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Advances in Image-Enhanced Bronchoscopy: I-Scan Technology and Its Role in Early Detection of Lung Cancer

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ABSTRACT

Background: Lung cancer remains the leading cause of cancer-related mortality globally, largely due to late-stage diagnosis and the subtlety of early mucosal changes. The early identification of pre-invasive and minimally invasive lung lesions is critical to improving outcomes, but conventional white light bronchoscopy (WLB) is limited by poor sensitivity for such lesions. Image-enhanced bronchoscopy (IEB) technologies, particularly I-Scan, have emerged as powerful tools in visualizing subtle airway changes, potentially bridging the diagnostic gap. This review examines the principles, technical aspects, and diagnostic utility of I-Scan bronchoscopy in the early detection of lung cancer. It compares I-Scan with WLB and other image-enhancement technologies, reviews clinical studies, and discusses the practical and economic implications of adopting I-Scan in routine respiratory endoscopy practice.

Conclusion: I-Scan bronchoscopy offers significant advances in detecting and delineating pre-invasive and early-stage lung cancer compared to conventional techniques. Its ability to enhance mucosal and vascular patterns, combined with ease of use, positions I-Scan as a promising adjunct in early cancer diagnostics. Integration with artificial intelligence and molecular profiling further expands its potential role in personalized lung cancer care. Ongoing clinical validation, cost-effectiveness studies, and training are necessary to fully realize the benefits of I-Scan and ensure its optimal implementation in real-world settings.

Keywords: *Image-Enhanced Bronchoscopy, Early Detection, Lung Cancer*

Introduction

Lung cancer continues to be the leading cause of cancer-related deaths worldwide, responsible for more fatalities than breast, prostate, and colorectal cancers combined. A critical factor contributing to the high mortality is the frequent diagnosis at advanced, often inoperable, stages, when curative interventions are limited and survival rates are poor. The five-year survival rate for lung cancer remains

10.48047/jocaaa.2024.33.06.58

below 20%, but for patients diagnosed at a very early stage, survival can exceed 70%, underscoring the vital importance of effective early detection strategies [1,2].

Traditional screening modalities such as low-dose computed tomography (LDCT) have improved mortality rates among high-risk populations. However, LDCT cannot reliably detect subtle pre-invasive or microinvasive endobronchial lesions, which frequently arise in the central airways and may progress silently before becoming radiographically evident. Thus, bronchoscopic evaluation is essential for patients with suspected central airway pathology or symptoms unexplained by imaging alone [3,4].

White light bronchoscopy (WLB) has been the mainstay of endobronchial visualization for decades. While WLB is effective for overt tumors and gross airway abnormalities, its ability to identify subtle epithelial and vascular changes associated with early cancer or pre-cancerous lesions is limited by poor contrast and subjective interpretation [5]. To address this diagnostic gap, a new generation of image-enhanced bronchoscopy (IEB) technologies has emerged. Among them, I-Scan technology leverages advanced digital post-processing algorithms to accentuate surface and vascular patterns, thereby improving visualization of lesions that would be missed by WLB [6].

Despite these advances, the real-world impact of I-Scan bronchoscopy on early lung cancer detection, its comparative utility against other IEB modalities, and its integration into diagnostic workflows remain areas of ongoing research and debate. This review aims to critically assess the development, technical principles, and clinical performance of I-Scan bronchoscopy, positioning it within the evolving landscape of bronchoscopic imaging for lung cancer. By highlighting current evidence, knowledge gaps, and future directions, this article seeks to provide a practical resource for clinicians and investigators seeking to optimize diagnostic pathways for early lung cancer.

Lung Cancer: Epidemiology and Early Detection Challenges

Lung cancer represents a global health crisis, accounting for nearly 2.2 million new cases and 1.8 million deaths annually, making it the most common cause of cancer-related mortality worldwide. Despite advances in therapeutics, survival rates remain poor, with a five-year survival rate hovering around 17–20% across most populations [7]. The primary reason for this dismal prognosis is the high proportion of patients diagnosed at an advanced stage, when curative treatment options are limited. In contrast, patients detected at an early, localized stage can achieve survival rates exceeding 70%, emphasizing the critical value of early diagnosis [8].

Over the past decade, trends in lung cancer incidence and mortality have shown modest improvement, particularly in high-income countries. These changes are attributed to declining smoking rates, improved public awareness, advances in screening, and access to newer treatments. However, significant geographic disparities persist, with increasing incidence and mortality rates observed in

10.48047/jocaaa.2024.33.06.58

several low- and middle-income regions, where tobacco control policies are less stringent and early detection resources remain scarce [9]. Socioeconomic status, sex, race, environmental exposures, and genetic predisposition further modulate risk and outcomes, making lung cancer a heterogeneous disease at both the population and molecular levels [10].

The importance of early detection is underscored by the natural history of lung carcinogenesis. Pre-invasive and microinvasive lesions often arise in the bronchial epithelium and may progress insidiously for years before becoming radiographically apparent. By the time symptoms develop or lesions are visible on imaging, the disease is typically advanced. Traditional screening tools such as chest X-ray and sputum cytology have demonstrated limited sensitivity and are no longer recommended [11]. The introduction of low-dose computed tomography (LDCT) for high-risk populations has led to reductions in lung cancer mortality, but LDCT cannot reliably detect small or centrally located pre-invasive lesions [12].

