A Case Study

An Introduction to Cone Beam CT in Bronchoscopic Interventions

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Introduction

Use of cone beam CT (CBCT) imaging during bronchoscopic interventions has increased rapidly in recent years, with numerous studies reporting the use of Siemens Healthineers fixed and mobile systems. The primary clinical application has been transbronchial biopsy of peripheral lung lesions (PLLs);[1-10] however, additional applications such as transbronchial tumor ablation[11] and cryobiopsyfor interstitial lung disease[12] have been reported as well.

Recent studies have shown that CBCT can be used for intra-procedural visualization of PLLs, to determine the positioning of devices relative to target lesions,[1-10] and to assess the presence and location of atelectasis[6-9] (Figures 1 and 2). Furthermore, it is the only bronchoscopic navigation technology which provides definitive 3D imaging evidence of accurate navigation of tools to the target lesions. CBCT guidance falls into two categories: 1) fluoroscopic overlay of anatomic targets which are segmented using an early intraprocedural scan; and 2) tool-in-lesion confirmation using a later intraprocedural CBCT acquired just before an intervention, i.e. biopsy or ablation.

Why Use CBCT?

Diagnostic yield is 70% using guided bronchoscopy, which includes radial probe endobronchial ultrasound (rpEBUS), ultrathin bronchoscopes, virtual bronchoscopic navigation, and electromagnetic navigation (EMN).[13] Also, a recent meta-analysis reported an overall sensitivity for cancer of 77% using EMN.[14] Other recent studies have used CBCT to help elucidate why these values aren't higher. CT-to-body divergence is defined as any change in target lesion size or location between a pre-procedural CT and subsequent intervention which could impact navigation. Thus, any navigation technology which relies on pre-procedural CT can suffer from errors due to CT-to-body divergence. One common cause of CT-to-body divergence is Atelectasis, which has been reported in almost 90% of patients undergoing bronchoscopic intervention, although not all atelectasis will impact lesion visualization or navigation.[15]

Recent studies have shown that CBCT can be used to identify atelectasis and help correct for errors in tool positioning caused by CT-to-body divergence.[6-9] In recent years, CBCT has been added to procedural workflows, including those that use technologies susceptible to CT-to-body divergence. Early studies report a positive impact to both navigation accuracy and diagnostic yield after adoption of CBCT, due to the ability to identify lesion location and tool positioning errors, and to confirm tool-in-lesion. One study suggested that by adding CBCT to an existing workflow with EBUS and thin/ultrathin bronchoscope, diagnostic yield could increase by up to 20%, and navigation accuracy by up to 25%.[6]

By using CBCT alongside EMN, diagnostic yield could be increased by as much as 25%, with 87.5% navigation accuracy;[16] and by combining CBCT with VBN and an ultrathin bronchoscope, a diagnostic yield of 90% has been reported.[17]

The goal of Robotic navigation systems is improved stability and control of the guide catheter's distal tip, which should help target small PLLs more accurately. Like other navigation systems, these robots rely on pre-procedural CT for guidance and are susceptible to CT-to-body divergence errors. Early clinical evidence indicates that diagnostic yield with robotic systems is approximately equal to EMN. However, the addition of CBCT may result in improved navigational accuracy and diagnostic yield.[10]

Much of the interest in both CBCT and robotic bronchoscopy has been focused on the introduction of bronchoscopic ablation therapy, with multiple devices scheduled to begin clinical trials soon. For ablative therapies to succeed, practitioners will need to ensure accurate placement of devices prior to therapy; thus, CBCT is poised to play a vital role in these trials.[11]

Regardless of which navigation or imaging technologies are utilized, the addition of CBCT has been shown to improve navigation accuracy and diagnostic yield. A thorough examination of CBCT applications in bronchoscopic interventions has also been published recently.[18]

CBCT Image Acquisition

CBCT image acquisition is fundamentally different from multi-slice CT (MSCT).[18] With CBCT, multiple 2D projection images are acquired as the C-arm rotates around the patient. The projection images are then reconstructed into a stack of axial images which are similar in appearance to MSCT images. Spatial resolution is also similar between CBCT and MSCT, but contrast resolution – the ability to distinguish among soft tissues – is inferior with CBCT.

