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REVIEW

Electromagnetic navigation guided bronchoscopy

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Abstract

This review describes the technique and applications of an emerging bronchoscopic approach utilizing three-dimensional reconstructions of chest computed tomography scans to facilitate electromagnetic guidance to peripheral lung nodules. This approach, electromagnetic navigation bronchoscopy, is useful for biopsy, placement of fiducial markers, or dye marking of overlying pleura prior to thoracoscopic wedge resection. This technique offers some potential advantages over other forms of biopsy. The design, application, relative advantages and pitfalls of this system are the subject of this review.

Keywords: *CT scan; lung biopsy; lung nodule; 3D reconstruction; bronchoscopy.*

Introduction

A variety of sampling techniques are now available to provide options for clinicians and patients who require biopsy of a lung nodule or nodules. These range from computed tomography (CT) guided percutaneous biopsy, to video assisted thoracoscopic surgery (VATS) and, more recently, the development of a system that combines three-dimensional chest computed tomography (CT) reconstruction of a virtual bronchoscopic image, with electromagnetic guidance. Electromagnetic navigation bronchoscopy (ENB) uses a steerable probe and a narrow extended working channel, which are coupled together. This combined probe and working channel fits through the working channel of a standard therapeutic fiberoptic bronchoscope, and this system is the subject of this review.

Gould *et al.*[1] provide excellent evidence-based guidelines for the management of lung nodules elsewhere and this is not covered here, other than to say that application of ENB must be considered in the context of a multidisciplinary approach in the care of patients with lung nodules. Many patients with lung nodules either require no biopsy because they are considered at very low risk for lung cancer and a more conservative approach (serial observation) may be more reasonable, while others are at such high risk that biopsy (other than at the time of surgical exploration) is not useful. However, there are patients for whom surgery is not an option, in whom a tissue diagnosis is required to guide treatment decisions. These include patients who have significant co-morbid illnesses that preclude surgery, and those with suspected metastatic disease. Once a decision has been made to attempt to biopsy a lung nodule, the options should be discussed with the patient in the context of local expertise, and the relative risks and benefits of each option. In general, choosing among options for biopsy comes down to a trade-off between certainty (sensitivity of the technique) and risk (degree of invasiveness). The most invasive biopsy is a surgical exploration; video assisted thoracoscopic surgery (VATS) or thoracotomy provides the most definitive tissue sample for the pathologist. However, for most patients, and for the purpose of this review, biopsy refers to tissue taken at the time of a CT guided percutaneous procedure, or a bronchoscopic procedure. Until recently, the CT guided percutaneous biopsy was the preferred choice for biopsy of peripheral nodules in non-surgical patients, due to the lack of sensitivity of transbronchial biopsy. The development of ENB provides another option for biopsy of peripheral

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nodules, one with a lower risk of pneumothorax, and also gives clinicians a tool for locating nodules with fiducial markers (for stereotactic radiation therapy) and pleural tattoos to guide surgeons resecting small nodules that are not palpable.

Bronchoscopy

In the evaluation of patients with suspected lung cancer, fiberoptic bronchoscopy is useful for accessing centrally located lesions and mediastinal lymph nodes. Transbronchial needle aspiration of enlarged mediastinal lymph nodes is safe and has a reasonable diagnostic accuracy in cases of malignant mediastinal lymph node metastasis. Real time linear probe endobronchial ultrasound increases sensitivity and permits the biopsy of much smaller lymph nodes in both the mediastinum and hilar lymph node stations. The accuracy of bronchoscopy for lung parenchymal lesions declines rapidly as the distance from the main stem bronchi increases, so that traditional transbronchial sampling techniques have less than 20% sensitivity for peripheral lung nodules[2]. ENB increases the yield of bronchoscopic biopsy of peripheral lung nodules. Experienced users of this newer technique report a 69–80% sensitivity for the diagnosis of small peripheral lung nodules (as small as 7 mm, ranging up to 8 cm, and average size less than 2 cm)[3,4]. It should be noted that this is less than what is reported for CT guided biopsy, hence the trade-off between accuracy, and a lower risk of pneumothorax[5]. The ENB system is divided into three phases, pre-planning, registration, and navigation.