Therefore, there remains an urgent need for diagnostic technologies that can bridge the gap between radiologic detection and histopathological confirmation at the earliest stages of disease. Bronchoscopic examination, particularly with advanced image-enhancement techniques, holds promise for addressing this critical unmet need in lung cancer care [13].

Conventional Bronchoscopy: Strengths and Limitations

Conventional white light bronchoscopy (WLB) remains the foundational endoscopic technique for the evaluation of patients with suspected lung cancer or unexplained central airway symptoms. WLB allows for direct visualization of the tracheobronchial tree, detection of endobronchial masses, strictures, or mucosal irregularities, and acquisition of tissue samples via biopsy, brushing, or lavage. Over the years, the technique has undergone significant technical refinements, including improvements in optics, flexibility, and sampling tools, which have contributed to increased diagnostic yield for overt and exophytic lesions [14].

Despite these advancements, WLB has critical limitations, particularly when it comes to the detection of early, flat, or subtle mucosal lesions. The contrast between normal and pathologically altered bronchial mucosa under white light is often minimal, making it challenging for even experienced bronchoscopists to recognize pre-invasive or microinvasive changes. As a result, studies have demonstrated that WLB alone may detect fewer than 30% of carcinoma in situ (CIS) and 70% of microinvasive tumors, often missing the window for curative intervention [15]. The diagnostic sensitivity of WLB is further compromised by factors such as inflammation, hemorrhage, and anatomical variations, which can obscure or mimic neoplastic changes [16].

Sampling error is another important challenge in conventional bronchoscopy. Even when a lesion is identified, obtaining an adequate and representative tissue sample for definitive histopathological

10.48047/jocaaa.2024.33.06.58

diagnosis can be difficult, particularly in cases of submucosal, peribronchial, or peripheral tumors. This can lead to false-negative results and delays in diagnosis and treatment [17]. While advanced sampling techniques such as transbronchial needle aspiration (TBNA) and navigational bronchoscopy have improved diagnostic yield for peripheral lesions, the inherent limitations of WLB in visualizing early mucosal changes remain a significant barrier [18].

Given these constraints, there is a pressing need for technologies that can enhance mucosal visualization, improve lesion detection, and guide targeted biopsies. The development of image-enhanced bronchoscopy (IEB) modalities represents a major step forward in addressing these limitations, enabling earlier and more accurate diagnosis of lung cancer and its precursors [19].

Development of Image-Enhanced Bronchoscopic Technologies

The last two decades have witnessed remarkable innovation in bronchoscopic imaging, driven by the urgent need to improve early detection of lung cancer beyond the capabilities of conventional white light bronchoscopy (WLB). Recognizing that subtle epithelial and vascular changes often herald pre-cancerous or early malignant transformation, researchers and device manufacturers have developed a range of image-enhanced bronchoscopy (IEB) modalities to accentuate mucosal abnormalities and improve diagnostic yield [20].

Autofluorescence bronchoscopy (AFB) was among the first IEB technologies to be widely adopted in clinical practice. By exploiting the differential fluorescence emission of normal versus diseased bronchial tissue under blue-violet light, AFB significantly improves sensitivity for the detection of premalignant and early malignant lesions compared to WLB alone. However, the low specificity of AFB and its tendency to generate false positives, particularly in inflamed or reactive mucosa, have limited its widespread use [21].

Narrow band imaging (NBI) represents another major advance, utilizing filtered blue and green light to enhance the visualization of submucosal microvasculature and epithelial patterns. NBI allows for the identification of angiogenic squamous dysplasia and other vascular changes associated with neoplasia, providing valuable information on lesion characterization and margins. Clinical studies have shown that NBI can improve both the sensitivity and specificity of bronchoscopic examination, particularly when combined with magnification or high-definition imaging [22].

Additional digital enhancement technologies, such as Fuji Intelligent Chromo Endoscopy (FICE) and high magnification bronchovideoscopy, have further expanded the bronchoscopist's toolkit for early cancer detection. More recently, probe-based modalities, including radial endobronchial ultrasound (R-EBUS), confocal laser endomicroscopy (CLE), and optical coherence tomography (OCT), have provided detailed real-time assessment of airway microanatomy, aiding in the evaluation of both central and peripheral lesions [23,24].

10.48047/jocaaa.2024.33.06.58

Amid this technological evolution, I-Scan technology has emerged as a promising digital IEB modality, offering real-time surface and vascular enhancement through post-processing algorithms. Unlike some other techniques, I-Scan can be toggled instantly during routine bronchoscopy, providing seamless integration with standard workflows and potentially reducing examination time and costs [25]. As comparative studies accumulate, the unique features and advantages of I-Scan are being increasingly recognized, warranting a focused review of its principles, technical aspects, and clinical impact.