Despite this, lesion conspicuity with CBCT has been shown to be sufficient for intraprocedural guidance.[1-12]

CBCT image quality relates directly to the number of acquired projection images and the dose per projection image. However, image artifacts are more common with CBCT because of the relatively longer acquisition and increased scatter radiation from flat panel detectors.[18]

Cone Beam CT is an available feature on Siemens Healthineers mobile platform (Cios Spin) and all fixed angiographic systems, regardless of model or age.

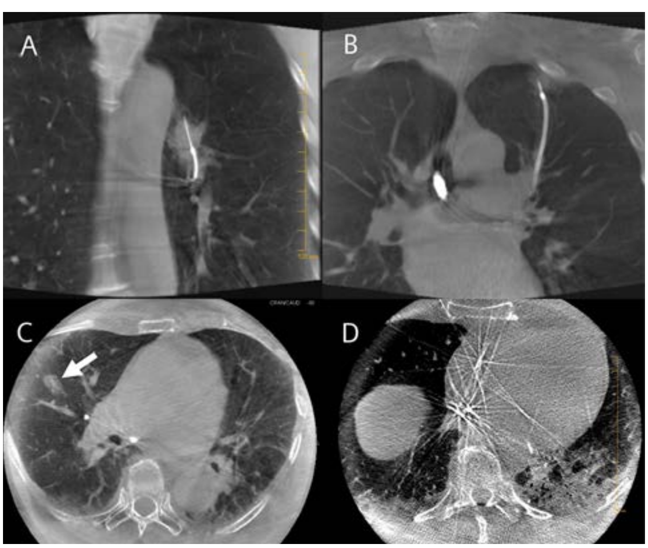

Figure 1. CBCT images of PLLs and atelectasis using a fixed angiographic system. (A) solid lesion; (B) semi-solid lesion; (C) ground glass opacity (GGO) lesion, denoted by arrow; (D) dependent sublobar atelectasis. Images (A) and (B) also depict Tool-in-Lesion confirmation during PLL biopsy.

Images courtesy of Krish Bhadra, MD (Memorial Hospital, Chattanooga, TN USA)

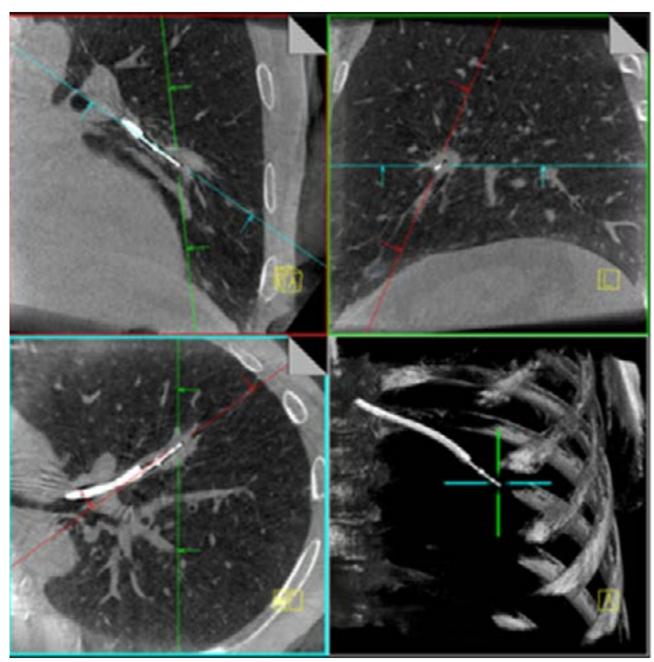

Figure 2. CBCT images using Cios Spin mobile system. MPR images and VRT (bottom right) from a single acquisition demonstrate lesion appearance and tool-in-lesion confirmation prior to biopsy.

