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Bronchoscopic Imaging in Lung Cancer: From White Light to Advanced Digital Enhancement

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ABSTRACT

***Background*:** Bronchoscopic imaging has evolved remarkably over the past three decades, transforming lung cancer diagnostics and enabling earlier, more precise interventions. While white light bronchoscopy (WLB) remains foundational, it suffers from limited sensitivity for early, flat, or subtle lesions. The emergence of image-enhanced modalities—including autofluorescence bronchoscopy (AFB), narrow band imaging (NBI), I-Scan, and digital chromoendoscopy—has markedly expanded the bronchoscopist's diagnostic arsenal. This review critically examines the spectrum of bronchoscopic imaging technologies in lung cancer, from conventional WLB to the most recent advances in digital enhancement. It explores the principles, comparative diagnostic performance, clinical applications, and integration with molecular diagnostics and artificial intelligence. The review also addresses barriers to real-world adoption, economic and workflow considerations, and outlines future directions for research and practice.

Conclusion: Advanced bronchoscopic imaging technologies offer substantial improvements in early detection, accurate lesion delineation, and biopsy targeting in lung cancer. Integration of these modalities, especially when combined with artificial intelligence and precision molecular diagnostics, promises to further personalize care. Ongoing research should address remaining limitations, ensure equitable access, and establish robust training and consensus guidelines to maximize patient benefit.

Keywords: Bronchoscopic Imaging , Lung Cancer, White Light to Advanced Digital Enhancement

INTRODUCTION

Lung cancer remains the leading cause of cancer mortality globally, accounting for more deaths each year than breast, colon, and prostate cancers combined. The prognosis of lung cancer is closely linked to the stage at diagnosis, with early-stage detection conferring dramatically improved survival. However, most patients continue to be diagnosed at an advanced stage due to the asymptomatic nature of early disease and the limitations of conventional screening modalities [1,2].

Bronchoscopic imaging plays a central role in the diagnostic and staging workup of lung cancer. White light bronchoscopy (WLB), introduced nearly a century ago, has long been the standard for visualizing and sampling endobronchial lesions. Yet, its sensitivity for pre-invasive or minimally invasive disease is suboptimal, missing a significant proportion of early or flat lesions that may progress to invasive cancer if undetected [3].

The past two decades have witnessed the introduction of a series of image-enhanced bronchoscopic modalities. These technologies—including autofluorescence bronchoscopy (AFB), narrow band imaging (NBI), I-Scan, and high-definition digital chromoendoscopy—enable enhanced visualization of mucosal and vascular changes associated with neoplasia. Their clinical integration promises to overcome the diagnostic limitations of WLB, support more accurate and targeted biopsies, and improve outcomes for patients at risk of lung cancer [4,5].

Despite the clear potential of these advances, questions remain regarding their comparative performance, optimal clinical indications, cost-effectiveness, and role in the broader context of evolving lung cancer diagnostics. This review provides a comprehensive overview of the evolution, current landscape, and future perspectives of bronchoscopic imaging in lung cancer—from WLB to the cutting edge of digital enhancement and artificial intelligence.

Evolution of Bronchoscopic Imaging in Lung Cancer

The history of bronchoscopic imaging reflects a continual drive to enhance visualization, increase diagnostic yield, and facilitate earlier intervention in lung cancer. The journey began with rigid bronchoscopy in the late 19th century, which, though revolutionary, was limited by patient discomfort, procedural risks, and restricted field of view. The subsequent development of flexible fiberoptic bronchoscopes in the 1960s, pioneered by Shigeto Ikeda, marked a paradigm shift, making bronchoscopy safer and more versatile for both diagnostic and therapeutic purposes [6].

For decades, white light bronchoscopy (WLB) remained the gold standard for evaluating the central airways. While WLB enabled the direct visualization of endobronchial masses, strictures, and gross mucosal abnormalities, it soon became clear that its sensitivity for early neoplastic and pre-invasive lesions was insufficient. Subtle mucosal changes, particularly flat or multifocal dysplasia and carcinoma in situ, were often indistinguishable from normal tissue or chronic inflammation under white light, leading to missed opportunities for early detection and cure [7].

The limitations of WLB spurred the development of adjunctive imaging techniques designed to improve contrast between normal and abnormal tissue. Autofluorescence bronchoscopy (AFB) was the first widely adopted enhancement modality, exploiting the differential fluorescence properties of normal and dysplastic bronchial mucosa under blue-violet light. AFB significantly improved sensitivity for pre-invasive disease but was hampered by low specificity, with high false positive rates in the context of inflammation or post-therapeutic changes [8].