Preplanning

The process used for ENB starts with the software. DICOM formatted data from the patent's CT scan are loaded from a disc onto a planning computer (SuperDimension, Minneapolis, MN), allowing the software to reconstruct axial, sagittal, and coronal images of the chest from the CT data. The software also displays a three-dimensional virtual bronchoscopic view, through which the user navigates using an intuitive interface with a standard computer mouse (Fig. 1). The quality of the three-dimensional virtual bronchoscopic images (and consequently of the planning process) is highly dependent upon the CT scan parameters. The maximum

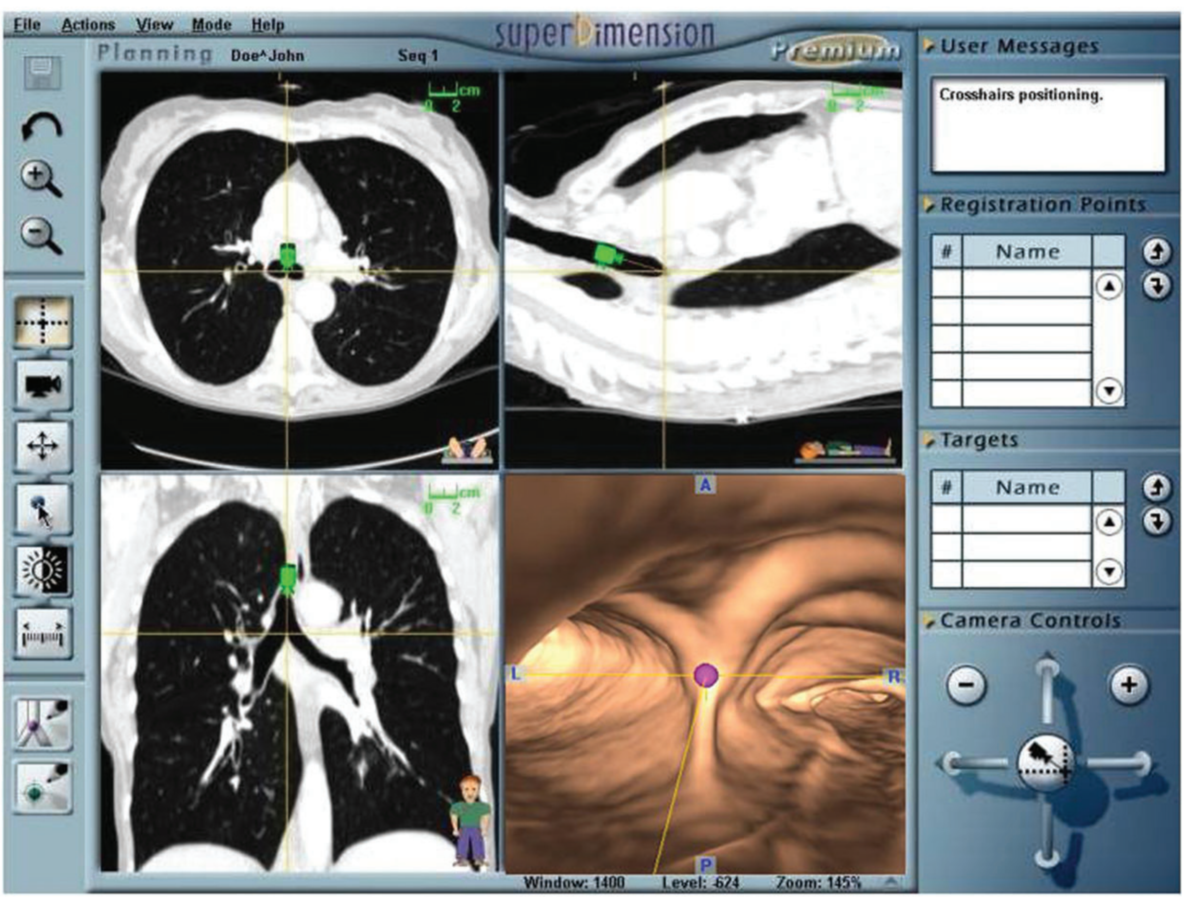

Figure 1 **Software planning user interface displaying (clockwise from bottom right panel) three-dimensional bronchoscopic 'tip view', along with coronal, axial, and sagittal planar reconstruction of the DICOM formatted CT data.**

