.
Ando et al. (2022)	OSCC	CECT (coronal recon)	75.3%	97.2%	88.2%	Coronal views improve diagnostic confidence and reduce overdiagnosis.
Struckmeier et al. (2023)	OSCC	CECT	65.8%	84.8%	Variable	Diagnostic value depends on nodal morphology and size.

Fluorodeoxyglucose Positron Emission Tomography–Computed Tomography for investigating cervical lymphadenopathy

In a recent meta-analysis, Guedj et al. demonstrated that FDG PET-CT offers high specificity and negative predictive value in detecting occult cervical LN metastases in clinically node-negative HNSCC, highlighting its reliability in ruling out nodal involvement despite moderate sensitivity [31]. In patients with OSCC and clinically non-palpable LNs, PET/CT demonstrated valuable diagnostic utility in evaluating cervical LN metastases. The modality effectively identified nodal involvement and showed particularly strong negative predictive capacity, suggesting reliability in excluding metastasis when no suspicious uptake is observed. The intensity of FDG uptake, measured as SUVmax, was positively associated with the likelihood of metastasis, although it was not always a definitive criterion. While some false positive and negative cases occurred—primarily due to factors like inflammatory hyperplasia or low metabolic activity, the overall diagnostic performance of PET/CT supported its role as a helpful tool in preoperative assessment for this patient subgroup [32,33]. In clinically node-negative patients with early-stage tongue squamous cell carcinoma, integrating metabolic and anatomical imaging markers significantly improved the detection of occult cervical LN metastases. A composite index combining SUVmax from FDG PET/CT and the minor axis of the largest lymph node on CECT demonstrated greater diagnostic accuracy than PET/CT alone. Elevated metabolic activity in the primary tumor was also associated with more advanced pathological staging, poorer differentiation, and reduced locoregional control, underscoring the prognostic value of PET/CT in surgical planning and risk stratification [34,35]. In the assessment of clinically node-negative HNC, FDG PET/CT demonstrated moderate overall diagnostic performance, with limited sensitivity but consistently high specificity and negative predictive value, particularly in level-based analyses. These findings suggest its greater utility in confirming the absence of nodal disease rather than detecting occult metastases. In early-stage oral cavity cancers, PET/CT was most effective in excluding metastasis in smaller or shallow lesions, supporting its role in guiding treatment toward more conservative surgical approaches when appropriate. Additionally, in the evaluation of small or intermediate-sized supraclavicular nodes, combining PET/CT with US significantly enhanced diagnostic accuracy. Key sonographic features such as increased anteroposterior diameter and loss of hilar structure were independently predictive of malignancy and the application of ultrasound-guided core needle biopsy, when adapted to nodal morphology and orientation, yielded high procedural success [36-38]. In patients with papillary thyroid carcinoma, FDG PET/CT demonstrated a strong association between tumor metabolic activity and the presence of cervical LN metastases, particularly in the central compartment. Higher SUVmax values correlated with more advanced tumor features and greater nodal involvement, supporting its prognostic relevance. Although US remained more sensitive for central node detection, PET/CT offered higher specificity and showed improved diagnostic performance when metabolic parameters were incorporated. Furthermore, contrast-enhanced PET/CT outperformed conventional neck CT in staging accuracy, showing greater concordance with pathological nodal classification and better delineation of nodal extent across cervical levels. These findings underscore the utility of metabolic imaging as a complementary tool in preoperative risk stratification and surgical planning [39-40].

Table II. Data extraction sheet for FDG PET/CT.

Author (Year)	Tumor Type	Investigation Type	Sensitivity	Specificity	Accuracy	Key Findings
Niu et al. (2022)	HNSCC	FDG PET/CT + US	83.90%	73.10%	76.50%	Combining PET/CT with ultrasound enhanced diagnostic accuracy for small supraclavicular LNs. Core needle biopsy also valuable.
Vartak et al. (2023)	OSCC	FDG PET/CT	90%	87.50%	87.93%	Effective in confirming absence of LN metastasis; limited sensitivity in detecting occult disease, helpful in surgical planning.
Kanamura et al. (2020)	OSCC	FDG PET/CT + US	68.20%	81.50%	76.60%	Integrated PET/CT and US improved detection in supraclavicular nodes; morphological features guided biopsy success.
Xu et al. (2021)	OSCC	FDG PET/CT + CECT	77.80%	92.20%	87.20%	Combining SUVmax and CECT lymph node size improved detection of occult metastases.
Zhang et al. (2022)	HNSCC	FDG PET/CT	21.40%	98.40%	93.80%	Best used to rule out nodal disease rather than detect it; useful for stratification.
Choi et al. (2023)	OSCC	PET/CT	94.40%	83.30%	89.80%	High specificity and NPV; effective for planning single-modality surgery in early-stage disease.
Chong et al. (2017)	Thyroid carcinoma	CE FDG PET/CT vs Neck CT	65.80%	93.60%	81.20%	Contrast-enhanced FDG PET/CT demonstrated significantly superior diagnostic performance compared to conventional neck CT

