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Review Article

ADVANCES IN FLEXIBLE BRONCHOSCOPY FOR EARLY DIAGNOSIS OF LUNG CANCER

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ABSTRACT: Lung cancer remains the leading cause of cancer-related death. In central airway lesions, flexible bronchoscopy (FB) is the diagnostic backbone, as it allows direct visualization, lesion localization, and sampling, while integrating new technologies such as autofluorescence bronchoscopy (AFB), narrow-band imaging (NBI), endobronchial ultrasound (EBUS), optical coherence tomography (OCT), electromagnetic/CBCT-guided navigation bronchoscopy (ENB, CBCT), robotic bronchoscopy, and "real-time pathology" techniques such as confocal laser endomicroscopy (CLE). Over the past 5–7 years, evidence shows these technologies significantly enhance sensitivity/early detection, increase diagnostic yield for small peripheral nodules, reduce complications compared with transthoracic biopsy, and open the era of artificial intelligence (AI) for lesion recognition and procedural training. This article summarizes key advances, clinical impact, limitations, and implementation prospects in Vietnam.

Keywords: flexible bronchoscopy (FB), lung cancer.

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1. BACKGROUND & THE NEED FOR INNOVATION

Central airway tumors and precancerous lesions (dysplasia, carcinoma in situ) are often missed by conventional X-ray/CT, while early detection enables minimally invasive treatment and better survival. Flexible bronchoscopy has therefore been "armed" with new imaging and navigation modules to see earlier – reach deeper – biopsy more accurately. For staging, EBUS-TBNA has become the standard of care in mediastinal assessment at initial diagnosis [1,2].

2. ADVANCES IN ENDOSCOPIC IMAGING TECHNOLOGY

2.1. Narrow-Band Imaging (NBI) & magnification bronchoscopy

NBI enhances mucosal microvascular contrast, helping identify twisted, truncated, or proliferative vessels suggestive of dysplasia/early cancer. Recent studies (2025) show NBI improves diagnostic accuracy for airway mucosal abnormalities compared to white light bronchoscopy. When combined with high magnification, its ability to detect abnormal vasculature is further improved, useful for guiding biopsy [7].

2.2. Next-generation Autofluorescence Bronchoscopy (AFB)

AFB remains highly sensitive for detecting flat/precancerous lesions but traditionally suffers from low specificity. Current strategies emphasize AFB + white light/NBI to improve specificity, and fluorescence-guided biopsy shows added value in suspicious mucosal lesions [8].

2.3. Endobronchial Optical Coherence Tomography (EB-OCT)

EB-OCT provides in vivo microstructural "optical histology" with micrometer resolution, helping differentiate dysplasia, carcinoma in situ, and invasive disease, as well as delineating lesion margins for intervention. Recent reviews confirm EB-OCT is safe, real-time, and has the potential to become an "optical biopsy" to guide treatment [9].

2.4. Confocal Laser Endomicroscopy (CLE/nCLE)

Needle-based CLE (nCLE) provides real-time cellular-level imaging at the needle tip during biopsy, functioning as a "bedside microscope" to confirm malignant tissue before sampling. Multicenter studies show nCLE is feasible, safe, and reduces unnecessary punctures by guiding needle repositioning [9].

3. ADVANCES IN ACCESSING & NAVIGATING PERIPHERAL LESIONS

3.1. Electromagnetic Navigation Bronchoscopy (ENB) & hybrid CBCT systems

ENB allows scope navigation using a "3D CT map" to reach peripheral nodules. The NAVIGATE trial and updated reviews report diagnostic yields of ~70–75% with low complication rates [3,4]. Combining ENB with hybrid operating rooms equipped with cone-beam CT (CBCT) increases tool-in-lesion confirmation and improves diagnostic yield for nodules <2 cm [6].

3.2. Robotic-Assisted Bronchoscopy (RAB) vs. ENB

Robotic bronchoscopy improves stability and distal reach. Recent head-to-head trials show RAB is non-inferior to ENB for peripheral nodule diagnosis. The trend is to combine RAB with CBCT, rEBUS, or nCLE to maximize lesion confirmation [5].