Images courtesy of Jonathan Hovda, MD (Abbot Northwestern, Minneapolis, MN USA)

Systems capable of CBCT

Mobile

With its 3D imaging capabilities, Cios Spin is ideally suited for bronchoscopic interventions. (Figure 3) 3D imaging on Cios Spin is true CBCT, and can be used both for lesion visualization and tool-in-lesion confirmation. Cios Spin combines seamlessly with robotic systems, and will fit into bronchoscopy suites that are typically too small for a fixed angiographic system. Price is another attractive feature of Cios Spin; not only does it have a lower price point than fixed systems, but it also avoids installation costs. Because of its mobility, Cios Spin can be used across multiple procedure rooms. Lastly, Cios Spin should be paired with a radiolucent table suitable for 3D imaging, as tables with metal side rails may interfere with the 3D acquisition and can cause image artifacts.

Fixed

Siemens Healthineers offers 4 fixed angiographic system configurations, all of which are capable of CBCT (DynaCT): Floor, Biplane, Ceiling, and Robotic. (Figure 4.)

Robotic systems (zeego and pheno) consist of a base situated away from the patient table and an articulating arm that extends to the patient. This configuration is ideal for hybrid OR environments because it offers unparalleled patient access but can also easily be moved in and out without interfering with ancillary equipment, e.g. during staging or if used in conjunction with robotic navigation. Room setup is easily configured using a robotic system, as the c-arm typically comes around the bronchoscopist's left shoulder. In addition, the table can be rotated 15° or 30° to increase availabile space at head side, e.g. to incorporate robotic navigation.

Figure 3. Cios Spin provides 2D and 3D (CBCT) capabilities in a mobile platform.