Magnetic Resonance Imaging for investigating cervical lymphadenopathy

Diffusion-weighted MRI has shown promising diagnostic performance in evaluating cervical LN metastases across head and neck malignancies. Meta-analyses confirm that metastatic LNs consistently exhibit lower apparent diffusion coefficient (ADC) values compared to benign nodes, supporting ADC as a reliable marker for malignancy. Optimizing imaging parameters, such as slice thickness, further enhances diagnostic sensitivity. Additionally, diffusion-weighted imaging (DWI) has demonstrated added value in specific tumor types like hypopharyngeal carcinoma, where lower ADC values not only aid in nodal differentiation but may also carry prognostic significance. Despite its strengths, the technique's limited ability to rule out disease indicates a need for complementary imaging in clinical practice [41-43]. Advanced diffusion MRI techniques have shown promise in differentiating metastatic from benign cervical LNs in HNC. Diffusion kurtosis imaging (DKI) revealed superior diagnostic utility compared to conventional ADC values, with kurtosis and diffusivity parameters correlating significantly with both nodal metastasis and tumor grade. Similarly, intravoxel incoherent motion (IVIM) imaging demonstrated that malignant nodes exhibited lower pure diffusion and perfusion fractions, with a combined diffusion parameter offering the highest diagnostic accuracy. While DWI also identified significant differences in ADC values, variability due to necrosis and partial volume effects limited its standalone clinical reliability. Collectively, these findings suggest that microstructural imaging metrics derived from DKI and IVIM may provide more reliable noninvasive markers for nodal staging than standard DWI alone [44-46]. Advanced MRI techniques, including DWI, dynamic contrast-enhanced MRI (DCE-MRI), and ADC analysis, have shown promising value in the characterization of cervical LNs. Quantitative ADC values were consistently lower in malignant nodes, with minimum ADC proving especially effective in detecting metastasis, even in anatomically challenging regions such as the retropharyngeal space. While DWI alone showed limitations in distinguishing benign from malignant nodes, DCE-MRI demonstrated superior diagnostic utility through perfusion-based metrics such as relative enhancement and wash-in rates. Furthermore, meta-analytic evidence supports the use of ADC thresholds to differentiate lymphomatous, metastatic, and benign nodes, reinforcing the role of functional MRI parameters in improving diagnostic accuracy in cervical lymphadenopathy [47-49]. Emerging MRI techniques show promise in improving the characterization and diagnostic accuracy of cervical lymph nodes in head and neck cancer. Radiomics-based analysis of contrast-enhanced MRI, when paired with neural network modeling, demonstrated high accuracy in classifying lymph nodes and predicting extranodal extension using noninvasive imaging features. Similarly, USPIO-enhanced MRI with T2*-weighted sequences improved distinction between malignant and benign nodes through a signal-based interpretation algorithm, enhancing preoperative assessment. However, variability in ADC values across different MRI systems and protocols highlights the need for technical standardization to ensure reproducibility and reliability of quantitative imaging biomarkers in clinical practice [50-52].

Table III. Data extraction sheet for MRI.