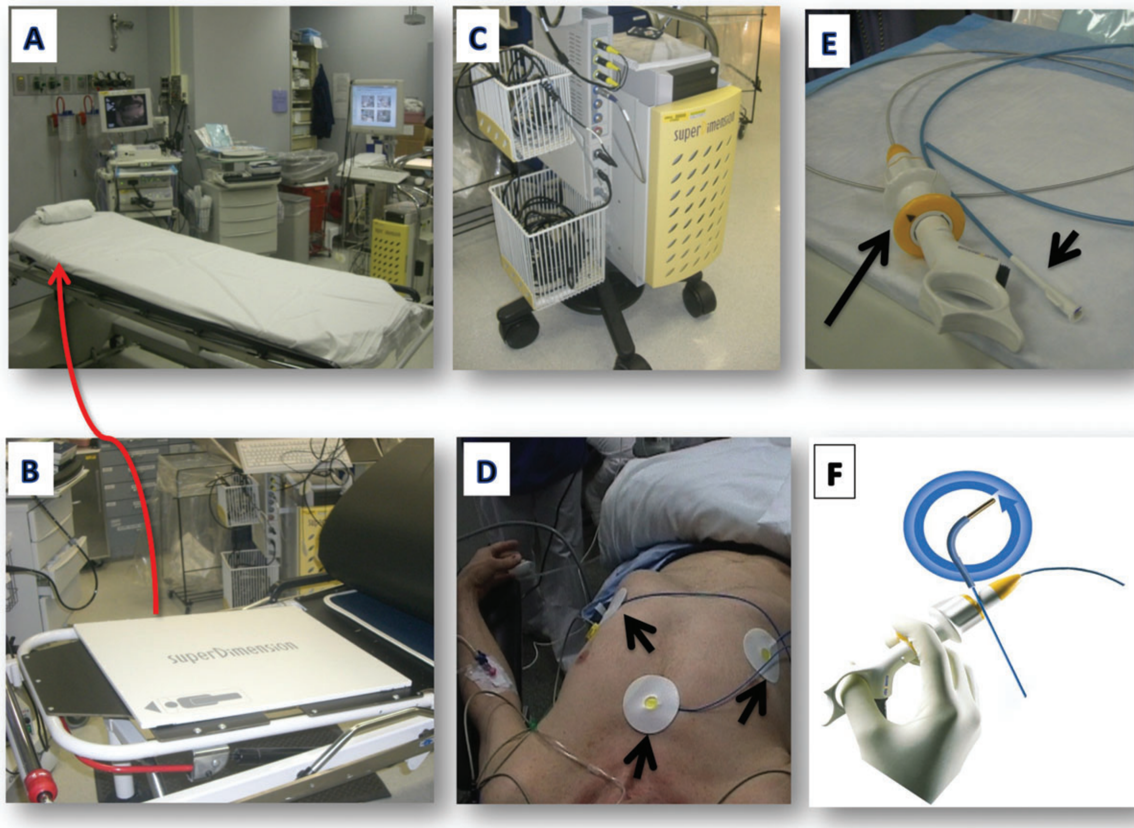

Figure 2 **Procedure room set-up. (A,B) Fluoroscopy table with the location board underneath the patient's chest. (C) Procedure cart containing the location processor, cables, and a PC with the planning software. (D) Patient sensors (black arrows) that allow tracking of the lungs during respiratory motion. (E) The locatable guide (large arrow) and extended working channel (small arrow) combine (F) to allow steering of the working channel to the target lesion(s).**

slice thickness of the scan should be 3.0 mm, with 50% overlap between the slices. The quality of the planning images improves inversely with the slice thickness. As long as the overlap is 50%, then the thinner the slices, the better for planning purposes. One exception to this is that the software cannot process a data file containing more than approximately 650 images. The thinnest slice thickness I have used for planning is 1.25 mm slices at 0.625 mm intervals. At this size a diagnostic CT of an average size adult yields 400–500 images, a volume of data handled easily by the current software. These thinner slices result in excellent detail of bronchi down to a few millimeters in diameter in the virtual model of the airway. Any respiratory motion artifact on the CT will degrade the accuracy of the registration, and therefore CT scans are best obtained during a full breath hold as is the standard with diagnostic CT scanning. If the patient has already had a diagnostic CT scan that fits the parameters described above, no additional CT is required. For most patients, the CT scan obtained for initial evaluation of the nodule is all that is required.