Principles of I-Scan Technology

I-Scan technology, developed by Pentax, represents a significant advancement in digital image-enhanced endoscopy, including bronchoscopic applications. Unlike optical filtering systems such as narrow band imaging (NBI), I-Scan is a software-based technology that uses real-time digital post-processing of reflected white light images. This digital approach provides three primary enhancement algorithms—Surface Enhancement (SE), Contrast Enhancement (CE), and Tone Enhancement (TE)—each targeting different aspects of mucosal and vascular architecture to improve lesion detection and characterization [26].

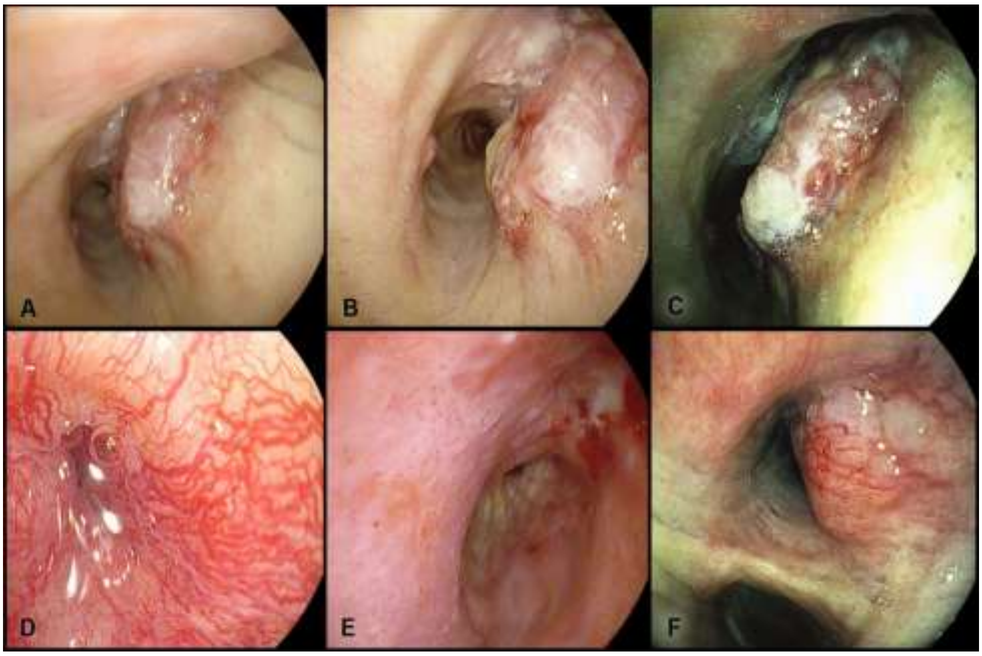

Figure (1) Sample figures of typical bronchoscopy findings illustrating the effect of i-scan image enhancement technique and differences in vascular patterns. (A–C) A centrally located squamous cell carcinoma in the right main stem bronchus with high-definition bronchoscopy (A), surface enhancement (i-scan1, B) and the combination of surface and tone enhancement (i-scan 2, C). (D–F) Different vascular patterns are illustrated. (D) Tortuous or spiral vessels, (E) dotted vessels and (F) abrupt ending vessels [26].

Surface Enhancement (SE) analyzes the luminance intensity of each pixel within the bronchoscopic image. By adjusting pixel brightness and contrast, SE highlights subtle changes in mucosal texture,

10.48047/jocaaa.2024.33.06.58

such as irregularities, granularity, or erosions that might indicate dysplasia or early neoplastic transformation. This is especially useful for delineating flat lesions or those with ill-defined borders under conventional white light [27].

Contrast Enhancement (CE) digitally enhances color differences, particularly by accentuating blue hues in relatively dark regions of the mucosa. This function is designed to expose minor vascular and tissue irregularities surrounding surface abnormalities, which may be otherwise overlooked during standard examination. CE can be particularly valuable for screening large mucosal areas for early or multifocal changes [28].

Tone Enhancement (TE) decomposes the image into red, green, and blue channels, individually adjusts their color frequencies, and then recombines them to generate a new composite image. This process provides superior contrast for subtle differences in mucosal coloration, vessel patterns, and lesion margins. TE is primarily used for a more detailed examination of already detected abnormalities, supporting lesion characterization and the identification of optimal biopsy sites [29].

One of the key strengths of I-Scan is its real-time capability: the bronchoscopist can switch between enhancement modes instantaneously with a button press on the endoscope or processor, allowing flexible and dynamic adaptation to the clinical scenario. Additionally, because I-Scan works by post-processing, it maintains the brightness and natural color tones of conventional images, ensuring familiarity and comfort for endoscopists [30].

By providing a spectrum of enhancement options tailored to screening, detection, and characterization, I-Scan technology has the potential to bridge existing diagnostic gaps in early lung cancer detection and to streamline endoscopic workflows.

Technical Aspects and Modes of I-Scan Bronchoscopy

The successful clinical application of I-Scan bronchoscopy relies on understanding its technical modes and the operational workflow during airway examination. I-Scan technology is fully integrated into compatible Pentax bronchoscopes and video processors, allowing seamless toggling between standard white light and various enhancement modes in real time. The system's intuitive interface ensures minimal disruption to the procedural flow and a gentle learning curve for bronchoscopists already familiar with digital endoscopy [31].