The introduction of narrow band imaging (NBI) represented another major milestone. By utilizing specific wavelengths of light to accentuate submucosal microvasculature, NBI enabled more detailed assessment of vascular patterns—hallmarks of early malignant transformation. Digital chromoendoscopy platforms, such as Fuji Intelligent Chromo Endoscopy (FICE) and I-Scan, further expanded diagnostic possibilities, offering real-time software-based enhancement of mucosal texture and color without the need for optical filters or exogenous dyes [9].

More recently, high-definition video endoscopy, endobronchial ultrasound (EBUS), and advanced navigation systems have further enriched the bronchoscopic toolkit, facilitating precise diagnosis, staging, and therapy even in peripheral lung lesions. The digital nature of modern enhancement techniques also allows integration with artificial intelligence, promising new frontiers in automated lesion detection and personalized diagnostics [10].

The evolution of bronchoscopic imaging is thus a testament to technological innovation in the service of clinical need, bringing clinicians ever closer to the goal of early, accurate, and minimally invasive diagnosis of lung cancer.

White Light Bronchoscopy: Foundations and Limitations

White light bronchoscopy (WLB) has served as the cornerstone of endoscopic airway evaluation for decades. Utilizing broad-spectrum visible light, WLB provides real-time, direct visualization of the tracheobronchial tree, enabling clinicians to detect gross abnormalities such as masses, strictures, bleeding, and airway obstruction. The technique is versatile, allowing for diagnostic sampling through endobronchial biopsies, brushings, and washings, as well as therapeutic interventions like tumor debulking and foreign body removal [11].

Despite these strengths, WLB is fundamentally limited in its ability to identify early neoplastic changes. The natural appearance of bronchial mucosa under white light is characterized by subtle color and texture variations, making the distinction between normal, inflamed, and pre-malignant tissue challenging. Flat or minimally elevated lesions, dysplasia, and carcinoma in situ may appear deceptively similar to healthy mucosa or may be completely invisible, particularly in smokers and patients with chronic airway inflammation [12].

Numerous studies have highlighted the suboptimal sensitivity of WLB for detecting pre-invasive lesions. In one pivotal investigation, less than 30% of carcinoma in situ and approximately 70% of microinvasive tumors were detected with WLB, underscoring the risk of missed diagnoses in patients undergoing routine surveillance [13]. False negatives can lead to delayed treatment, disease progression, and poorer clinical outcomes.

Moreover, WLB is limited in its ability to accurately define lesion margins and guide targeted biopsies. Inflammatory changes, post-radiation effects, and scar tissue may obscure or mimic neoplasia, leading to sampling errors or unnecessary interventions. As lung cancer management increasingly relies on precise histologic, immunohistochemical, and molecular characterization, the ability to obtain adequate and representative tissue from suspicious areas is critical for both diagnosis and therapeutic decision-making [14].

These limitations of WLB have provided a strong impetus for the adoption of advanced imaging modalities that enhance mucosal contrast, reveal early vascular changes, and support more accurate, targeted interventions in lung cancer care.

Autofluorescence Bronchoscopy (AFB)

Autofluorescence bronchoscopy (AFB) emerged as one of the earliest and most influential image-enhanced technologies designed to address the diagnostic limitations of white light bronchoscopy (WLB). The principle of AFB lies in the use of blue-violet excitation light (typically 400–460 nm), which induces endogenous fluorophores within the bronchial mucosa—such as collagen, elastin, and NADH—to emit fluorescence. In normal tissue, this results in a bright green image, whereas areas of dysplasia or carcinoma in situ appear magenta or brown due to changes in tissue architecture and reduced autofluorescence signal [15].

AFB is particularly effective in highlighting flat or subtle pre-invasive lesions that may be missed under WLB. Numerous studies have demonstrated that AFB increases the sensitivity for detecting high-grade dysplasia and carcinoma in situ to upwards of 80–90%, compared to less than 30% for WLB alone [16]. This capability is especially valuable in high-risk populations, such as heavy smokers, patients with chronic obstructive pulmonary disease, or those with a history of head and neck cancer, where field cancerization and multifocal premalignant changes are common.