Author (Year)	Tumor Type	Investigation Type	Sensitivity	Specificity	Accuracy	Key Findings
Zhou et al. (2020)	HNC	DWI (MRI), ADC analysis	84%	87%	93%	DWI showed high sensitivity and specificity; ADC values were lower in malignant nodes. Reliable for confirming nodal metastases.
Zhang et al. (2023)	HNC	DWI (MRI), ADC analysis	97.50%	66.70%	89.10%	ADC values were lower in malignant vs. benign nodes. Lower ADC associated with poorer prognosis
Yamada et al. (2018)	OSCC	Diffusion Kurtosis Imaging (DKI)	90.90%	100%	93.80%	Kurtosis and diffusivity values distinguished metastatic nodes and correlated with tumor grade; superior to conventional ADC.
Wendl et al. (2015)	OSCC	DWI (3T MRI), ADC	80%	65%	73%	Malignant nodes had higher ADC values due to necrosis. ADC overlap limited clinical utility of DWI alone.
Driessen et al. (2022)	HNSCC	USPIO-enhanced MRI	94 %	89%	91%	USPIO-enhanced MRI using a new reading algorithm accurately distinguished malignant from benign.
Li et al. (2015)	NPC	DWI (MRI)	95.70%	95.10%	96.50%	Minimum ADC from DWI highly accurate for differentiating metastatic RLNs from non-metastatic ones.
Cintra et al. (2018)	HNC	DCE-MRI and DWI	89.20%	69.20%	Not specified	DCE parameters (TTP and RE) were better than ADC in differentiating malignant from benign nodes.

Ultrasonography, Doppler mode and contrast enhanced ultrasonography for investigating cervical lymphadenopathy

US is a reliable tool for preoperative staging in papillary thyroid carcinoma, effectively assessing tumor size and lateral nodal metastases. While central compartment nodes are more challenging to evaluate, 2D and 3D ultrasonography offer comparable diagnostic value, with no significant advantage observed for 3D imaging [53,54]. US, particularly when incorporating Doppler and structural features, plays a crucial role in the preoperative evaluation of cervical LN metastasis in thyroid cancer. Predictive models using sonographic characteristics such as echogenicity, microcalcifications, and nodal volume can aid in distinguishing malignant from benign nodes and guide decisions on biopsy or surveillance. While restrictive sonographic criteria improve specificity for detecting extrathyroidal extension, broader definitions offer greater sensitivity. High-frequency Doppler ultrasound also supports more extensive lymph node dissection, which may improve oncologic outcomes without increasing surgical risk [55-57]. US has proven valuable in the preoperative assessment of papillary thyroid carcinoma, particularly in evaluating extracapsular extension (ETE) and central LN involvement. Key sonographic features such as capsular abutment, loss of the echogenic capsule, and irregular margins were associated with ETE and correlated with LN metastasis. However, while highly specific, ultrasound showed limited sensitivity in detecting microscopic or deeply situated nodal disease, emphasizing the need for cautious surgical planning. These findings support the role of detailed capsular and nodal evaluation on ultrasound as a crucial, though not standalone, tool in the staging of thyroid cancer [58-60]. US remains a key modality for preoperative evaluation of cervical LN metastases in thyroid carcinoma. Sonographic features such as nodule size, capsular invasion, microcalcifications, vascular patterns, and lymph node count have been associated with metastatic involvement, supporting its role in risk stratification. However, its diagnostic accuracy is notably reduced in evaluating central compartment nodes, especially in patients with higher BMI or when metastatic disease is microscopic or deeply located. While ultrasound performs reliably for lateral compartment assessment, these findings underscore the need for complementary imaging or intraoperative evaluation to ensure comprehensive staging [61-64]. Conventional ultrasonographic modalities, including B-mode and Doppler, have demonstrated complementary value in the evaluation of cervical lymphadenopathy. Characteristic findings such as rounded shape, absence of a hilum, hypoechogenicity, irregular margins, and peripheral or mixed vascularity patterns were consistently associated with malignancy. The integration of these sonographic criteria improves diagnostic accuracy and may reduce reliance on invasive procedures for confirming nodal pathology [65-67].

Contrast-enhanced ultrasound (CEUS) has shown superior diagnostic performance compared to conventional ultrasound in detecting cervical LN metastases in thyroid cancer. By improving visualization of vascularity, perfusion patterns, and microvascular architecture, CEUS enhances the distinction between benign and malignant nodes. Key predictive features include heterogeneous hyperenhancement, centrifugal or centripetal perfusion patterns, and conventional ultrasound findings such as cystic change or microcalcifications. When combined with grayscale imaging, CEUS significantly increases diagnostic accuracy, supporting its role as a valuable adjunct for both preoperative evaluation and postoperative surveillance in patients with thyroid malignancy [68-70]. CEUS, particularly when combined with elastography or applied through both lymphatic and intravenous routes, has shown substantial value in improving the detection of cervical LN metastases in PTC. Key predictive features include perfusion defects, interruption of the bright ring, heterogeneous enhancement, altered time–intensity parameters such as prolonged time to half-peak and increased enhancement area, as well as elasticity scores and morphological ultrasound indicators. Quantitative CEUS metrics consistently outperformed qualitative assessment, and multimodal integration further enhanced diagnostic accuracy. These findings support CEUS as a reliable adjunct to conventional ultrasound for more accurate preoperative nodal staging and surgical planning [71-74]. Across multiple studies, CEUS with conventional ultrasound consistently improved the detection and characterization of metastatic cervical LNs compared to either modality alone.