I-Scan offers three main enhancement modes, each tailored to a specific diagnostic objective.

- **I-Scan 1 (Surface Enhancement, SE):** Primarily used during the initial survey of the bronchial mucosa, this mode preserves natural color tones while accentuating epithelial texture. This assists in the early detection of abnormal surfaces, particularly flat lesions that might otherwise blend into the surrounding tissue under white light [32].

10.48047/jocaaa.2024.33.06.58

- **I-Scan 2 (SE + Tone Enhancement, TE):** Combining surface and tone enhancement, this mode provides additional color contrast and sharper delineation of lesion margins and vascular architecture. I-Scan 2 is most valuable for further characterization of suspicious areas identified during the screening phase. By highlighting both mucosal and submucosal features, it helps distinguish between neoplastic, inflammatory, and benign vascular patterns, thereby supporting accurate diagnosis and optimal biopsy site selection [33].
- **I-Scan 3 (SE + TE, Advanced Color Mode):** Designed for detailed analysis, this mode further intensifies color contrast and vessel pattern visibility, making it particularly beneficial for characterizing ambiguous or multifocal lesions and for guiding endoscopic sampling in complex scenarios. I-Scan 3 is also helpful for novice endoscopists or those with color vision deficiencies, as it maximizes the visual separation of tissue types and abnormal vascular changes [34].

These modes can be cycled instantly during bronchoscopy, enabling a dynamic, problem-oriented approach tailored to each patient's airway pathology. Notably, I-Scan does not require any special dyes, filters, or magnification endoscopes, and its effectiveness is maintained even during distant viewing, enabling wide-area assessment of the bronchial tree [35].

From a technical standpoint, the use of I-Scan does not significantly prolong procedure time, nor does it require substantial changes in standard specimen acquisition techniques. Its digital, software-based design makes it adaptable to future upgrades and integration with artificial intelligence tools for lesion detection and classification.

Comparative Diagnostic Performance: I-Scan vs. Other Imaging Modalities

A critical aspect of adopting any new diagnostic technology is understanding its comparative performance versus established modalities. I-Scan bronchoscopy has been evaluated alongside traditional white light bronchoscopy (WLB), autofluorescence bronchoscopy (AFB), and narrow band imaging (NBI) for its ability to detect, delineate, and characterize early and pre-invasive lung cancer lesions. Most available evidence suggests that I-Scan offers a significant improvement over WLB alone, with diagnostic performance that approaches, and in some cases rivals, other advanced imaging techniques [36].

White Light Bronchoscopy (WLB) vs. I-Scan: Studies indicate that while WLB is effective for identifying gross or exophytic tumors, its sensitivity for flat, dysplastic, or early neoplastic lesions remains low. In a comparative clinical trial, I-Scan improved the detection rate of subtle mucosal changes by enhancing the contrast and texture of epithelial surfaces, resulting in a higher sensitivity for early-stage lesions compared to WLB [37]. Furthermore, I-Scan's ability to highlight vascular

10.48047/jocaaa.2024.33.06.58

patterns enables better delineation of lesion margins, which is crucial for targeted biopsy and accurate diagnosis [38].

I-Scan vs. Autofluorescence Bronchoscopy (AFB): AFB has historically been valued for its high sensitivity in detecting pre-invasive airway lesions. However, AFB's low specificity—largely due to the high rate of false positives in inflamed or reactive mucosa—has limited its adoption. Comparative analyses demonstrate that while I-Scan's sensitivity for high-grade dysplasia or carcinoma in situ may be slightly lower than AFB, its specificity is generally higher, resulting in fewer unnecessary biopsies and interventions [39]. Additionally, I-Scan provides brighter images and can be used for wide-field surveillance without the need for dim lighting or additional hardware.

I-Scan vs. Narrow Band Imaging (NBI): NBI excels in revealing submucosal microvascular patterns associated with neoplasia, particularly "Shibuya's descriptors" such as dotted, tortuous, or abruptly ending blood vessels. Recent prospective studies suggest that I-Scan and NBI have similar sensitivities for detecting vascular and surface changes of early lung cancer. However, I-Scan offers advantages in terms of image brightness, field of view, and ease of switching between enhancement modes, making it more practical for routine screening and follow-up [40]. Moreover, I-Scan does not require magnification endoscopes to achieve optimal visualization, potentially reducing procedure time and equipment costs [41].

Other Digital Modalities: Compared to other digital technologies such as FICE or high-definition bronchovideoscopy, I-Scan provides comparable or superior performance in surface and color enhancement, with the additional benefit of user-friendly operation and rapid mode cycling.
In summary, I-Scan bridges the diagnostic gap between high sensitivity (as seen with AFB and NBI) and high specificity (exceeding AFB), with strong practical advantages in workflow integration and wide-field surveillance. Its adoption is supported by both clinical trial data and growing real-world experience, especially in settings where precise delineation of mucosal abnormalities is critical [42].