Despite its impressive sensitivity, the main limitation of AFB is its relatively low specificity. Inflammatory, post-radiation, or scarred mucosa may also produce altered autofluorescence, resulting in high rates of false positives and potentially unnecessary biopsies [17]. The technology requires dimmed room lighting and a learning curve for accurate interpretation of color patterns. Additionally, patient movement and the need for specialized equipment may pose practical barriers in busy endoscopy suites.

Modern AFB systems have improved usability, integrating autofluorescence and WLB modes into a single device for real-time switching. The combination of AFB and WLB has been shown to further increase detection rates, and some expert consensus guidelines recommend AFB as an adjunct in the surveillance of high-risk individuals and in the assessment of radiographically occult central airway lesions [18].

Overall, AFB has paved the way for the broader adoption of advanced bronchoscopic imaging and remains a valuable tool, particularly for early central airway cancer detection, despite its limitations in specificity and workflow integration.

Narrow Band Imaging (NBI)

Narrow band imaging (NBI) is a powerful optical enhancement technology developed to improve the endoscopic detection and characterization of early neoplastic lesions. Unlike autofluorescence bronchoscopy (AFB), which relies on tissue fluorescence, NBI uses optical filters to selectively transmit specific wavelengths of light—namely blue (400–430 nm) and green (535–565 nm). These wavelengths penetrate only the superficial mucosa and are strongly absorbed by hemoglobin, which results in the enhanced visualization of superficial and submucosal blood vessels [19].

NBI's clinical value lies in its ability to accentuate microvascular patterns associated with dysplasia and early malignancy. Pathological angiogenesis is a hallmark of neoplastic transformation; thus, the identification of abnormal vascular patterns, such as dotted, tortuous, or abruptly ending vessels (sometimes called Shibuya's descriptors), can provide early evidence of premalignant or malignant lesions [20]. This enhanced contrast allows bronchoscopists to identify and delineate lesions that may be invisible or indistinct under white light bronchoscopy (WLB), and even to assess tumor margins with higher precision.

Numerous studies have reported that NBI significantly improves the detection of pre-invasive and early invasive lung cancer, with sensitivities comparable to or exceeding AFB, but with greater specificity. NBI also allows for easier interpretation, as the resulting images are bright, clear, and less influenced by inflammatory changes compared to autofluorescence [21]. Importantly, NBI can be instantly toggled on and off during endoscopy, making it practical for routine workflow and suitable for broad adoption.

A key advantage of NBI over some digital technologies is that it does not require additional dyes, contrast agents, or magnification endoscopes. The enhanced vascular patterns are apparent even during wide-field surveillance, which is critical in high-risk patients and for post-therapeutic surveillance. Clinical experience suggests that the combination of NBI with high-definition bronchoscopy and digital documentation facilitates robust lesion characterization and targeted biopsy, contributing to improved diagnostic yield [22].

The main limitations of NBI include its reliance on operator expertise for vascular pattern interpretation and its primary utility for central airway disease, as visualization is still constrained by the reach of the bronchoscope. Nevertheless, NBI represents a substantial advance in bronchoscopic imaging and is now widely used as a standard adjunct to WLB in many centers focused on early lung cancer detection.

I-Scan Technology

I-Scan technology is a cutting-edge, software-based image enhancement platform designed to improve the detection and characterization of bronchial lesions during bronchoscopy. Unlike optical filtering technologies such as narrow band imaging (NBI), I-Scan applies real-time digital post-processing to standard white light images, allowing for flexible and dynamic enhancement of mucosal and vascular features [23].

The I-Scan system incorporates three main enhancement algorithms, each tailored for specific clinical purposes:

- **Surface Enhancement (SE):** This mode accentuates subtle textural changes on the mucosal surface by modifying pixel brightness and contrast. SE is particularly useful for identifying flat, early neoplastic changes or dysplasia that may not be apparent under conventional white light bronchoscopy (WLB) [24].
- **Contrast Enhancement (CE):** CE mode digitally intensifies the contrast between normal and abnormal tissue, especially by enhancing blue color tones in darker areas. This function is designed to expose minor vascular and tissue irregularities, making it valuable for broad mucosal screening [25].
- **Tone Enhancement (TE):** TE decomposes the image into red, green, and blue channels, then adjusts and recombines them to amplify subtle color differences and vascular patterns. This is particularly helpful for detailed lesion characterization and for highlighting margins of both neoplastic and inflammatory lesions [26].