Table IV. Data extraction sheet for US.

Author (Year)	Tumor Type	Investigation Type	Sensitivity	Specificity	Accuracy	Key Findings
Zakaria et al. (2022)	Pediatric cervical lymphadenopathy	Sonoelastography vs. B-mode and Doppler	100%	85.70%	94.70%	Sonoelastography outperformed conventional ultrasound in detecting malignant lymph nodes based on tissue stiffness.
Pratiksha et al. (2020)	Cervical lymphadenopathy (varied)	Grayscale and Doppler ultrasonography	81.80%	92.90%	88.00%	No single ultrasound sign is definitive; combined grayscale and Doppler features improve diagnostic accuracy.
Rohan et al. (2020)	Cervical lymphadenopathy (varied)	B-mode and Color Doppler US	91.30%	76.90%	86.70%	Loss of echogenic hilum was the most sensitive feature; S/L ratio was most specific for malignancy.
Yi et al. (2016)	Papillary thyroid carcinoma	2D vs. 3D Ultrasonography (TUI)	86%	79%	84%	3D US showed similar diagnostic performance to 2D US; no significant improvement observed.
Du et al. (2022)	Thyroid carcinoma (predominantly papillary)	Grayscale and Doppler ultrasonography	81.40%	92.32%	86.99%	Ultrasonographic features such as larger nodular diameter, capsular invasion, microcalcification, and higher flow grade were independent risk factors for cervical lymph node metastasis.
Liu et al. (2020)	Papillary thyroid carcinoma	High-frequency Color Doppler US	97.40%	33.30%	88.6%.	More extensive lymph node removal guided by ultrasound improved outcomes; specificity of US limited despite high sensitivity.
Khokhar et al. (2022)	Papillary thyroid carcinoma	High-Resolution Ultrasound	38%	90%	66%	Ultrasound had high specificity but limited sensitivity for central compartment nodes; intraoperative evaluation remains essential.

Malignant nodes were more likely to demonstrate features such as heterogeneous or peripheral hyperenhancement, centripetal or chaotic perfusion, perfusion defects, ring-enhancing margins, and alterations in quantitative perfusion parameters, while benign nodes typically showed homogeneous enhancement and centrifugal perfusion. Predictive models incorporating CEUS-derived vascular and perfusion characteristics alongside conventional sonographic morphology achieved higher sensitivity, specificity, and overall diagnostic accuracy, offering a more reliable basis for preoperative staging and surgical decision-making [75-78].