Clinical Utility of I-Scan in Early Detection of Lung Cancer

The core strength of I-Scan bronchoscopy lies in its clinical utility for the early detection of lung cancer, especially in high-risk individuals and patients with symptoms unexplained by radiographic imaging. By enhancing visualization of subtle mucosal changes and early vascular alterations, I-Scan enables bronchoscopists to identify lesions that are frequently overlooked by conventional white light bronchoscopy (WLB) [43]. Multiple clinical studies have demonstrated that I-Scan can detect pre-invasive lesions such as squamous dysplasia and carcinoma in situ, providing a critical window for intervention before the disease progresses to an advanced, less treatable stage.

One prospective cohort study of patients with suspected central airway pathology found that I-Scan bronchoscopy increased the detection rate of flat or minimally elevated lesions by over 20% compared

10.48047/jocaaa.2024.33.06.58

to WLB alone. Importantly, these lesions were often histologically confirmed as high-grade dysplasia or microinvasive carcinoma, both of which carry a high risk of progression but are potentially curable when detected early [44]. The ability to visualize subtle changes in the mucosal surface and vascular patterns allowed for more targeted and effective biopsies, improving the diagnostic yield and accuracy of bronchoscopic sampling.

I-Scan also proves valuable in the surveillance of patients at increased risk for secondary lung primaries, such as those with a history of head and neck cancer, heavy smokers, or patients with chronic obstructive pulmonary disease (COPD). In these populations, repeated surveillance with I-Scan facilitates the early identification and monitoring of multifocal or metachronous lesions, supporting timely intervention and improved outcomes [45]. Furthermore, the enhanced image clarity and user-friendly interface of I-Scan help reduce inter-observer variability, promoting consistency in lesion detection among bronchoscopists with varying experience levels.

Emerging evidence also suggests that I-Scan may aid in the detection of early-stage adenocarcinomas and atypical presentations of non-small cell lung cancer, expanding its utility beyond squamous cell and centrally located tumors [46]. While further large-scale studies are warranted, the growing body of clinical evidence positions I-Scan as a valuable adjunct in the diagnostic algorithm for early lung cancer, complementing radiologic screening and traditional endoscopic assessment.

Role of I-Scan in Biopsy Guidance and Lesion Delineation

Accurate biopsy and precise lesion delineation are fundamental to establishing a definitive diagnosis and staging in lung cancer. Traditional white light bronchoscopy (WLB) often struggles to distinguish the true margins of early or flat lesions, potentially leading to sampling errors or missed diagnoses. I-Scan technology directly addresses this limitation by enhancing both the surface detail and vascular pattern of the bronchial mucosa, thus providing clear demarcation between normal and abnormal tissue [47].

Several clinical series and case reports have highlighted that I-Scan facilitates the visualization of subtle lesion borders, allowing the bronchoscopist to target biopsies at the most suspicious and diagnostically valuable areas. In practical terms, this means fewer “blind” or random biopsies and an increased likelihood of capturing high-grade dysplasia or early malignancy in a single procedure [48]. For multifocal or patchy lesions, I-Scan also assists in distinguishing between contiguous neoplastic spread and benign, inflammatory, or post-therapeutic changes, which can mimic malignancy under white light alone.

The importance of targeted biopsy cannot be overstated, especially given the evolving standards in lung cancer pathology, where molecular and immunohistochemical profiling require adequate, high-quality tissue samples. Studies comparing I-Scan-guided versus conventional sampling have reported

10.48047/jocaaa.2024.33.06.58

higher diagnostic yields and lower rates of non-diagnostic or inconclusive biopsies when I-Scan was employed, particularly for carcinoma in situ and minimally invasive lesions [49]. Furthermore, improved lesion delineation has been shown to reduce procedural time and patient discomfort by minimizing the number of biopsies needed and avoiding unnecessary trauma to healthy tissue.

Another clinical advantage is the ability of I-Scan to guide biopsy in challenging situations, such as post-radiation changes, granulation tissue, or scarred airways. By providing real-time, enhanced visual feedback, I-Scan empowers bronchoscopists to optimize their sampling strategy, ultimately supporting more accurate diagnosis, optimal patient management, and appropriate therapeutic planning [50].

Diagnostic Yield in Central vs. Peripheral Lesions

The effectiveness of bronchoscopic imaging varies according to the anatomical location of lung lesions, with significant implications for the utility of image-enhanced techniques like I-Scan. Central airway lesions—including those in the trachea, mainstem bronchi, and proximal segmental bronchi—are traditionally more accessible and visible with bronchoscopy, making them suitable targets for advanced imaging and biopsy. Studies have shown that I-Scan markedly improves the diagnostic yield for pre-invasive and minimally invasive central airway lesions compared to white light bronchoscopy (WLB) alone, increasing both detection rates and biopsy accuracy for squamous dysplasia, carcinoma in situ, and early squamous cell carcinoma [51].

For central lesions, the enhancement of mucosal texture and vascular patterns with I-Scan allows for the identification of even flat or subtle changes that would otherwise be missed by conventional methods. This improvement is particularly critical in high-risk populations where central, multifocal, or synchronous lesions are more likely to occur. In one prospective cohort, the addition of I-Scan to routine bronchoscopy increased the detection of central airway neoplasia by up to 25%, while also improving lesion margin delineation and reducing false negatives [52].