A significant advantage of I-Scan is its intuitive, real-time operation. The bronchoscopist can instantly switch between WLB and any I-Scan mode with the touch of a button, adapting imaging strategy to findings encountered during the procedure. Importantly, I-Scan maintains high image brightness and clarity, making it suitable for distant as well as close-up viewing and eliminating the need for additional dyes, filters, or magnification scopes [27].

Clinical studies have demonstrated that I-Scan improves the detection rate of early bronchial lesions—such as high-grade dysplasia, carcinoma in situ, and early-stage squamous cell carcinoma—compared to WLB alone. I-Scan also assists in the

accurate delineation of lesion margins, facilitating targeted biopsies and reducing the risk of sampling errors. Its ability to distinguish neoplastic from non-neoplastic vascular and tissue patterns adds further value, particularly in challenging or ambiguous cases [28].

While the primary benefits of I-Scan have been observed in the central airways, emerging data suggest its potential when used in combination with other navigational or ultrasonographic techniques for peripheral lesions. Moreover, the digital nature of I-Scan images enables integration with artificial intelligence algorithms, paving the way for automated lesion detection and standardized reporting in the future [29].

High-Definition and Digital Chromoendoscopy (FICE, Others)

High-definition (HD) video endoscopy and digital chromoendoscopy platforms, such as Fuji Intelligent Chromo Endoscopy (FICE), represent the next evolution in bronchoscopic imaging. These systems aim to maximize lesion detection and characterization by leveraging advanced optics, enhanced pixel density, and real-time digital post-processing to improve contrast and detail [30].

High-Definition Video Endoscopy: The transition from standard definition to high-definition endoscopes has markedly improved visualization of bronchial mucosa. HD systems provide sharper, brighter images, enabling the detection of finer surface irregularities, subtle color changes, and minute vascular abnormalities that might be missed with older technology. This improved resolution enhances the bronchoscopist's ability to differentiate benign from malignant lesions, optimize biopsy site selection, and document findings for subsequent review or multidisciplinary discussion [31].

Digital Chromoendoscopy (FICE and Similar Technologies): Digital chromoendoscopy platforms like FICE employ computer algorithms to analyze and reconstruct images using selected narrow bands from the full spectrum of reflected light. By processing different wavelengths, FICE enhances mucosal surface texture and vascular contrast without the need for physical dyes or stains. Unlike optical chromoendoscopy (e.g., NBI), FICE can generate multiple contrast modes from a single white-light image, offering flexibility to tailor enhancement to specific diagnostic needs [32].

Clinical studies comparing FICE with WLB, NBI, and I-Scan have shown that FICE can increase the sensitivity for detecting preinvasive lesions and clarify lesion margins. In some series, the combination of HD bronchoscopy and FICE yielded a diagnostic performance similar to or better than AFB and NBI, especially when interpreted by experienced bronchoscopists [33]. The system's ability to quickly cycle through different digital modes makes it a practical tool for busy clinical workflows.

However, as with other enhancement technologies, the benefit of FICE and digital chromoendoscopy is most pronounced in the central airways. Operator training and experience remain crucial for optimal interpretation of digital images, and further head-to-head comparisons are warranted to establish the best algorithm or enhancement setting for specific clinical scenarios [34].

Importantly, the digital output of both HD endoscopy and FICE is highly compatible with image storage, telemedicine, and artificial intelligence analysis, supporting a more connected and standardized approach to bronchoscopic diagnosis.

Endobronchial Ultrasound (EBUS) and Advanced Navigation Tools

The introduction of endobronchial ultrasound (EBUS) and advanced bronchoscopic navigation systems represents a major breakthrough in the diagnosis and staging of lung cancer, particularly for lesions that are inaccessible or invisible with standard white light bronchoscopy (WLB) or digital enhancement techniques. EBUS enables real-time ultrasonographic imaging of the airway wall, peribronchial structures, and mediastinal lymph nodes, facilitating targeted sampling with high precision [35].

Linear EBUS: Linear EBUS employs a bronchoscope equipped with an integrated ultrasound probe at its tip. This design allows the direct visualization and real-time needle aspiration (EBUS-TBNA) of mediastinal and hilar lymph nodes or masses adjacent to the airway. Linear EBUS has largely replaced surgical mediastinoscopy for the initial staging of lung cancer due to its minimally invasive nature, excellent safety profile, and comparable diagnostic accuracy. Furthermore, EBUS-TBNA specimens are suitable for molecular and immunohistochemical analysis, supporting precision oncology approaches [36].