As the user navigates through the virtual airway, the view is displayed as it would appear through the bronchoscope. The three planar images of the chest move with the virtual scope as well. The operator selects and marks well-recognized anatomic landmarks in the planning phase using the mouse by touching each spot; usually the main carina, and the carinae delineating the right upper lobe, middle lobe, a basilar segment from the right lower lobe, the left upper lobe, and one of the left lower lobe basilar segments (Fig. 1). Any easily recognizable landmark is appropriate, as long as it can be seen through the bronchoscope. During the planning phase the target(s) to be biopsied are also marked. The ability to biopsy multiple nodules in one procedure without an appreciable increase in the risk of pneumothorax must be considered one of the advantages of ENB. The size and location of each target nodule are marked, and the planning software then saves a compressed version of the data to a removable USB drive. This drive can then be inserted into the USB slot of the computer located in the procedure room. In the procedure room, the location board, a flat plate located under the patient, generates a magnetic field (Fig. 2A,B). This location board is connected to the location processor, and from that to a computer that also has the ENB software (SuperDimension, InReach™. Fig. 2C). The location board and processor generate a sensing volume, and when the patient is

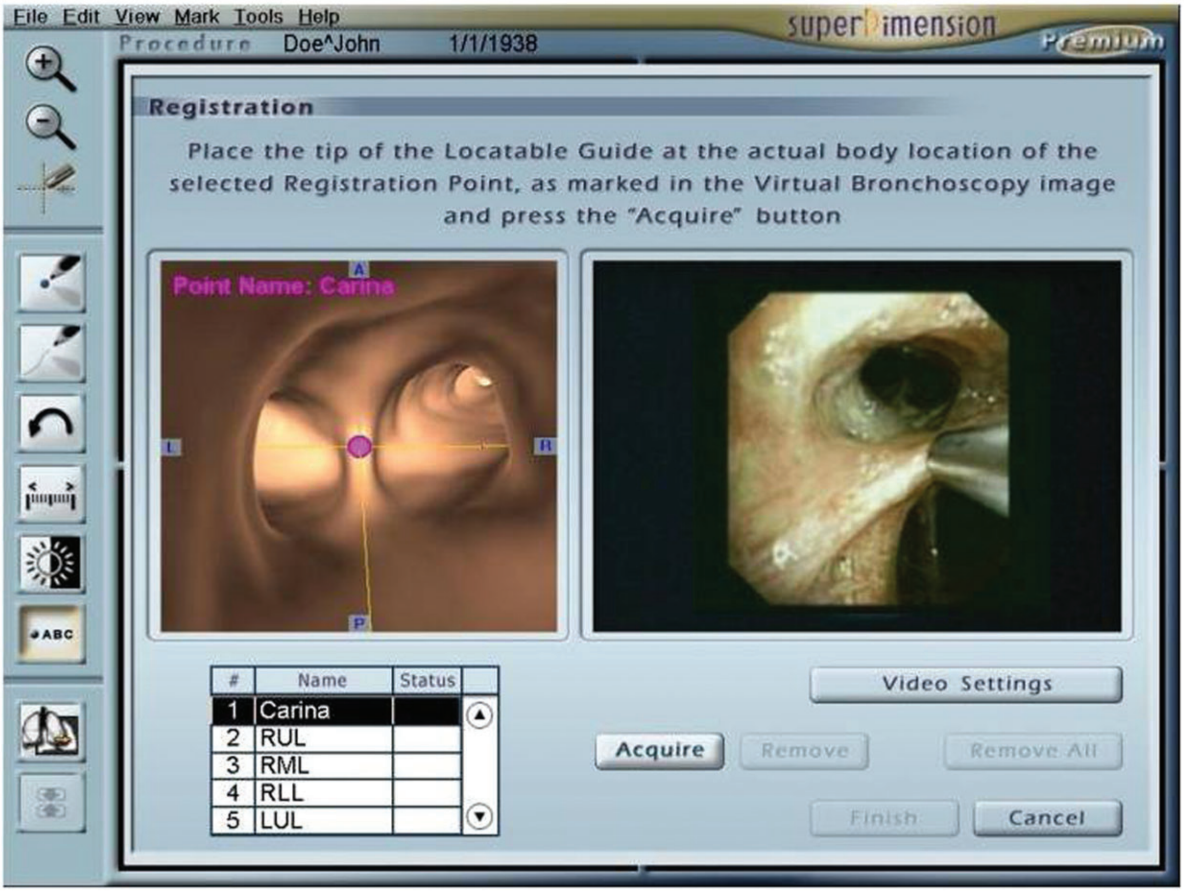

Figure 3 **Registration of anatomic landmarks with side-by-side view of the virtual and real-time bronchoscopic images.**