Peripheral pulmonary lesions present unique challenges. These lesions, located beyond the segmental bronchi and frequently involving subsegmental or smaller airways, may be invisible to standard bronchoscopy. Although the direct visualization benefits of I-Scan are inherently limited in the periphery due to bronchoscopic reach, there is emerging evidence that digital enhancement can aid in detecting subtle mucosal abnormalities at the distal limits of endoscopic access. Furthermore, when combined with navigational techniques such as radial endobronchial ultrasound (R-EBUS) or electromagnetic navigation, I-Scan may assist in real-time assessment of peripheral airway involvement, guiding targeted sampling in ambiguous or borderline lesions [53].

Overall, while the incremental value of I-Scan is greatest for central airway disease, its use in conjunction with advanced navigation tools may expand its utility to select peripheral cases.

10.48047/jocaaa.2024.33.06.58

Importantly, the high specificity and ability to reduce unnecessary biopsies make I-Scan a practical adjunct in both central and, to a lesser extent, peripheral lung cancer evaluation [54].

Safety, Workflow, and Practical Considerations

The integration of I-Scan technology into routine bronchoscopic practice has been largely favorable from both a safety and workflow perspective. Since I-Scan relies on digital post-processing rather than optical filters, dyes, or exogenous contrast agents, it does not add any inherent procedural risk or require changes in patient preparation. Multiple clinical reports and real-world experience have demonstrated that I-Scan bronchoscopy is as safe as standard white light bronchoscopy (WLB), with no increase in adverse events such as bleeding, infection, or airway trauma attributable to the use of image enhancement [55].

From a workflow standpoint, I-Scan offers key advantages. The instantaneous, button-based switching between enhancement modes allows the bronchoscopist to adapt the imaging modality in real time, depending on the clinical context and endoscopic findings. This flexibility minimizes interruption and ensures that the enhanced imaging does not prolong the procedure significantly compared to conventional WLB. Furthermore, because I-Scan maintains high image brightness and does not require dimmed lighting or magnification endoscopes, it can be seamlessly integrated into standard bronchoscopic suites without major equipment upgrades or modifications [56].

In terms of specimen handling and biopsy, I-Scan does not alter established protocols. The technology's main contribution is to improve the targeting of biopsies and reduce sampling errors, not to change the type or processing of collected tissue. As a result, pathology departments and diagnostic workflows remain unchanged, except for the potential to receive more diagnostically relevant specimens [57].

Training requirements for I-Scan are modest. Because the system preserves the natural color palette and endoscopic feel of conventional bronchoscopy, the learning curve is gentle, and most bronchoscopists can achieve proficiency after a brief period of supervised practice. Educational resources, including comparative image atlases and video tutorials, further accelerate operator familiarity and confidence in using the various enhancement modes [58].

Overall, the adoption of I-Scan is associated with high user satisfaction, minimal disruption to clinical workflows, and a safety profile equivalent to standard bronchoscopy, making it a practical and attractive addition to the diagnostic armamentarium for lung cancer.

Integration with Artificial Intelligence and Molecular Diagnostics

The future of bronchoscopic diagnostics is being shaped by the convergence of digital imaging, artificial intelligence (AI), and molecular pathology. I-Scan technology, by producing high-quality, high-contrast digital images, is ideally suited for integration with AI-based image analysis systems.

10.48047/jocaaa.2024.33.06.58

Such integration promises to further improve diagnostic accuracy and consistency, particularly in the detection of subtle pre-cancerous or early cancerous changes that may be missed by the human eye, especially among less experienced bronchoscopists [59].

Recent pilot studies have demonstrated that AI algorithms trained on I-Scan-enhanced bronchoscopic images can reliably identify and classify mucosal abnormalities, achieving sensitivities and specificities that approach or exceed expert-level performance. AI-guided bronchoscopy holds the potential to standardize lesion detection, reduce inter-observer variability, and provide real-time decision support during procedures. This is especially valuable in settings with limited access to highly specialized expertise or where bronchoscopic volumes are high [60].

Beyond visual diagnosis, the enhanced targeting enabled by I-Scan supports the collection of optimal tissue samples for advanced molecular and immunohistochemical testing. As lung cancer management increasingly relies on the identification of actionable genomic alterations (such as EGFR, ALK, ROS1, and PD-L1), obtaining high-quality and representative biopsy specimens has become a critical goal. By accurately delineating lesion margins and identifying the most suspicious regions, I-Scan improves the likelihood of capturing tissue suitable for next-generation sequencing (NGS), multiplex molecular assays, and predictive biomarker analysis [61].

Furthermore, the digital nature of I-Scan images facilitates the development of quantitative image analysis and “radiomics” features that could, in the future, be correlated with molecular phenotypes and patient outcomes. The synergy between advanced imaging, AI interpretation, and precision diagnostics is expected to accelerate the shift toward personalized lung cancer management, enabling earlier, more accurate, and more tailored therapeutic decisions [62].