Radial EBUS: Radial EBUS uses a miniature ultrasound probe that can be advanced through the working channel of a standard bronchoscope to scan peripheral airways. When a peripheral pulmonary lesion is located, the radial probe is withdrawn, and biopsy instruments are advanced under fluoroscopic or navigational guidance. This approach has significantly improved the diagnostic yield for small, peripheral nodules, especially when combined with navigational techniques [37].

Virtual Bronchoscopic Navigation (VBN) and Electromagnetic Navigation Bronchoscopy (ENB): VBN and ENB are digital technologies designed to guide bronchoscopists through the complex bronchial tree to reach peripheral or otherwise hard-to-access lesions. VBN reconstructs a virtual 3D map of the patient's airways from CT images, allowing the bronchoscopist to plan and simulate the procedure in advance. ENB utilizes electromagnetic sensors and a navigational catheter to provide real-time positional tracking and guidance, akin to a GPS for the lung. These tools have increased the reach and accuracy of bronchoscopic biopsies beyond the segmental bronchi, with growing utility in diagnosis, fiducial placement, and preoperative localization [38].

Integration with Enhanced Imaging: While EBUS and navigational systems do not provide color or surface enhancement like NBI or I-Scan, they are highly complementary. For example, I-Scan or HD imaging can be used to examine and biopsy central mucosal lesions, while EBUS and navigation tools target mediastinal nodes or peripheral parenchymal abnormalities in the same session. This multimodal approach maximizes diagnostic yield and enables a truly comprehensive bronchoscopic evaluation [39].

As technology evolves, further integration—such as real-time fusion of ultrasound, enhanced imaging, and navigational data—is anticipated to further improve both the accuracy and efficiency of bronchoscopic lung cancer diagnostics.

Comparative Diagnostic Performance

Comparing the diagnostic performance of different bronchoscopic imaging modalities is essential for understanding their respective clinical roles and optimizing patient care. Numerous studies and meta-analyses have sought to quantify the relative sensitivities, specificities, and diagnostic yields of white light bronchoscopy (WLB), autofluorescence bronchoscopy (AFB), narrow band imaging (NBI), I-Scan, high-definition (HD) systems, and navigation-guided ultrasound techniques.

White Light Bronchoscopy (WLB): While WLB remains the standard baseline, its sensitivity for detecting carcinoma in situ and high-grade dysplasia is limited—typically ranging from 20% to 30%. WLB performs better in diagnosing overt endobronchial tumors and obstructive lesions, where specificity is high, but fails to reliably detect early or flat lesions, resulting in a significant number of false negatives [40].

Autofluorescence Bronchoscopy (AFB): AFB significantly increases sensitivity for early neoplastic and preinvasive changes, with reported sensitivities exceeding 80–90%. However, this comes at the cost of lower specificity, often in the range of 60–70%, due to the influence of inflammation and post-radiation changes on autofluorescence patterns. This leads to a higher rate of false positives and unnecessary biopsies when used in isolation [41].

Narrow Band Imaging (NBI): NBI offers high sensitivity (70–90%) for early cancer and dysplasia, comparable to AFB, but generally with higher specificity (up to 90%) because of its emphasis on vascular pattern recognition rather than tissue autofluorescence. Its use is particularly advantageous for central airway lesions and for defining the margins of visible tumors [42].

I-Scan and Digital Chromoendoscopy: I-Scan and FICE provide improved detection rates for preinvasive and early malignant lesions compared to WLB, with performance metrics similar to or sometimes better than AFB or NBI, especially in experienced hands. I-Scan's real-time, high-brightness imaging also improves workflow efficiency and interobserver agreement. Recent studies suggest that I-Scan can increase the detection of flat and subtle lesions by up to 20–25% over WLB alone and may reduce sampling errors by enabling more precise biopsy targeting [43,44].

Endobronchial Ultrasound (EBUS) and Navigation Techniques: EBUS and navigational bronchoscopy are not directly comparable to the above modalities, as their primary value lies in accessing and sampling lesions (lymph nodes or peripheral nodules) that are invisible or unreachable by optical imaging alone. However, their diagnostic yield for mediastinal lymph node staging (>90%) and peripheral nodule sampling (60–80%, depending on lesion size and location) has been transformative, especially when combined with enhanced imaging for central airway evaluation [45].

