

# Improved Virtual Bronchoscopy Using a Multi-Slice Helical CT Scanner

Ronald M. Summers<sup>\*</sup>, Michael C. Sneller, Carol A. Langford, James H. Shelhamer, Bradford J. Wood

Diagnostic Radiology Department, Warren Grant Magnuson Clinical Center  
National Institutes of Health, Bethesda, MD 20892-1182

## ABSTRACT

Virtual bronchoscopy reconstructions of the airway noninvasively provide useful morphologic information of structural abnormalities such as stenoses and masses. To date, virtual bronchoscopy has been mainly applied to the central airways. In this paper, we show how virtual bronchoscopy can be applied to more peripheral airways by making use of the capabilities of a multi-slice helical CT scanner.

Keywords: Bronchus; trachea; Wegener's granulomatosis; region growing; surface rendering; virtual bronchoscopy; visualization; multi-slice helical CT; segmentation

## 1. INTRODUCTION

Virtual bronchoscopy is known to be useful for detecting airway stenoses due to inflammation, tumor, or post-operative change<sup>1-6</sup>. It is a noninvasive post-processing technique that reconstructs endoluminal views of the airway from helical CT scans of a patient's chest. The endoluminal views simulate what a pulmonologist would see during a conventional bronchoscopy and are useful for diagnosis, communication with referring physicians, treatment planning and medical education<sup>7</sup>. Computer-aided diagnostic techniques can be applied to virtual bronchoscopy reconstructions to automatically identify abnormalities<sup>8-10</sup>.

To date, we have performed virtual bronchoscopy with a first-generation helical CT scanner. This scanner produces virtual bronchoscopy reconstructions that are sufficient to detect pathology well in the central airways. We now present our initial experience with a second-generation helical CT scanner that has multi-slice capability<sup>11,12</sup>.

## 2. METHODS

The patient population had Wegener's granulomatosis and suspected airway disease<sup>13</sup>. There were seven subjects (mean age [ $\pm$  s.d.]  $37 \pm 12$  years; 6 male, 1 female). All had both single-slice and multi-slice helical CT with virtual bronchoscopy (VB) reconstruction. The single-slice CT scan always came before the multi-slice CT scan. Mean time between the two scans was  $371 \pm 373$  days (range 18 to 920 days).

Thoracic CT scans were first done using a single-slice helical CT scanner (SS-CT) (General Electric HiSpeed Advantage). Scanning was done from the level of the vocal cords through the costophrenic sulci using 3 mm collimation, helical pitch 2 (6 mm table motion per rotation), 140 kVp, 160 mAs, 1 sec tube rotation, overlapping reconstructions with a section interval of 1 mm, and an effective z-axis resolution of approximately 4.6 mm. Scanning was done in two or three breathholds. A bone reconstruction algorithm was used.

Subsequently, thoracic CT scans were done using a multi-slice helical CT scanner (MS-CT) (G.E. LightSpeed QX/i). The technique for the MS-CT scans was 1.25 mm collimation, HS mode (helical pitch 6; 7.5 mm table motion per

---

\* Send correspondence to R.M.S.

E-mail: rms@nih.gov

Web site: <http://www.cc.nih.gov/drd/summers.html>

rotation), 120 kVp, 100 mAs, 0.8 sec tube rotation, non-overlapping reconstructions with a section interval of 1.25 mm, and an effective z-axis resolution of approximately 1.6 mm. Scanning was done in two breathholds. The manufacturer's "standard" reconstruction algorithm was used.

We switched from the bone to the standard reconstruction algorithm for the MS-CT data because the standard algorithm produced a smoother and more pleasing reconstruction than the bone algorithm. The bone algorithm produced extremely noisy virtual bronchoscopy reconstructions from the MS-CT data that were deemed unacceptable.

Virtual bronchoscopy three-dimensional surface renderings of the central airways were generated from the CT data<sup>6</sup>. A standard isosurface tessellation algorithm was applied and an OpenInventor scene graph of the airways was produced<sup>14,15</sup>. The surfaces generated with this method can be used for virtual bronchoscopy. The virtual bronchoscopies were visualized using a generic virtual endoscopy navigation software tool<sup>16</sup>. Processing and display were done on an Indigo2 workstation with Maximum Impact graphics (Silicon Graphics, Inc.) having 320 MB main memory and using a single 195 MHz R10000 processor.

The SS-CT scans were compared to the MS-CT scans. We compared the overall quality and extent of visualization of peripheral airways on virtual bronchoscopy reconstructions produced from the SS-CT and MS-CT scans in the same subjects. Quality and extent of visualization were determined by counting the number of segmental and subsegmental bronchi that were visible in the three-dimensional surface reconstruction used for virtual bronchoscopy. A bronchus was counted if its origin was visible on an exoscopic view of the airway (e.g., see Figure 1a and b). Although there is anatomic variability and there are differences in nomenclature among various authors, we assumed a normal airway to have 18 segmental and 42 subsegmental bronchi<sup>17</sup>.