Current Limitations and Future Directions

Despite the promising clinical advantages of I-Scan bronchoscopy in the early detection and characterization of lung cancer, several limitations must be acknowledged. First, the body of evidence supporting its diagnostic superiority over other advanced imaging modalities, such as NBI or AFB, is still growing and is mostly limited to single-center studies or relatively small cohorts. Larger, multicenter, randomized trials are needed to more definitively establish its role in diverse patient populations and across different levels of operator experience [63].

Second, the effectiveness of I-Scan remains largely confined to lesions within the reach of standard bronchoscopes—primarily central airways. While there is some benefit in identifying mucosal abnormalities at the segmental and subsegmental level, the technology does not overcome the inherent limitation of endoscopic access to small or peripheral lesions, which often require complementary techniques such as radial EBUS or navigation bronchoscopy for optimal evaluation [64]. The incremental diagnostic yield for peripheral lesions remains an area for further research.

10.48047/jocaaa.2024.33.06.58

Operator learning curve and interpretation variability, although lower than with other enhancement techniques, still present challenges. The lack of universally accepted visual criteria for dysplasia or carcinoma in situ under I-Scan enhancement may lead to inconsistent reporting and biopsy targeting, particularly among less experienced bronchoscopists. The development and dissemination of standardized training modules and image atlases are essential to promote uniformity in clinical practice [65].

Economic considerations, including equipment costs and reimbursement models, may also influence widespread adoption, especially in low-resource settings. However, the reduction in unnecessary biopsies and potential for earlier diagnosis may offset initial investments, a hypothesis that warrants robust health-economic evaluation [66].

Looking to the future, integration with artificial intelligence holds great promise for automating lesion detection, quantification, and classification. Prospective studies combining I-Scan with AI algorithms and molecular biomarker analysis could redefine bronchoscopic diagnosis, facilitating a more personalized, efficient, and accurate approach to lung cancer care. Furthermore, advancements in endoscopic device design and digital connectivity may expand the utility of I-Scan for distal airway evaluation and telemedicine applications [67].

Conclusion

The introduction of I-Scan technology marks a significant step forward in the early detection and precise characterization of lung cancer within the bronchoscopic suite. By enhancing the visualization of subtle mucosal and vascular abnormalities, I-Scan addresses key limitations of conventional white light bronchoscopy and supports a more accurate, targeted approach to biopsy and diagnosis. Evidence suggests that I-Scan improves the detection of pre-invasive and early-stage lesions, particularly in the central airways, and reduces both sampling errors and unnecessary interventions. Importantly, I-Scan achieves these diagnostic gains with a high degree of safety, minimal impact on workflow, and a user-friendly interface that supports rapid adoption in clinical practice. Its ability to integrate seamlessly with existing endoscopic infrastructure, and its potential compatibility with artificial intelligence tools, position it as a leading modality in the evolution toward more precise, personalized lung cancer diagnostics

Nevertheless, several challenges remain. Larger, multicenter trials are needed to confirm its advantages across broader patient populations, and further work is required to expand its utility to peripheral lesions and standardize interpretive criteria. Ongoing advancements in training, AI integration, and economic evaluation will be critical to realizing the full potential of I-Scan bronchoscopy and ensuring its accessibility in diverse healthcare settings. In summary, I-Scan represents a powerful adjunct to the modern bronchoscopist's toolkit. As the field moves toward earlier diagnosis, risk-adapted

10.48047/jocaaa.2024.33.06.58

surveillance, and precision therapy, technologies like I-Scan will play an increasingly central role in improving outcomes for patients at risk of lung cancer.

REFERENCES

1. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2019. CA Cancer J Clin. 2019;69(1):7-34.
2. McErlean AM, Ginsberg MS. Epidemiology of lung cancer. Semin Intervent Radiol. 2011;28(2):93-98.
3. Pinsky PF, Gierada DS, Black W, et al. Performance of Lung-RADS in the National Lung Screening Trial: A retrospective assessment. Ann Intern Med. 2015;162(7):485-491.
4. Rivera MP, Mehta AC, Wahidi MM. Establishing the diagnosis of lung cancer: Diagnosis and management of lung cancer, 3rd ed: American College of Chest Physicians evidence-based clinical practice guidelines. Chest. 2013;143(5 Suppl):e142S-e165S.
5. Andolfi M, Potenza R, Capozzi R, et al. The role of bronchoscopy in early diagnosis of lung cancer. Diagnostics (Basel). 2016;6(4):40.
6. 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.
7. Siegel RL, Miller KD, Wagle NS, Jemal A. Cancer statistics, 2023. CA Cancer J Clin. 2023;73(1):17-48.
8. McErlean AM, Ginsberg MS. Epidemiology of lung cancer. Semin Intervent Radiol. 2011;28(2):93-98.
9. Tyler CV, Dongarwar D, Salihu HM. Trends in global lung cancer incidence and mortality: Impact of tobacco control and screening. Thorac Cancer. 2023;14(2):107-115.
10. Brawley OW, Glynn TJ, Khuri FR, et al. The future of cancer screening after COVID-19. CA Cancer J Clin. 2021;71(2):128-140.
11. National Lung Screening Trial Research Team, Aberle DR, Adams AM, Berg CD, et al. Reduced lung-cancer mortality with low-dose computed tomographic screening. N Engl J Med. 2011;365(5):395-409.
12. Pinsky PF, Gierada DS, Black W, et al. Performance of Lung-RADS in the National Lung Screening Trial: A retrospective assessment. Ann Intern Med. 2015;162(7):485-491.
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. Gasparini S. Flexible bronchoscopy. Curr Opin Pulm Med. 1999;5(2):107-111.
15. Andolfi M, Potenza R, Capozzi R, et al. The role of bronchoscopy in early diagnosis of lung cancer. Diagnostics (Basel). 2016;6(4):40.
16. 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.
17. 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.