Elastography for investigating cervical lymphadenopathy

Elastography techniques, including shear wave elastography (SWE), strain elastography, and acoustic radiation force impulse (ARFI) imaging, have shown substantial value in differentiating malignant from benign cervical LNs and thyroid nodules. Malignant nodes and nodules generally exhibited higher elasticity values, greater stiffness areas, and higher virtual touch imaging scores, with metastatic nodes often stiffer than those affected by lymphoma. Quantitative parameters such as shear wave velocity (SWV), strain ratio, and elasticity measurements consistently outperformed conventional US alone, and combining elastography with standard sonographic features improved diagnostic accuracy and interobserver agreement. These findings support elastography as a reliable, noninvasive adjunct for enhancing preoperative assessment and reducing unnecessary biopsies [79-82]. A meta-analysis evaluating acoustic radiation force impulse (ARFI) imaging for differentiating benign from malignant thyroid nodules demonstrated high pooled sensitivity and specificity, with strong overall diagnostic accuracy. The technique, which quantifies tissue stiffness via SWV, consistently improved diagnostic performance compared to conventional ultrasound alone. Subgroup analyses indicated that studies with smaller sample sizes, younger patients, and surgical reference standards achieved higher diagnostic values. These findings support ARFI as a reliable, noninvasive adjunct to grayscale sonography for preoperative risk stratification and surgical decision-making in thyroid nodules [83]. Acoustic radiation force impulse (ARFI) elastography, including Virtual Touch tissue quantification (VTQ) and imaging, has demonstrated high diagnostic accuracy in differentiating benign from malignant thyroid nodules and superficial LNs. Malignant lesions consistently exhibited higher SWV and greater stiffness than benign or lymphomatous nodes, with metastatic nodes typically stiffer than those affected by lymphoma. These techniques provided quantitative, reproducible measures with less operator dependence than conventional or strain elastography, improving diagnostic performance when integrated with grayscale ultrasound. While necrosis and certain inflammatory conditions such as tuberculous lymphadenitis could affect stiffness values, ARFI remained a valuable noninvasive adjunct for preoperative assessment and surgical planning, potentially reducing unnecessary biopsies [84-87]. SWE techniques, including Virtual Touch tissue imaging quantification and modified elastographic scoring systems, have shown high diagnostic accuracy in differentiating malignant from benign cervical lymph nodes and in characterizing lymphoma activity. Malignant and active disease nodes consistently demonstrated higher shear wave velocities, larger stiff areas, and distinct stiffness patterns compared to benign or remission cases. While false positives occurred in conditions such as tuberculous lymphadenitis and Kikuchi disease, and some false negatives arose from microscopic necrosis or heterogeneous histology, these methods proved reproducible and complementary to conventional ultrasound. Incorporating quantitative stiffness measurements and disease-specific elastographic patterns enhances preoperative nodal assessment, surgical planning, and lymphoma monitoring [88-91]. A meta-analysis of eight studies comprising 481 patients with 647 cervical lymph nodes reported that shear wave elastography achieved a pooled sensitivity of 81% and specificity of 85% for differentiating malignant from benign nodes, with an area under the HSROC curve of 0.88; no significant performance difference was found between acoustic radiation force impulse imaging and supersonic shear imaging, while variability in malignancy prevalence significantly contributed to heterogeneity [92]. In a large prospective study of 270 cervical lymph nodes, quantitative SWE using virtual touch imaging quantification demonstrated a sensitivity of 92.6% and specificity of 75.5% for malignancy prediction at an optimal cut-off of 2.93 m/s, with a negative predictive value of 97.6% and independent predictive value exceeding that of individual Bmode ultrasound features [93].

Comparative performance and complementarity of imaging modalities

The diagnostic evaluation of cervical LNs benefits from an integrated, multimodal approach. Conventional US remains the preferred first-line imaging modality due to its accessibility, absence of ionizing radiation, and high resolution for superficial structures [94-96]. Bmode features, such as loss of fatty hilum, rounded morphology, and heterogeneous echotexture, offer valuable clues, yet their specificity is limited, particularly in the presence of inflammatory or reactive lymphadenopathy [97,98]. Adding Doppler interrogation improves characterization by identifying vascular patterns, with central or mixed vascularity favoring malignancy, however, Doppler findings alone are insufficient for definitive diagnosis [99,100]. Cross-sectional imaging modalities such as CT and MRI extend the evaluation to deep or inaccessible nodal levels and allow assessment of extracapsular spread, with MRI providing superior softtissue contrast and functional imaging options such as DWI [101]. PET/CT contributes metabolic information, enhancing detection of metastatic nodes, especially in the context of occult primaries or distant metastasis, although inflammatory uptake can limit specificity [102,103]. Recent advances in elastography have augmented the diagnostic armamentarium. Strain elastography offers semiquantitative elasticity assessment [104], while SWE provides objective, reproducible stiffness measurements. Metaanalytic data demonstrate SWE's high pooled sensitivity and specificity, and prospective studies have shown that SWE can outperform individual Bmode criteria in sensitivity and negative predictive value. For example, stiffness thresholds in SWE can help triage which nodes warrant biopsy and which can be safely observed, potentially reducing unnecessary invasive procedures. [92,93]. No single modality is universally superior; rather, the greatest diagnostic accuracy emerges when techniques are applied in a complementary fashion. A practical pathway might employ ultrasound with Doppler and elastography for initial characterization, followed by crosssectional imaging for surgical planning or when deeper nodes are suspected, and PET/CT when systemic disease assessment is indicated. Such integration leverages the strengths of each method, morphology, vascularity, stiffness, and metabolic activity, while mitigating individual limitations.