3.3. Risk–benefit compared with transthoracic biopsy

Systematic reviews (2023–2024) report guided bronchoscopy (ENB/RAB) achieves comparable diagnostic yields in many clinical contexts but with fewer complications (notably pneumothorax) compared to CT-guided transthoracic biopsy [3,6].

4. ADVANCES IN STAGING & NODAL SAMPLING

4.1. Standardized EBUS-TBNA

EBUS-TBNA is now first-line for diagnosis and nodal staging, supported by updated evidence and guidelines [1,2]. Current efforts focus on standardizing sample acquisition/handling, optimizing puncture number, needle size, ROSE, and combining with EUS-B to maximize mediastinal access.

4.2. "Molecular biology from the needle"

EBUS/ENB samples increasingly suffice for genomic sequencing, PD-L1, and even RNA-seq—essential for personalized therapy [1,2].

5. ARTIFICIAL INTELLIGENCE (AI) IN BRONCHOSCOPY

AI applications are rapidly emerging: (i) real-time lesion detection in NBI/white light video; (ii) smart navigation on virtual maps; (iii) skill assessment and standardized training. A 2025 systematic review shows AI outperformed humans in sensitivity for lesion detection in research datasets, and two-stage NBI-AI trials have automatically detected lesions in bronchoscopy videos [10].

6. CLINICAL IMPACT OF THESE ADVANCES

1.Early detection & targeted biopsy – NBI/AFB/OCT enable biopsy guidance in flat lesions, increasing carcinoma in situ detection [7–9].

2.Improved access to difficult peripheral nodules – ENB, RAB, CBCT, rEBUS, and nCLE combinations enhance diagnostic yield while minimizing complications [3–6].

3.Optimal staging in one session – Combined EBUS/EUS-B allows accurate nodal staging in a single procedure [1,2].

4.Toward "real-time pathology" – EB-OCT and nCLE enable histologic confirmation during the procedure [9].

7. LIMITATIONS & KNOWLEDGE GAPS

- **AFB**: still limited by low specificity; needs WLB/NBI combination [8].
- **OCT/CLE**: promising but lack large-scale gold-standard correlation [9].
- **RAB/ENB/CBCT**: yield depends on lesion size/location and operator expertise; comparative evidence still accumulating [3–6].
- **AI**: risks of data bias and model transparency issues [10].

8. IMPLEMENTATION IN VIETNAM

- **Tertiary centers:** prioritize EBUS/EUS-B for staging; ENB/RAB + CBCT for selected cases; NBI/AFB for screening flat lesions [1,3,6,7,8].
- **Training & standardization:** adopt updated specimen acquisition/processing guidelines; integrate structured bronchoscopy training modules and inter-hospital mentorship systems [1].
- **Local research:** build national bronchoscopy video databases, evaluate cost-effectiveness of navigation configurations (ENB vs. RAB ± CBCT), and pilot OCT/nCLE trials [6,9].

- **Barriers & considerations:** current challenges include limited equipment availability and high setup costs (especially for RAB and CBCT), uneven operator training between urban and provincial hospitals, and reimbursement constraints from health insurance. Additionally, standardization of pathology correlation and data-sharing infrastructure remains limited, requiring coordinated policy and funding efforts from national health authorities.