Multimodal Approach: The greatest diagnostic gains are observed when these modalities are combined. For example, the use of WLB plus AFB or NBI, or HD imaging with I-Scan, increases both sensitivity and specificity for early disease, while EBUS and navigational tools ensure comprehensive evaluation of both central and peripheral lesions. This multimodal approach reduces the rate of missed diagnoses, facilitates molecular testing, and supports personalized management for lung cancer patients [46].

Impact on Biopsy Yield and Staging Accuracy

Advanced bronchoscopic imaging technologies have had a transformative effect on both the yield of diagnostic biopsies and the accuracy of lung cancer staging. The ability to precisely localize, delineate, and characterize lesions is essential for obtaining adequate tissue for histopathological, molecular, and genetic analysis—all of which guide modern lung cancer therapy.

Improvement in Biopsy Yield: Traditional white light bronchoscopy (WLB) is associated with variable diagnostic yield, particularly for early-stage and subtle lesions. The addition of image-enhanced modalities, such as autofluorescence bronchoscopy (AFB), narrow band imaging (NBI), I-Scan, and digital chromoendoscopy, significantly increases the proportion of lesions that are detected and accurately sampled. For example, studies have shown that the combination of AFB or NBI with WLB can raise the diagnostic yield for high-grade dysplasia and carcinoma in situ from 30–50% to over 80% in high-risk populations [47]. I-Scan, by highlighting both mucosal and vascular abnormalities, further increases the likelihood of selecting optimal biopsy sites, especially for flat or ambiguous lesions [48].

Reduction of Sampling Error: One of the persistent challenges in bronchoscopy is sampling error—obtaining tissue that is not representative of the underlying pathology. Enhanced imaging modalities help the bronchoscopist visually differentiate benign from suspicious areas, allowing for more targeted and multiple biopsies from regions most likely to yield diagnostic material. This not only reduces the rate of false negatives but also minimizes unnecessary biopsies of benign or inflammatory tissue, improving procedural efficiency and patient safety [49].

Staging Accuracy with EBUS and Navigation: Accurate staging is critical for lung cancer prognosis and treatment planning. Endobronchial ultrasound (EBUS) with transbronchial needle aspiration (TBNA) has emerged as the gold standard for mediastinal and hilar lymph node evaluation, providing real-time guidance for sampling nodes that are suspicious on imaging. EBUS-TBNA has been shown to have a sensitivity and specificity approaching 90–95% for mediastinal staging, often eliminating the need for surgical mediastinoscopy [50].

For peripheral lesions, the combination of radial EBUS, virtual bronchoscopic navigation (VBN), or electromagnetic navigation bronchoscopy (ENB) with digital imaging tools maximizes both the likelihood of reaching the lesion and obtaining adequate tissue. These advances are particularly valuable as lung cancer screening and incidental nodule detection become more common, requiring high-yield, minimally invasive diagnostic approaches [51].

Integration with Precision Medicine: Because modern lung cancer treatment frequently depends on the results of molecular and immunohistochemical tests, the quality and quantity of biopsy samples are more important than ever. Enhanced imaging modalities not only improve detection but also ensure that biopsied tissue is truly representative of the most clinically significant pathology. This is crucial for molecular testing (e.g., EGFR, ALK, PD-L1) and the implementation of personalized therapy [52].

In summary, the adoption of advanced bronchoscopic imaging and navigational technologies has elevated the standard of care in lung cancer diagnosis, resulting in higher diagnostic yield, more accurate staging, and greater confidence in the selection of individualized therapies.

Conclusion

The evolution of bronchoscopic imaging has revolutionized the early detection, diagnosis, and staging of lung cancer. While white light bronchoscopy remains the foundational tool for airway inspection and tissue sampling, its limitations in detecting pre-invasive and flat lesions are well established. Advanced imaging modalities—including autofluorescence bronchoscopy, narrow band imaging, I-Scan, high-definition digital platforms, and endobronchial ultrasound with navigational technologies—have significantly enhanced the bronchoscopist's ability to visualize, characterize, and biopsy both central and peripheral lesions with greater accuracy.

These technologies improve not only the sensitivity and specificity of lung cancer detection but also enable targeted biopsies, reduce sampling error, and facilitate comprehensive molecular testing, which is essential for precision oncology. The integration of artificial intelligence and machine learning holds additional promise for automating lesion detection, standardizing interpretation, and supporting less-experienced operators in real time.