10.48047/jocaaa.2024.33.06.58

18. Zaric B, Perin B, Milenkovic B, et al. Advanced bronchoscopic techniques in lung cancer diagnosis. J Thorac Dis. 2016;8(9):E1163-E1169.
19. 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.
20. Sariköse E, Turan D. Advanced bronchoscopic imaging techniques for early detection of lung cancer. Turk Thorac J. 2016;17(2):77-84.
21. Zaric B, Perin B, Stojsic V, et al. Autofluorescence bronchoscopy in lung cancer diagnosis. Eur J Cancer Prev. 2013;22(6):503-510.
22. Georgakopoulou VE, Zaric B, Perin B, et al. Narrow band imaging in the early detection of lung cancer. Respiration. 2025;104(2):127-135.
23. Dincer HE. Role of advanced bronchoscopic techniques in the diagnosis and staging of lung cancer. Ann Thorac Med. 2015;10(2):87-93.
24. 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.
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. Koraa R. I-Scan Technology in Pulmonology. Lung India. 2024;41(2):157-162.
27. Kodashima S, Fujishiro M. Novel image-enhanced endoscopy with i-scan technology. World J Gastroenterol. 2010;16(9):1043-1049.
28. 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.
29. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
30. 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.
31. Koraa R. I-Scan Technology in Pulmonology. Lung India. 2024;41(2):157-162.
32. 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.
33. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
34. Kodashima S, Fujishiro M. Novel image-enhanced endoscopy with i-scan technology. World J Gastroenterol. 2010;16(9):1043-1049.
35. 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.
36. 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.
37. Koraa R. I-Scan Technology in Pulmonology. Lung India. 2024;41(2):157-162.
38. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
39. Zaric B, Perin B, Stojsic V, et al. Autofluorescence bronchoscopy in lung cancer diagnosis. Eur J Cancer Prev. 2013;22(6):503-510.
40. Georgakopoulou VE, Zaric B, Perin B, et al. Narrow band imaging in the early detection of lung cancer. Respiration. 2025;104(2):127-135.
41. Kodashima S, Fujishiro M. Novel image-enhanced endoscopy with i-scan technology. World J Gastroenterol. 2010;16(9):1043-1049.
42. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
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.

10.48047/jocaaa.2024.33.06.58

44. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
45. Koraa R. I-Scan Technology in Pulmonology. Lung India. 2024;41(2):157-162.
46. Georgakopoulou VE, Zaric B, Perin B, et al. Narrow band imaging in the early detection of lung cancer. Respiration. 2025;104(2):127-135.
47. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
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. Kodashima S, Fujishiro M. Novel image-enhanced endoscopy with i-scan technology. World J Gastroenterol. 2010;16(9):1043-1049.
51. 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.
52. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
53. Dincer HE. Role of advanced bronchoscopic techniques in the diagnosis and staging of lung cancer. Ann Thorac Med. 2015;10(2):87-93.
54. Koraa R. I-Scan Technology in Pulmonology. Lung India. 2024;41(2):157-162.
55. 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.
56. Kodashima S, Fujishiro M. Novel image-enhanced endoscopy with i-scan technology. World J Gastroenterol. 2010;16(9):1043-1049.
57. Koraa R. I-Scan Technology in Pulmonology. Lung India. 2024;41(2):157-162.
58. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
59. Gursoy M, Cai G. Artificial intelligence improves bronchoscopy performance: the future is now. Respiration. 2025;104(2):95-96.
60. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
61. Cortiana M, Tabbò F, Casorzo L, et al. Personalized medicine in lung cancer: the role of precision diagnostics. Front Oncol. 2024;14:1376421.
62. Pettit C, Sharma S, Lee M, et al. Advances in liquid biopsy and next-generation sequencing in lung cancer diagnostics. Clin Lung Cancer. 2023;24(1):45-57.
63. 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.
64. Dincer HE. Role of advanced bronchoscopic techniques in the diagnosis and staging of lung cancer. Ann Thorac Med. 2015;10(2):87-93.
65. van der Heijden EH, Ashraf O, Heideman DA, et al. Image enhancement techniques in bronchoscopy: clinical update. Respiration. 2018;95(6):403-415.
66. Kodashima S, Fujishiro M. Novel image-enhanced endoscopy with i-scan technology. World J Gastroenterol. 2010;16(9):1043-1049.
67. Gursoy M, Cai G. Artificial intelligence improves bronchoscopy performance: the future is now. Respiration. 2025;104(2):95-96.