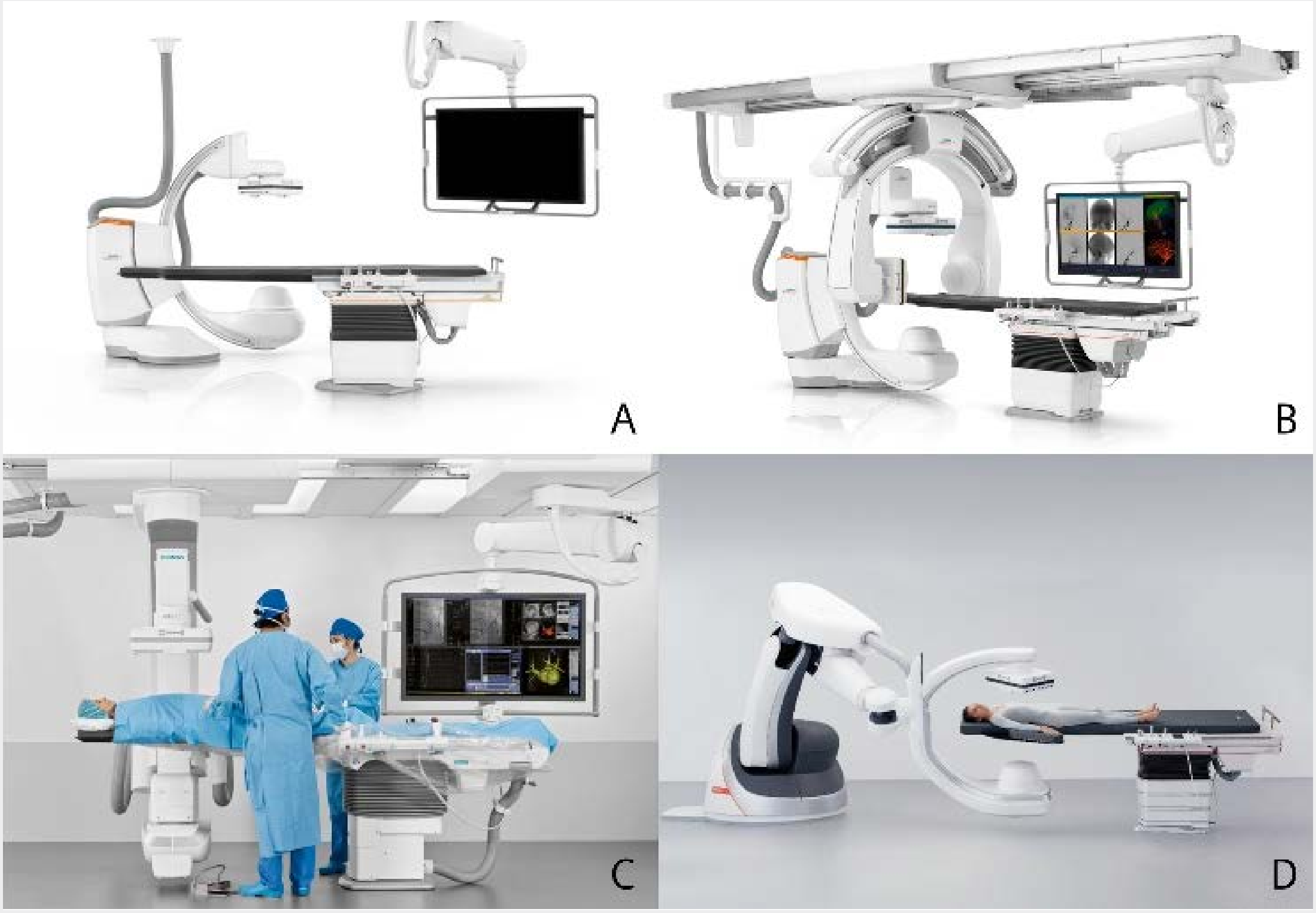

Figure 4. Siemens fixed angiographic systems come in different configurations: Floor (A); Biplane (B); Ceiling (C); and Robotic (D). All systems are capable of performing CBCT.

Robotic systems can perform CBCT at head, left or right sides, and are the only systems which allow CBCT with a rotated patient table. Robotic systems also provide the most CBCT protocol options. In addition to the recommended protocols – as described in Workflows section below – robotic systems also offer protocols for large BMI patients. In cases where a non-robotic c-arm is not capable of clearing the patient, either the Large Volume or DynaCT 360 protocols provide enhanced capabilities not found in any other system or by any other manufacturer.

Ceiling systems are commonly found in Interventional Radiology and Cardiology departments in US hospitals, and they are extremely well suited for use in bronchoscopic interventions. Because they are mounted on ceiling rails, they allow easy access to the patient's head and can be moved away from the patient's chest when desired, e.g. during lymph node sampling or during navigation, e.g. robotic, EMN. Ceiling mounted systems can perform CBCT at head side, or with the c-arm rotated to the patient's left or right sides.

Floor systems and Biplane systems have the C-arm base located just above the patient's head. Bronchoscopic interventions are feasible with human operators – the table can be rotated away from C-arm base during navigation to allow more room at patient's head, then rotated back for CBCT. However, floor mounted systems are not compatible with robotic navigation. These systems perform CBCT in a propeller acquisition, with the axis of rotation just above the patient's head, which may limit access to the base of lungs in taller patients.

Augmented Fluoroscopy

Multiple software tools are available for lesion segmentation and fluoroscopic overlay on Siemens Healthineers fixed angiographic systems. Augmented fluoroscopy is possible regardless of system age, using any of the following software tools: Polyline; Stroke-based segmentation; iGuide Toolbox; and iPilot Dynamic or iPilot Live, in conjunction with InSpace drawing tools. With any of these tools, segmentation is performed manually by drawing a contour (or contours) around the target lesion. Once completed, the augmented fluoroscopy overlay will remain accurate during C-arm and table movements. (See Figure 5.)

Figure 5. Augmented fluoroscopy in a lung phantom. Top: Target lesion segmented using Stroke-based segmentation software. (Segmentation is shown as a yellow line.) MIddle: Volume rendered technique (VRT) image from Tool-in-lesion CBCT showing ablation probe, segmented lesion (yellow, sroke-based segmentation result), and planned ablation zone (green, segmented using Polyline tool). Bottom: Augmented fluoroscopic overlay of target lesion

Workflows

Cone Beam CT. For Cios Spin, the 30 second high quality acquisition is recommended. With any fixed system, the Body DynaCT protocols are recommended: either 5 sec DCT, 6 sec DCT, or 8 sec DCT, depending on system type. Regardless of system, it is important to secure the bronchoscope to the table before 3D acquisition using a dedicated holder or custom solution, e.g., Mediflex Surgical Products. (See Figure 6.) In addition, laser crosshairs can be used to help isocenter the lesion.

