

EDITORIAL

The Intelligent Future of Bronchoscopy: Transforming Lung Cancer Diagnosis with Artificial Intelligence

AKHTAR ALI

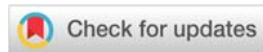
¹Assistant Professor, Pulmonology, Shalamar Institute of Health Sciences, LahoreCorrespondence to: Email: drakhtarshah@gmail.com

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BACKGROUND

Lung cancer is the foremost cause of death through cancer globally mainly due to the fact that the majority of patients report the disease at an advanced stage where treatment is no longer effective¹. Even though the use of low-dose computed tomography (LDCT) screening has greatly enhanced the detection rate of pulmonary nodules, the major challenge has changed to no longer from detection but sound diagnosis, localization, and staging². Flexible bronchoscopy has long been regarded as the basis of the diagnostic pathway of pulmonary lesions, but in numerous aspects it has been limited by reliance on the operator, inaccessibility of peripheral airways, and significant the inter-observer variability in the interpretation of bronchoscopy observations³. The latest technological progress in artificial intelligence (AI) is radically changing the field of interventional pulmonology by bringing real-time image guidance, drilling, and decision support to the bronchoscopy operation hence reformatting bronchoscopy operation as a computer-controlled and data-driven intervention⁴.

AI-Guided Navigation Through the Complex Airway

The multifurcated nature of the bronchial architecture is one of the biggest technical issues of peripheral bronchoscopy. Traditional navigation using only two-dimensional computed tomography (CT) images is not very accurate and even the expertise bronchoscopists make correct choice of the best route to the airway, in only a small fraction of instances⁵. To overcome this shortcoming, AI-controlled navigation systems tumble the airway tree by automatically extracting pre-procedural CT images and re-existing the high-resolution map of the bronchial tree of high-resolution three-dimensional that can be used in the precise planning of the procedure^{3,4}.

The latest deep learning architectures, especially hybrid convolutional neural network (CNN)-Transformer models have shown sensational results in bronchial anatomical landmark localization, such as carina, segmental bronchi, and peripheral airway bifurcations. Such models have continued producing higher diagnostic accuracies in comparison with expert bronchoscopists^{1,5,9}.

The Diagnostic Drop-Off and Overcoming

Although peripheral pulmonary nodules can be successfully navigated to, representative biopsy is difficult to get. This is commonly known as the diagnostic drop-off;

it is mainly due to the CT-to-body divergence (CTBD), in which, the localisation of the pulmonary lesions alters between the CT scan pre-procedure imaging and during the intraoperative respiratory condition. A shift of lesions by about 515 mm can seriously compromise the accuracy of biopsies^{3,11}.

The combination of AI and Cone-Beam Computed Tomography (CBCT), augmented fluoroscopy, and digital tomosynthesis has greatly enhanced the real-time lesion localization through the compensation of CTBD. The imaging with AI-assistance constantly updates the location of the lesion during the process, thus improving accuracy in

navigation³. The combination of mobile CBCT and robotic-assisted bronchoscopy has been shown to result in higher tool-in-lesion confirmation rates of about 34 to almost 99% compared to the ones with peripheral bronchoscopy, which is considered one of the richest improvements in the field of peripheral bronchoscopy³. In a similar vein, digital tomosynthesis built into newer navigation platforms requires no dedicated intraoperative CT scanners, but yields highly diagnostic results, and thus allows more advanced bronchoscopic interventions to be available to more accessible healthcare facilities³.

AI-supported Robotic-Assisted Bronchoscopy

Robotic-assisted bronchoscopy (RAB) is a point at which robotics, sophisticated imaging and AI intersect with pulmonary diagnostics. Modern robotic systems, such as the Ion™ Endoluminal System with shape-sensing technology and the Monarch™ Platform with electromagnetic navigation, offer exquisite stability, improved manoeuvrability and access into sixth and seventh-generation bronchi, which are not easily accessed via conventional bronchoscopes¹¹.

Recent advancements have also employed AI in the entire robotic navigation process. Navigation systems based on AI can decrease variability in operators, enhance process efficiency, and decrease the time to learn how to use the navigation more quickly by less experienced bronchoscopists⁶. The diagnostic results of robot bronchoscopy compared to transthoracic needle biopsy have been found to be around 80-90 percent in peripheral pulmonary nodules with a lower rate of complication than transthoracic needle biopsy, in terms of pneumothorax and bleeding^{3,4,11}.

Artificial Intelligence Artificial Vision

The use of AI is not limited to navigation of bronchoscopies, but also includes image analysis and pathology. The most common form of fallopian mediastinal lymph node staging is endobronchial ultrasound (EBUS), which has conventionally relied on subjective assessment of ultrasound features. Deep learning models have significantly contributed to the accuracy of diagnostics of EBUS through the automatic detection of malignant lymph node features by reporting a high level of accuracy of over 90, overcoming traditional visual observation⁴.

On the same note, AI-based Rapid On-Site Evaluation (ROSE) has come out as a significant remedy to the worldwide cytopathologist shortage. Improved convolutional neural networks such as enhanced ResNet-18 frameworks are quick to process Diff-Quik stained cytological samples during bronchoscopy, which gives instant information about the sufficiency of the specimen and the malignant bone forms⁷. Using AI-assisted ROSE has

been demonstrated to improve diagnostic accuracy, which is about 83 per cent to almost 96 per cent and stabilize inter-observer variability and repeat biopsy^{7,8}.

Difficulties to Clinical Implementation

Although technological advancements have been enormous, there are a few methodologies hurdles that must be overcome to ensure the full integration of AI into the normal clinical practice. One of the most important concerns is the high level of data leakage in AI studies that observe the inclusion of images of the same patient in the training and predicting data set, with an exaggerated output on the model performance¹. Patient-level data partitioning, multicenter validation cohorts, and prospective clinical trial could be employed in future studies that would provide sufficient generalizability in various groups of patients⁴.

The other significant problem is that deep learning algorithms are not that interpretable. Numerous AI systems are black box and cannot easily be comprehended by clinicians on the logic behind the automated predictions. Image-based image-related explainable AI (XAI) methods, such as Gradient-weighted Class Activation Mapping (Grad-CAM), are on the rise, as they can be used to visualize areas of an image as they influence an AI in decision-making, which enhances transparency, clinician trust and regulatory approval^{1,4}.

Toward a Single-Anesthetic Precision Workflow

Interventional bronchoscopy is shifting towards a paradigm of integrated Single-Anesthetic Bronchoscopy and Resection (SABR). In this clinical study, patients are then subjected to AI-controlled robotic bronchoscopy featuring immediate ROSE detection of the cancer, and robotic-assisted surgery resection is carried out during the same anesthetic session. This is a lean practice that reduces delays between diagnostic and treatment, decreases anxiety of patients, saves on healthcare costs and enhances clinical efficiency^{3,4}.

CONCLUSION

The field of interventional pulmonology is quickly changing into an operationally-driven, yet highly accurate, image-guided, and data-driven area of study, thanks to artificial intelligence. AI is enhancing the accuracy of diagnosis, procedure safety, and clinical efficiency, through developments in automated navigation of airways, robotic-assisted bronchoscopy, AI-enriched imaging, EBUS interpretation, and real-time cytopathological analysis. Despite the difficulties in model validation, explainability, and multicenter application, continued technological progress implies that AI-assisted bronchoscopy is soon

going to be the new standard of care in the diagnosis of pulmonary nodules as well as lung cancer staging, eventually leading to better patient outcomes and survival across the globe.

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