Figures

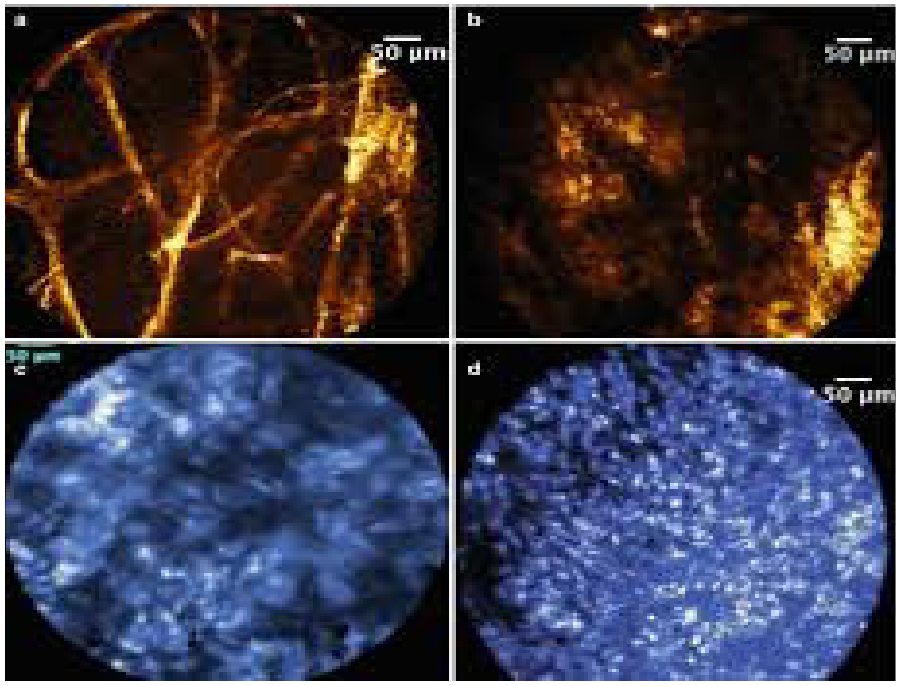

Figure 1. Autofluorescence (AFB) & Narrow-Band Imaging (NBI)

Comparison of white light vs. autofluorescence bronchoscopy. Flat precancerous lesions are more prominent under fluorescence. *Source: Thoracic Key – Diagnostic bronchoscopy: white light vs autofluorescence (thoracickey.com)*

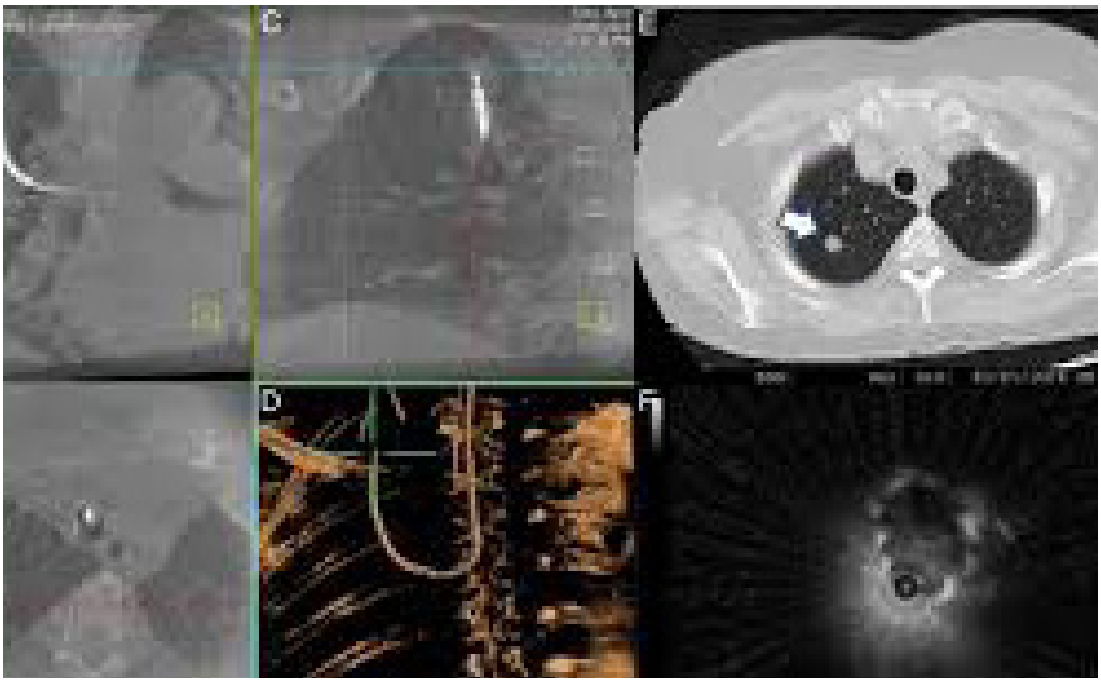

Figure 3. Radial-probe Endobronchial Ultrasound (r-EBUS)

Radial ultrasound probe within the airway generating concentric cross-sectional images of peripheral nodules. *Source: ResearchGate – Radial endobronchial ultrasound in peripheral lung nodules.*