Room Setup. A typical room configuration is shown in Figure 7. Although exact set up will vary among sites, the c-arm is typically positioned at left side, with bronchoscope cart, EMN cart (if applicable) and anesthesia placed on patient's right side. A CBCT test run is recommended before the procedure to ensure the c-arm can move unimpeded around the patient, especially if robotic navigation is used.

Transbronchial biopsy workflow. All patients will have a pre-procedural CT used for diagnosis and planning.

1. Pre-procedural CBCT can be used to check for changes in lesion appearance (size and location) and to segment the lesion for fluoroscopic overlay. (Figure 5)
2. Navigate guide catheter to lesion using either fluoro overlay or navigation method (EMN or robotic). Advance biopsy tool to lesion and secure bronchoscope for CBCT.
3. Intraprocedural CBCT for tool-in-lesion confirmation prior to biopsy. If needed, reposition biopsy tool and reacquire CBCT.
4. Biopsy with onsite pathology.

Transbronchial ablation workflow. CBCT can be used for navigation to the target lesion and to verify placement of the ablation probe prior to therapy.

1. Pre-procedural CBCT (optional) can be used to check for changes in lesion appearance (size/location) and to segment the lesion for overlay.
2. Navigate guide catheter to lesion using either fluoro overlay or navigation method (EMN or robotic). Advance ablation tool to lesion and secure bronchoscope for CBCT.
3. Intraprocedural CBCT for tool-in-lesion confirmation prior to therapy. If needed, reposition tool and reacquire CBCT to confirm correct positioning of ablation catheter.
4. The predicted ablation zone plotted manually, using dimensions from ablation device manufacturer, to ensure lesion is fully covered by ablation.
5. Ablate lesion according to device manufacturer specifications.

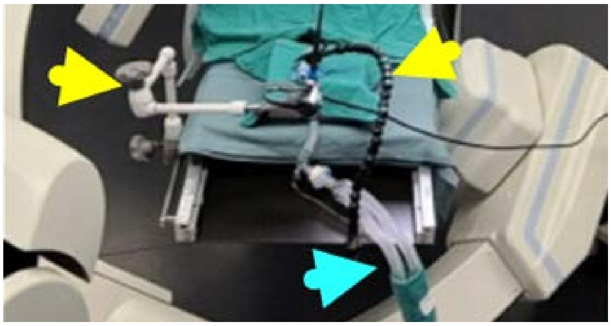

Figure 6. Bronchoscope holders (yellow arrowheads) attached to tableside rails used during CBCT. (Left) Neuwave Medical; (Right) GoPro camera holder. Ventilator tubes (blue arrowhead) are run straight from patient's head to avoid collision with C-arm.

Figure 7. Typical zeego room setup with bronchoscope tower and anesthesia equipment shown headside to patient's right

Radiation Dose

The most significant determinant of procedural radiation dose is the total number of CBCT spins performed. The radiation dose for each CBCT is proportional to the number of projection images and the dose per projection image, similar to image quality. As described elsewhere, the best measures of CBCT radiation dose are the air Kerma (or skin dose) and dose area product (DAP), both of which are reported on all Siemens systems. [6,18] Some studies have reported effective dose (E) with CBCT; however, most of these used generalized conversion factors which do not correspond to the C-arm system used in the study. The true conversion factors are system-specific, and will vary with anatomic location, but can be measured using a calibrated phantom. The effective dose associated with CBCT has been measured using phantoms in several studies, with values of 0.98 mSv and 1.33 mSv per acquisition using 2 Siemens fixed system types [2,19]. These effective dose values correspond to acquisitions with 248 and 312 projection images, respectively, and are similar to those of a low-dose CT of the chest as performed during the National Lung Screening Trial. A recent Siemens-internal phantom study using Cios Spin reported effective dose of 0.26 mSv for CBCT standard acquisition (200 projection images) and 0.84 mSv for CBCT high-quality acquisition (400 projection images). [20] (The high quality acquisition is recommended for imaging PLLs.)

Collimation can be used to reduce the field of view in cranio-caudal direction, and radiation dose will be reduced by an amount proportional to the degree of collimation. This technique will reduce scatter radiation and can result in improved image quality as well.

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20. *Date on File: Dose and image quality evaluation in transbronchial workflow.*

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