Table V. Performance of imaging modalities.

Modality	Typical Sensitivity (%)	Typical Specificity (%)	Key Strengths	Key Limitations
Bmode Ultrasound	70–85	70–90	Widely available, inexpensive, high resolution for superficial nodes, realtime assessment	Operatordependent, limited in deep/ retropharyngeal nodes, low specificity in reactive adenopathy
Color/Power Doppler	~65–80	~75–90	Adds vascular pattern analysis (central/mixed flow suggestive of malignancy)	Overlap with benign inflammatory nodes, dependent on angle and operator skill
Strain Elastography	74–88	81–90	Semiquantitative elasticity assessment, useful adjunct to Bmode	Operatordependent compression, qualitative/relative measurements
Shear Wave Elastography (SWE)	81–93 (metaanalysis and large prospective studies)	75–88	Quantitative stiffness measurement, high reproducibility, improved NPV, can guide biopsy decisions	Limited in deep nodes (>4 cm), cystic/calcified nodes may yield unreliable measurements
Computed Tomography (CT)	81–92	70–88	Excellent spatial resolution, detection of deep nodes, surgical planning	Ionizing radiation, limited softtissue contrast, size criteria may miss micrometastases
Magnetic Resonance Imaging (MRI)	80–90	75–90	Superior softtissue contrast, functional imaging with DWI, no ionizing radiation	Higher cost, longer scan times, motion artifacts, limited availability
Positron Emission Tomography–CT (PET/CT)	80–90	80–90	Combines metabolic and anatomic data, useful in unknown primaries and systemic staging	False positives with inflammation/ infection, high cost, radiation exposure

Discussion

The accurate evaluation of cervical LN metastasis is crucial in the management of head and neck cancers, particularly in squamous cell carcinoma and thyroid malignancies, where nodal involvement directly influences staging, prognosis, and treatment strategies [1-4]. Radiologic imaging plays a central role in both initial assessment and surveillance. Despite advancements, no single modality is definitive; thus, a multimodal approach remains standard.

US is the most widely used first-line modality due to its accessibility, high resolution, and lack of radiation. B-mode criteria such as the absence of a fatty hilum, a round shape, and heterogeneous echotexture are well-established indicators of malignancy [94-96]. Color and power Doppler improve diagnostic performance by assessing vascularity, with central or mixed flow suggesting malignancy [97]. However, both B-mode and Doppler are operator-dependent and less effective for deep-seated nodes or in obese patients [53-56]. Nevertheless, in daily clinical practice, ultrasound remains indispensable for surgical decision-making in papillary thyroid carcinoma and other superficial tumors, where the presence or absence of suspicious nodes can alter the extent of lymph node dissection, reduce surgical morbidity, and guide the need for postoperative radioactive iodine therapy.

CT offers excellent spatial resolution and is particularly valuable in evaluating extracapsular spread and nodes in inaccessible locations [22-26]. When combined with coronal reconstructions or arterial-phase imaging, its diagnostic accuracy improves further, particularly for lateral neck nodes in thyroid cancer [28]. However, its specificity is limited by reliance on size criteria alone [24,25]. In addition, ionizing radiation and contrast nephrotoxicity are relevant considerations, particularly in younger patients and those requiring repeated imaging. Despite these limitations, CT is often the most practical modality in oncologic staging pathways, particularly for patients requiring comprehensive assessment of both local disease and pulmonary metastases.

MRI provides superior soft-tissue contrast and functional information via DWI. Several meta-analyses confirm its high accuracy in differentiating malignant from benign nodes based on ADC values [41,42,49]. Advanced sequences, such as DK imaging and intravoxel incoherent motion, further enhance differentiation, though standardization remains a limitation [44,45]. MRI is particularly useful in the evaluation of retropharyngeal nodes, skull base invasion, and complex soft tissue relationships that are not easily appreciated on CT. However, longer scan times, higher cost, and motion artifacts can restrict its routine use, making it most suitable in specialized centers or selected patient groups.