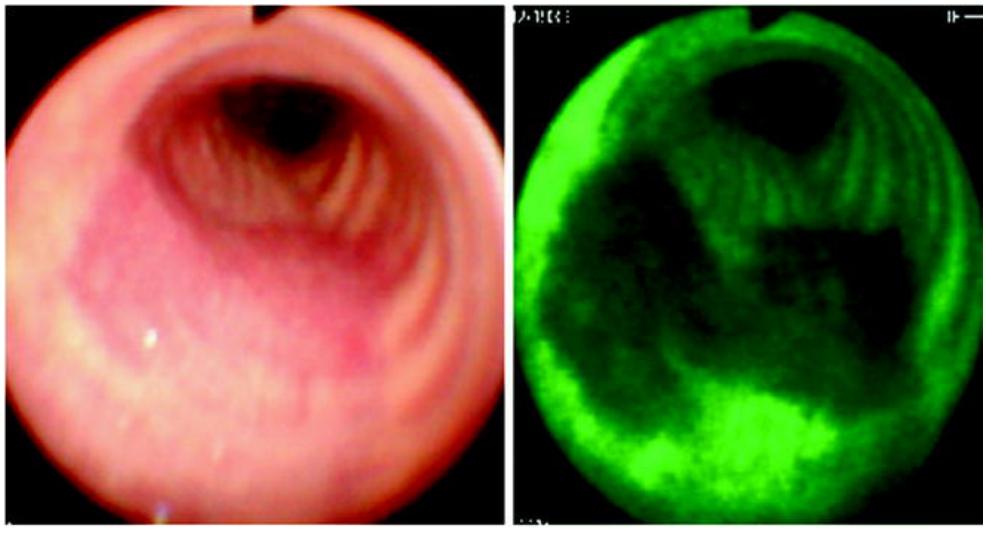

Figure 4. Confocal Laser Endomicroscopy (CLE / pCLE)

Microscopic cellular imaging at the needle tip, enabling "real-time pathology." *Source: Radiology Key – Autofluorescence and probe-based CLE in bronchoscopy (radiologykey.com).*

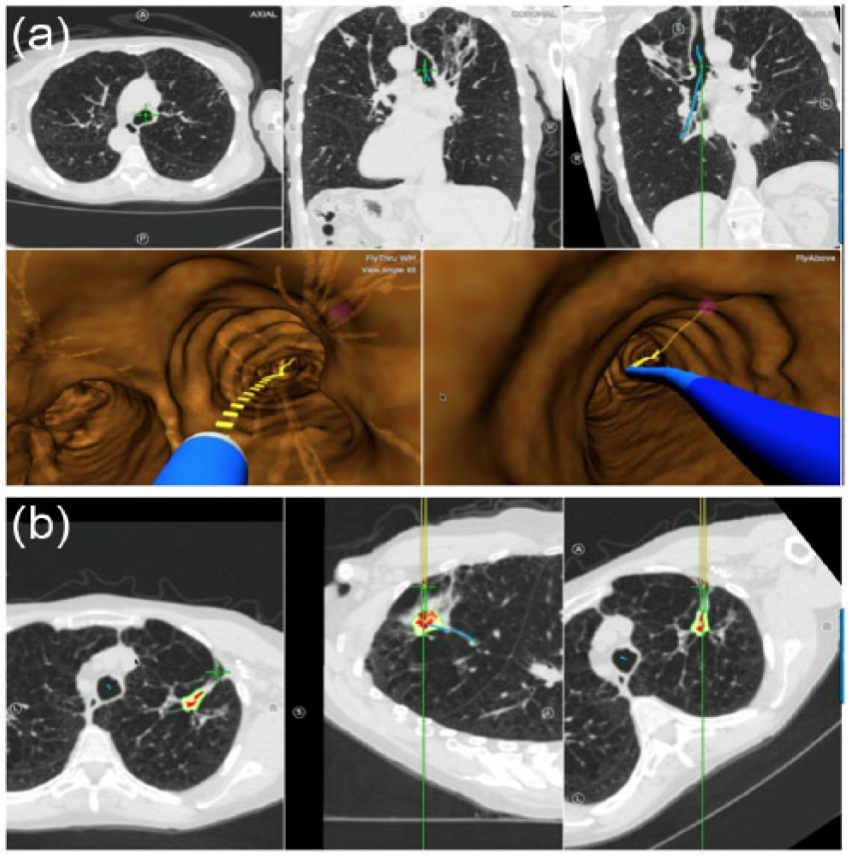

Figure 5. Electromagnetic Navigation Bronchoscopy (ENB)