positioned properly on the table, the patient's chest is encompassed by this volume. Three sensors are also placed on the patient's chest within the sensing volume, and these allow for tracking of the lung motion during spontaneous respiration (Fig. 2D). The procedure can be done with conscious sedation or with deeper sedation given with an endotracheal tube in place. The operator performs the procedure with a steerable probe (the locatable guide (LG), Fig. 2E) inserted into an extended working channel (EWC; a hollow plastic catheter, see Fig. 2E), both of which fit in the working channel of a therapeutic bronchoscope. The three-dimensional position of the tip of the LG within the chest (x, y, and z coordinates and roll, pitch, and yaw) is also detected by the location processor.

Registration

Once the patient is adequately sedated, the bronchoscopist inspects the airway with the fiberoptic scope, and then places the combined LG and EWC into the airway via the scope's working channel. The operator advances the scope and locatable guide to each of the anatomic registration points entered during the planning phase, and registers them within the patient by touching the same spots with the probe, and entering the point with a foot pedal (Fig. 3). Once the landmarks have been registered in the patient, the computer will report an average fiducial target registration error (AFTRE), which gives an estimation of the divergence between the CT anatomy and the patient's anatomy. The ideal AFTRE is less than 5 mm, but error rates less than 4 mm are achievable. In my experience, an AFTRE that is less than the size of the nodule is desirable. It is not necessary to use all the registration points entered during the planning phase if one proves particularly difficult to register accurately. The software may suggest particular points to re-register, or the user may select problematic points to delete from the registration. It is critical to have at least four accurately marked registration points that are well separated in space, with at least one on each side of the thorax, and one registration point should always be the main carina. After registration, the computer prompts the user to continue to the navigation phase, or allows a return to registration to improve accuracy.

Navigation

The navigation is achieved initially by approaching the proper airway segment containing the target with