PET/CT is invaluable in systemic staging and detecting occult nodal metastasis, especially in cases of unknown primary or suspected extranodal extension [9,31,36]. While its sensitivity and specificity are generally high, inflammatory nodes may yield false positives, and resolution may be inadequate for micrometastases [36,37]. For thyroid cancer, its use is typically reserved for high-risk or post-therapy surveillance scenarios [39,40]. Importantly, FDG uptake correlates with tumor aggressiveness and metabolic activity, providing prognostic information in addition to detection, which can influence the aggressiveness of surgical or systemic management.

Elastography, particularly SWE and ARFI imaging, adds a functional dimension to ultrasound by quantifying tissue stiffness. Meta-analyses report sensitivities and specificities exceeding 80% for differentiating malignant from benign nodes [12,92,93]. SWE has been shown to outperform conventional B-mode in sensitivity and negative predictive value, providing a non-invasive, reproducible adjunct to nodal assessment [13,88,90]. Combined techniques, such as elastography with CEUS, further enhance diagnostic accuracy [71-73]. In clinical application, elastography is particularly promising in triaging equivocal nodes for biopsy, reducing unnecessary invasive procedures while increasing diagnostic yield.

In thyroid cancer, high-resolution US remains essential, but studies show combined imaging (US + CT or elastography) improves nodal detection, particularly for lateral and central compartment metastases [7,53,59,62]. Similarly, in oral cavity and oropharyngeal cancers, imaging must account for anatomical complexity and the likelihood of occult metastases. Studies support the use of CT and MRI for surgical planning, especially in cN0 necks [2,3,22,23]. The integration of multiple imaging findings into treatment algorithms has been shown to improve oncologic outcomes by enabling earlier and more accurate detection of metastatic spread, thereby guiding more tailored interventions.

The role of imaging is evolving with radiomics and machine learning, which extract high-dimensional data from imaging for improved classification. Early studies suggest potential in predicting extranodal extension, nodal metastasis, and treatment response [50,56]. Integration of such approaches with traditional imaging could pave the way for more personalized, non-invasive diagnostics. Future directions also include the application of molecular imaging tracers beyond FDG, such as amino acid–based or hypoxia-specific agents, which may offer greater specificity in distinguishing malignant from inflammatory nodes.

Despite these advancements, challenges remain. Differentiating reactive nodes from early metastases can be difficult, especially in inflammatory or post-treatment settings. Operator dependence, interobserver variability, and lack of standardized protocols for newer techniques like elastography and CEUS can limit reproducibility. Furthermore, most available studies are single-center, with small patient cohorts and heterogeneous inclusion criteria, which reduces generalizability. The narrative design of this review itself represents a limitation, as it does not provide pooled quantitative estimates. Large-scale, multicenter prospective trials and standardized imaging protocols are needed to validate functional and multimodal approaches.

Taken together, current evidence indicates that no single imaging modality is sufficient; rather, complementary integration of ultrasound, cross-sectional imaging, and metabolic techniques yields the highest diagnostic accuracy. As research advances, the incorporation of radiomics, artificial intelligence, and molecular imaging holds the promise of not only improving diagnostic precision but also enabling risk-adapted, personalized management strategies for patients with cervical lymphadenopathy.

This review has several limitations. Most included studies were single-center with heterogeneous designs, small patient cohorts, and variable imaging protocols, which limits generalizability. The narrative review design also precludes pooled quantitative analysis. Finally, newer techniques such as elastography, CEUS, and radiomics lack standardized parameters, underscoring the need for multicenter prospective validation before routine clinical adoption.

Conclusions

Cervical lymph node evaluation is fundamental for accurate staging, prognosis, and therapeutic planning in head and neck cancers, including squamous cell carcinoma, thyroid carcinoma, and lymphomas. Among available techniques, ultrasound remains the preferred first-line modality for superficial and lateral neck assessment, particularly when combined with Doppler or elastography. CT and MRI provide complementary cross-sectional evaluation of deep or inaccessible nodes, with MRI offering superior soft-tissue characterization and functional sequences such as DWI. PET/CT contributes metabolic information that is especially valuable for systemic staging, unknown primary tumors, and high-risk thyroid carcinoma. Elastography and contrast-enhanced ultrasound add functional data that improve specificity and guide biopsy decisions. Optimal diagnostic performance arises from integrating these modalities according to clinical context, rather than relying on a single technique. Future directions include prospective multicenter validation of advanced techniques, as well as the application of radiomics and artificial intelligence to improve reproducibility, reduce operator dependence, and support individualized treatment strategies.

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