Real-time CT and virtual bronchoscopy simulation. *Source: Therapeutic Advances in Respiratory Disease – "An update on the role of advanced diagnostic bronchoscopy…" (Belanger & Akulian, 2017).*

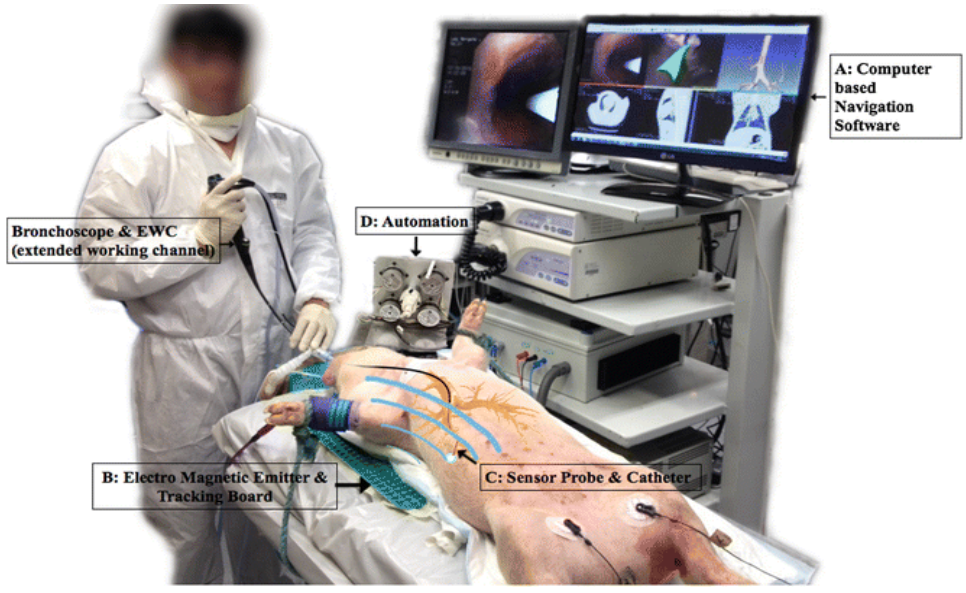

Figure 6. Components of the ENB system (animal model)

Key elements: tracking system, 3D CT map, electromagnetic generator. *Source: Navigational Bronchoscopy for Early Lung Cancer: A Road to Therapy (2016).*

Figure 7. Robotic-Assisted Bronchoscopy (RAB)

Bronchoscopy suite with robotic platform (Ion or equivalent) controlled via console. *Source: Montefiore Einstein – "robot-assisted bronchoscopy technology".*