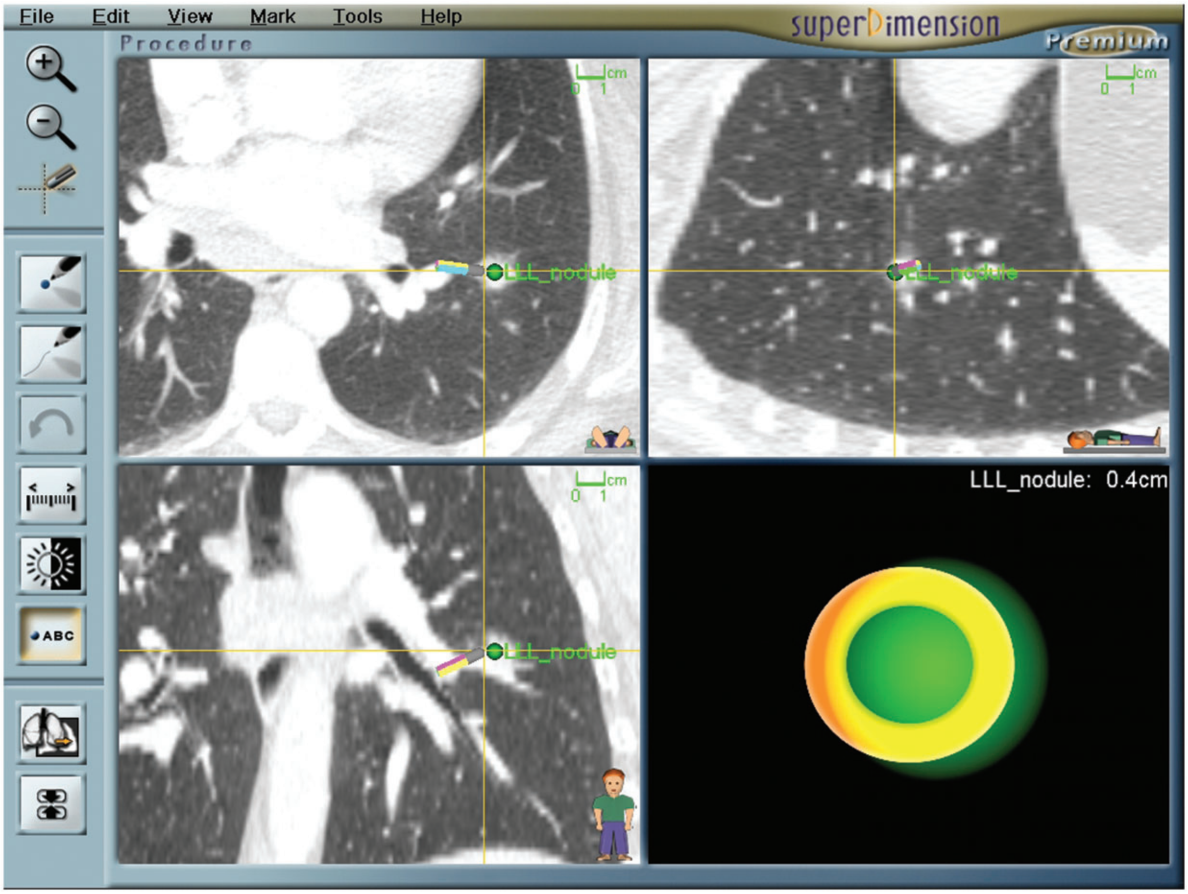

Figure 4 **Display during the navigation phase of the procedure shows real-time location of the tip of the locatable guide with simultaneous axial, sagittal, coronal, and 'tip view' which also displays the distance to the target lesion.**

the bronchoscope. Once the scope is wedged into the target segment, the LG EWC is advanced through the working channel and steered to the target using the four views displayed on the computer. Axial, sagittal, and coronal views of the chest move along with the tip of the LG, and the tip-view is displayed alongside the planar views of the CT scan (Fig. 4). The tip-view displays the distance to the nodule, and an arrow indicating the direction of turn required to reach the nodule. On the proximal end of the LG in the operators hand is a click-wheel with an identical arrow, and the operator can steer the distal end of the guide to the lesion by matching the clock position of the arrows on the guide with that suggested on the tip-view, and squeezing the trigger to deflect the tip in the direction of the target (see Fig. 2E, F). The tip is advanced toward the nodule until it is in sufficiently close proximity to allow biopsy tools to reach the lesion. Once in position, the operator locks the EWC in place at the entrance to the scope's working channel, and removes the LG, leaving the extended working channel in place near the nodule. Various techniques can be used for real time confirmation of the location of the EWC near or within the nodule as suggested by the virtual images generated by the location processor. Fluoroscopic images can be used, as well as a radial probe ultrasound catheter that fits through the working channel (Fig. 5A,B). A new and useful tool for visualizing the peripheral lung tissue in real time is a micro-endoscopic confocal laser catheter (CellVizio^{TM}) which passes easily through the EWC, and displays real time video on a microscopic level (Fig. 5C,D). Investigators are just beginning to establish a pattern of recognition for normal and diseased lung tissue using this system[6]. As with any transbronchial biopsy, the actual sampling should be done with fluoroscopic visualization to observe the position of the biopsy tools.

Once the EWC position is confirmed to the satisfaction if the bronchoscopist, biopsy tools can be advanced to the nodule through the EWC to take samples. Prior to the procedure, it is standard practice to mark the tools at their proximal end, so the operator knows how far to advance the tool prior to its emergence from the distal end of the EWC. The choice of biopsy tool is up to the operator, but any standard needle, cytology brush, or transbronchial forceps can be used to obtain either cytologic, or histopathologic material from the nodule. Between each pass of a biopsy tool, it is good practice to re-insert the locatable guide, to confirm that the EWC