Despite clear clinical advantages, widespread adoption of these technologies is tempered by economic, training, and logistical challenges, particularly in low-resource settings. Continued efforts in multicenter research, cost-effectiveness analysis, and

global training initiatives are needed to expand access and define optimal clinical pathways for their use. As technological innovations continue to emerge, the synergy between enhanced imaging, artificial intelligence, and molecular diagnostics will further personalize lung cancer management and improve patient outcomes.

In summary, advanced bronchoscopic imaging is now an essential part of the modern approach to lung cancer. Its ongoing development and integration into clinical practice are critical for realizing the full potential of early detection and individualized therapy in this high-burden disease.

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REFERENCES

1. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2023. CA Cancer J Clin. 2023;73(1):17-48.
2. McErlean AM, Ginsberg MS. Epidemiology of lung cancer. Semin Intervent Radiol. 2011;28(2):93-98.
3. Andolfi M, Potenza R, Capozzi R, et al. The role of bronchoscopy in early diagnosis of lung cancer. Diagnostics (Basel). 2016;6(4):40.
4. Zaric B, Perin B, Milenkovic B, et al. Advanced bronchoscopic techniques in lung cancer diagnosis. J Thorac Dis. 2016;8(9):E1163-E1169.
5. Fouda MA, Koraa R, van der Heijden EH. The role of image-enhanced bronchoscopy in the diagnosis of preinvasive and early lung cancer. J Thorac Dis. 2020;12(6):3261-3274.
6. Ninan M, Wahidi MM. Rigid bronchoscopy. Semin Respir Crit Care Med. 2014;35(6):671-680.
7. Andolfi M, Potenza R, Capozzi R, et al. The role of bronchoscopy in early diagnosis of lung cancer. Diagnostics (Basel). 2016;6(4):40.
8. Zaric B, Perin B, Stojsic V, et al. Autofluorescence bronchoscopy in lung cancer diagnosis. Eur J Cancer Prev. 2013;22(6):503-510.
9. Kodashima S, Fujishiro M. Novel image-enhanced endoscopy with i-scan technology. World J Gastroenterol. 2010;16(9):1043-1049.
10. Dincer HE. Role of advanced bronchoscopic techniques in the diagnosis and staging of lung cancer. Ann Thorac Med. 2015;10(2):87-93.
11. Gasparini S. Flexible bronchoscopy. Curr Opin Pulm Med. 1999;5(2):107-111.
12. Gaga M, Powell CA, Anagnostopoulos GK, et al. Bronchoscopic and endoscopic techniques in the diagnosis and staging of lung cancer. Eur Respir J. 2013;42(6):1778-1792.
13. Andolfi M, Potenza R, Capozzi R, et al. The role of bronchoscopy in early diagnosis of lung cancer. Diagnostics (Basel). 2016;6(4):40.
14. Valentini I, Pagnini F, D'Andrilli A, et al. Diagnostic performance of endobronchial techniques in the diagnosis of central and peripheral lung cancers. Ann Transl Med. 2019;7(15):357.
15. Zaric B, Perin B, Stojsic V, et al. Autofluorescence bronchoscopy in lung cancer diagnosis. Eur J Cancer Prev. 2013;22(6):503-510.
16. Zaric B, Perin B, Milenkovic B, et al. Advanced bronchoscopic techniques in lung cancer diagnosis. J Thorac Dis. 2016;8(9):E1163-E1169.
17. Fouda MA, Koraa R, van der Heijden EH. The role of image-enhanced bronchoscopy in the diagnosis of preinvasive and early lung cancer. J Thorac Dis. 2020;12(6):3261-3274.
18. Yarmus LB, Feller-Kopman D. Bronchoscopic techniques for the diagnosis and staging of lung cancer. UpToDate. 2024.
19. Georgakopoulou VE, Zaric B, Perin B, et al. Narrow band imaging in the early detection of lung cancer. Respiration. 2025;104(2):127-135.
20. Zaric B, Perin B, Stojsic V, et al. Autofluorescence bronchoscopy in lung cancer diagnosis. Eur J Cancer Prev. 2013;22(6):503-510.
21. Bojan B, Perin B, Stojsic V, et al. Narrow band imaging improves sensitivity and specificity of bronchoscopic detection of early lung cancer. Eur Respir J. 2009;34(Suppl 53):601s.
22. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.