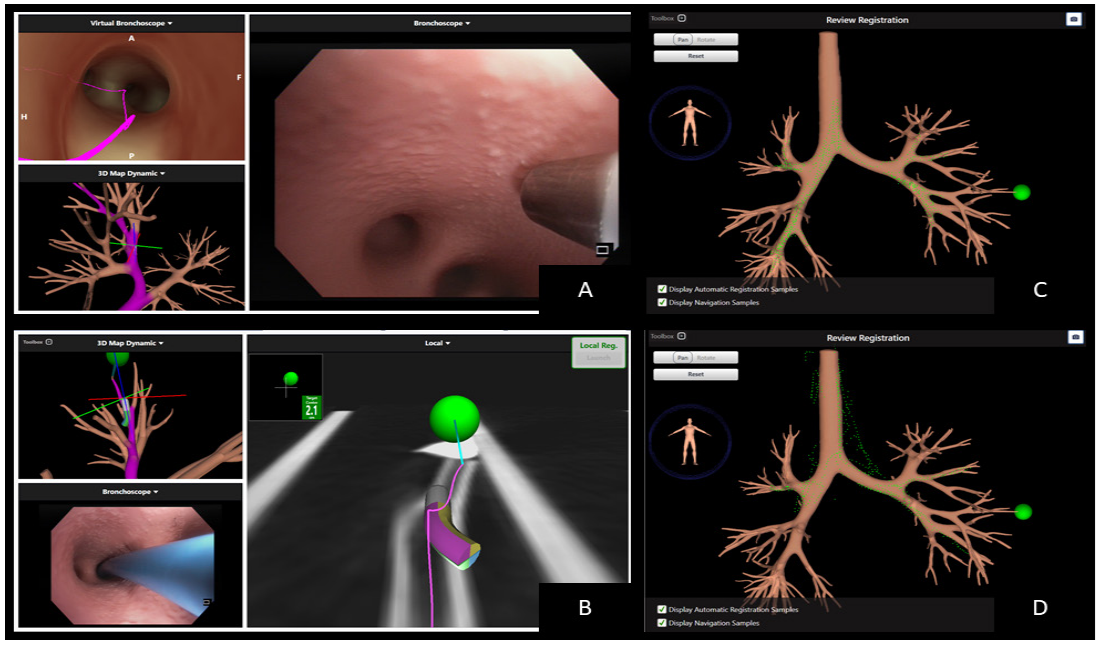

Figure 8. ENB with 3D airway mapping

3D virtual airway map with tool localization and CT-to-body alignment. *Source: JoVE – "Radial-endobronchial ultrasound electromagnetic navigation".*

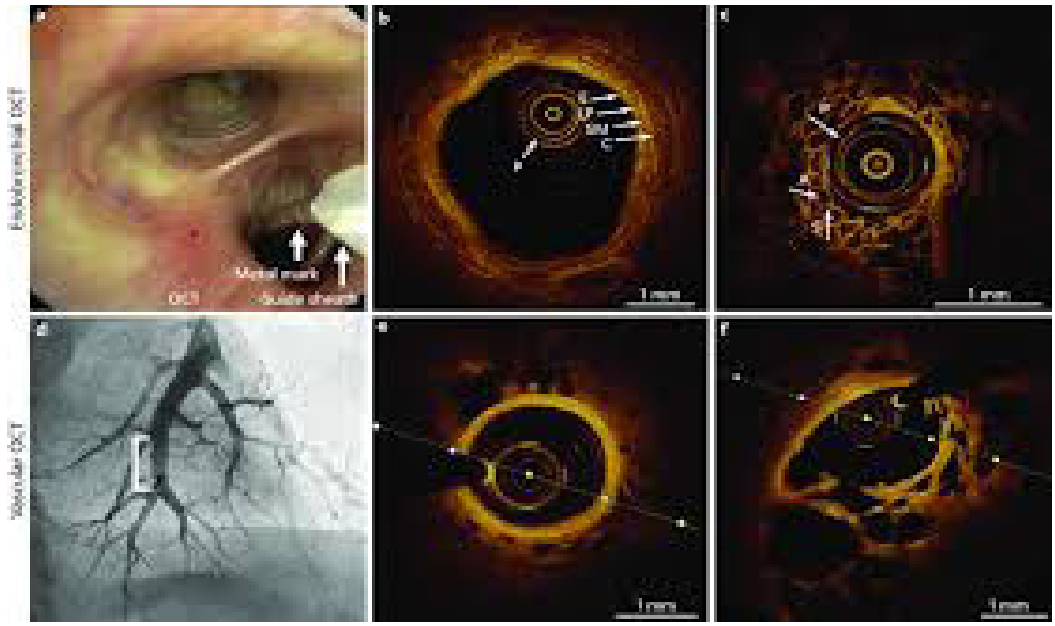

Figure 2. Endobronchial Optical Coherence Tomography (EB-OCT)

In vivo OCT cross-sectional imaging of airway microstructure. *Source: ResearchGate – Endobronchial OCT imaging of airway microstructure*.

9. CONCLUSION

The modern FB ecosystem is shifting from "see & sample" to "multimodal navigation + real-time optical histology + AI support." Recent evidence highlights:

NBI/AFB improve detection of flat/precancerous lesions [7,8];

EBUS/EUS-B remain the staging cornerstone [1,2];

ENB/RAB combined with CBCT/rEBUS/nCLE boost diagnostic yield for peripheral nodules [3–6];

EB-OCT/nCLE pave the way for "optical biopsy" [9];

AI is increasingly supporting lesion recognition and training [10].

Strategic implementation, combined with training, standardization, and local research, will help these advances shorten diagnostic delay and improve prognosis for lung cancer patients in Vietnam.

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