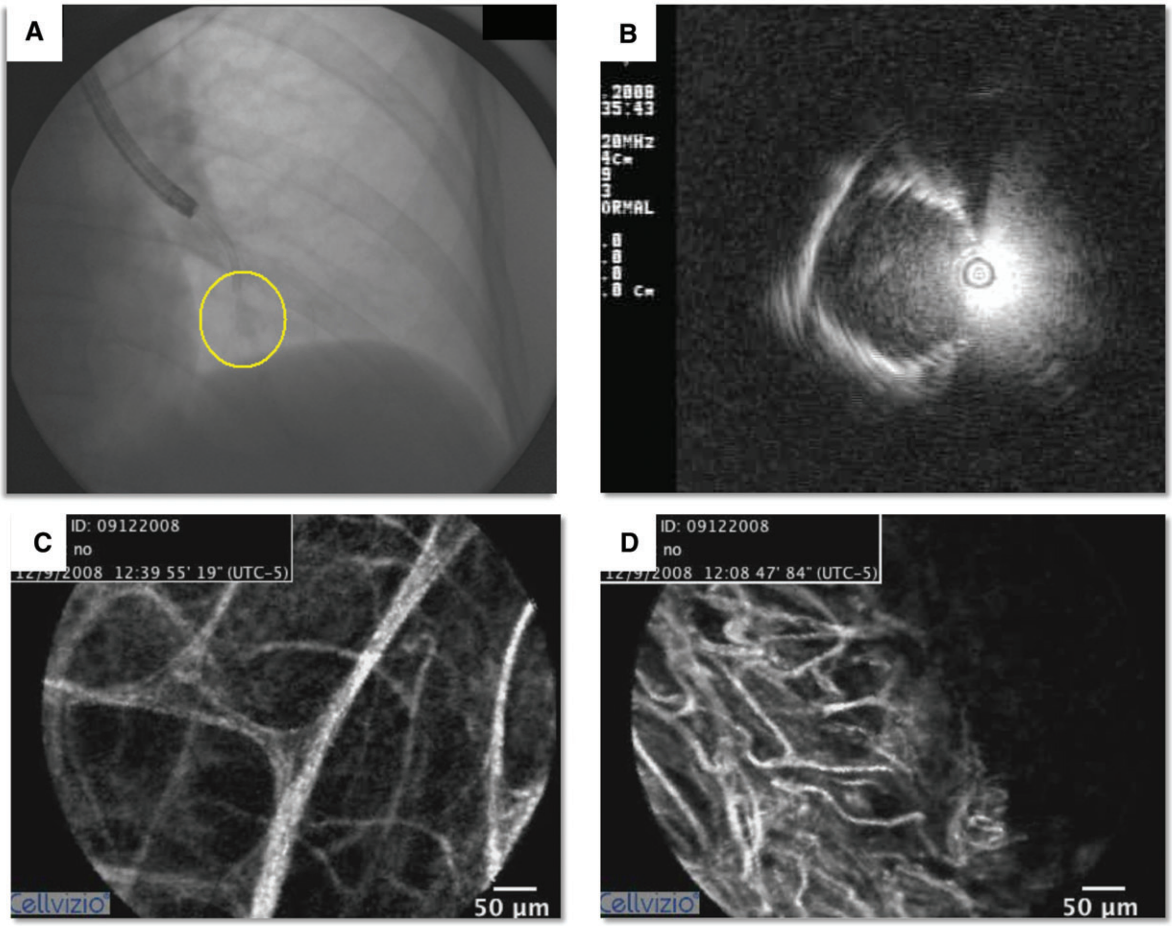

Figure 5 **When performing biopsies, some form of real time confirmation of the location of the working channel is necessary. This can be done with (A) bi-planar fluoroscopy, (B) a radial ultrasound probe advanced through the working channel, or (C,D) confocal laser micro-endoscope ((C) showing normal lung; (D) showing abnormal lung architecture).**

was not displaced from its location within or near the nodule by the act of taking the tissue sample. Fluoroscopy during the procedure is also useful to monitor the location of the EWC and biopsy tools. Likewise, the use of a radial probe ultrasound image to re-confirm the location of the EWC is very helpful.

Other uses

ENB is now gaining wider use as a tool for diagnosis of peripheral lung nodules, and there have been other uses published for this system. These include placement of fiducial markers in and around nodules to guide stereotactic radiotherapy[7]. In addition, there are nodules that a surgeon plans to biopsy or resect with a VATS approach, but is concerned that they will not be able to palpate the nodule through a thoracoscopic incision. In these cases, ENB permits the bronchoscopist to navigate the overlying pleura and deliver a tattoo through a needle passed via the EWC (usually indigo-carmine). The surgeon then visualizes the tattoo through the thoracoscope eliminating the need to palpate the nodule. This approach can reduce the duration of the procedure and reduce the likelihood of conversion to thoracotomy[8]. Some users have developed the technique for delivering brachytherapy by a transbronchial route for patients who cannot tolerate external beam radiotherapy (T. McLemore, Tyler, TX, personal communication). This emerging technology was originally developed for the diagnosis of malignancy in the lung, but it also provides the bronchoscopist with a tool to use in the diagnosis and treatment of a variety of lung diseases. For radiologists, it is important to be aware of ENB so that they can work with users of this system to assure CT scan parameters are appropriate if the use of ENB is considered likely in the management of their patients.

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