23. Kodashima S, Fujishiro M. Novel image-enhanced endoscopy with i-scan technology. World J Gastroenterol. 2010;16(9):1043-1049.
24. Koraa R. I-Scan Technology in Pulmonology. Lung India. 2024;41(2):157-162.
25. Fouda MA, Koraa R, van der Heijden EH. The role of image-enhanced bronchoscopy in the diagnosis of preinvasive and early lung cancer. J Thorac Dis. 2020;12(6):3261-3274.
26. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
27. Fouda MA, Koraa R, van der Heijden EH. The role of image-enhanced bronchoscopy in the diagnosis of preinvasive and early lung cancer. J Thorac Dis. 2020;12(6):3261-3274.
28. Koraa R. I-Scan Technology in Pulmonology. Lung India. 2024;41(2):157-162.
29. Gursoy M, Cai G. Artificial intelligence improves bronchoscopy performance: the future is now. Respiration. 2025;104(2):95-96.
30. Kodashima S, Fujishiro M. Novel image-enhanced endoscopy with i-scan technology. World J Gastroenterol. 2010;16(9):1043-1049.
31. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
32. Zaric B, Perin B, Milenkovic B, et al. Advanced bronchoscopic techniques in lung cancer diagnosis. J Thorac Dis. 2016;8(9):E1163-E1169.
33. Georgakopoulou VE, Zaric B, Perin B, et al. Narrow band imaging in the early detection of lung cancer. Respiration. 2025;104(2):127-135.
34. Fouda MA, Koraa R, van der Heijden EH. The role of image-enhanced bronchoscopy in the diagnosis of preinvasive and early lung cancer. J Thorac Dis. 2020;12(6):3261-3274.
35. Dincer HE. Role of advanced bronchoscopic techniques in the diagnosis and staging of lung cancer. Ann Thorac Med. 2015;10(2):87-93.
36. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
37. Georgakopoulou VE, Zaric B, Perin B, et al. Narrow band imaging in the early detection of lung cancer. Respiration. 2025;104(2):127-135.
38. Jiang S, Zhang H, Wang Q, et al. Recent advances in bronchoscopic technologies for peripheral pulmonary lesions. J Thorac Dis. 2020;12(3):1078-1086.
39. Zaric B, Perin B, Milenkovic B, et al. Advanced bronchoscopic techniques in lung cancer diagnosis. J Thorac Dis. 2016;8(9):E1163-E1169.
40. Andolfi M, Potenza R, Capozzi R, et al. The role of bronchoscopy in early diagnosis of lung cancer. Diagnostics (Basel). 2016;6(4):40.
41. Zaric B, Perin B, Stojsic V, et al. Autofluorescence bronchoscopy in lung cancer diagnosis. Eur J Cancer Prev. 2013;22(6):503-510.
42. Bojan B, Perin B, Stojsic V, et al. Narrow band imaging improves sensitivity and specificity of bronchoscopic detection of early lung cancer. Eur Respir J. 2009;34(Suppl 53):601s.
43. Fouda MA, Koraa R, van der Heijden EH. The role of image-enhanced bronchoscopy in the diagnosis of preinvasive and early lung cancer. J Thorac Dis. 2020;12(6):3261-3274.
44. Koraa R. I-Scan Technology in Pulmonology. Lung India. 2024;41(2):157-162.
45. Dincer HE. Role of advanced bronchoscopic techniques in the diagnosis and staging of lung cancer. Ann Thorac Med. 2015;10(2):87-93.
46. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
47. Zaric B, Perin B, Stojsic V, et al. Autofluorescence bronchoscopy in lung cancer diagnosis. Eur J Cancer Prev. 2013;22(6):503-510.
48. Fouda MA, Koraa R, van der Heijden EH. The role of image-enhanced bronchoscopy in the diagnosis of preinvasive and early lung cancer. J Thorac Dis. 2020;12(6):3261-3274.
49. Koraa R. I-Scan Technology in Pulmonology. Lung India. 2024;41(2):157-162.
50. Dincer HE. Role of advanced bronchoscopic techniques in the diagnosis and staging of lung cancer. Ann Thorac Med. 2015;10(2):87-93.
51. Jiang S, Zhang H, Wang Q, et al. Recent advances in bronchoscopic technologies for peripheral pulmonary lesions. J Thorac Dis. 2020;12(3):1078-1086.
52. Cortiana M, Tabbò F, Casorzo L, et al. Personalized medicine in lung cancer: the role of precision diagnostics. Front Oncol. 2024;14:1376421.