### 3. RESULTS

Virtual bronchoscopy images of the same patient scanned nine months apart, first with SS-CT and subsequently with MS-CT are shown in Figure 1. Note that many of the smaller airway branches not seen on the virtual bronchoscopy from the SS-CT are visible on the virtual bronchoscopy from the MS-CT.

Virtual bronchoscopy using MS-CT was capable of demonstrating more peripheral airways than the SS-CT. For example, the mean number of segmental bronchi visible at VB was  $13 \pm 4$  with MS-CT and  $8 \pm 4$  with SS-CT ( $n = 7$ ;  $p = 0.002$ , paired t-test). The mean number of subsegmental bronchi visible at VB was  $12 \pm 5$  with MS-CT and  $2 \pm 2$  with SS-CT ( $n = 7$ ;  $p = 0.003$ , paired t-test). There was also less spiral artifact with the multi-row detector CT virtual bronchoscopy (Figure 1).

### 4. DISCUSSION

Using the new multi-slice CT scanner, we were able to achieve 3 times greater z-axis resolution (1.6 mm versus 4.6 mm) for the same radiation dose and anatomic extent of coverage per breathhold. We were able to see five more segmental bronchi and nine more subsegmental bronchi on VB using MS-CT compared to SS-CT (allowing for round-off error). This represented an increase in number of visible bronchi of 67% and 440% for segmental and subsegmental bronchi, respectively. Using the number of bronchi expected anatomically as the denominator, the percentage of visible segmental and subsegmental bronchi increased from 44% to 72% and 5% to 29%, respectively. Spiral artifact was also less prominent on the MS-CT virtual bronchoscopy studies, which yields more pleasing reconstructions. The significance of these capabilities is that they allow physicians to visualize smaller more peripheral airways and potentially detect smaller lesions before they become symptomatic.

Visibility of a small airway branch requires both sufficient resolution and contrast to resolve the interface between the lumen and airway wall and to segment the airway lumen. Since segmental and subsegmental bronchi have diameters on the order of one to three mm, voxel resolution must be within this range to detect these smaller airways. We were unable to attain this resolution with the SS-CT technique while at the same time maintaining the desired extent of anatomic coverage per breathhold. The MS-CT scanner is able to achieve sufficient spatial resolution and anatomic coverage because it can scan three to four times faster than the SS-CT scanner. At the same time, the MS-CT images had sufficient contrast

resolution and signal-to-noise ratios necessary to produce three-dimensional models of the smaller airways using a region-growing segmentation and isosurface extraction algorithm.

The improved z-axis resolution for equivalent extent of anatomic coverage is possible because the multi-slice scanner takes advantage of multiple rows of x-ray detectors. The multiple rows of x-ray detectors allow the scanner to produce multiple images per rotation of the x-ray tube, in contrast to the single image produced per tube rotation with a SS-CT scanner.

Extent of anatomic coverage is important because with greater coverage, fewer breathholds are required. With fewer breathholds, fewer artifacts occur when scans done on different breathholds are aligned to produce a complete three-dimensional airway model.

Ideally, one would like to compare CT scans done on the same subject on the same day using both types of scanners but then the patient would receive twice the usual radiation dose. In our project, we compared virtual bronchoscopy studies from the same subjects scanned at different times on the first- and second-generation helical CT scanners. Consequently, the patients' disease status could have been different when the two scans were done. However, such changes would not be expected to be so widespread and timed so as to affect only the SS-CT scan. Also, there was no CT or clinical evidence to support the presence of widespread disease in these subjects. Therefore, we attribute the marked superiority of the MS-CT virtual bronchoscopies to the superior spatial and contrast resolution of the MS-CT scanner.

We switched from a bone reconstruction algorithm (for SS-CT scans) to a "standard" algorithm (for MS-CT scans). We did this because the MS-CT scans had poorer signal-to-noise characteristics which produced noisier VB reconstructions when the bone algorithm was used. The change of reconstruction algorithm is an additional variable that could affect the results. For example, the standard algorithm smooths the images, which could make it more difficult to reconstruct smaller airways. Nevertheless, our results show that we could segment and visualize smaller airways with the MS-CT data. There are additional potential side effects of using a smoother reconstruction algorithm. Studies of VB of simulated endobronchial lesions in an airway phantom scanned with SS-CT showed that smaller lesions are less conspicuous with the standard algorithm compared to the bone algorithm<sup>18</sup>. It is possible, therefore, that the same is true for VB using the MS-CT scans. The improved z-axis resolution may offset the reduced conspicuity of the standard reconstruction algorithm. Smoothing by the standard reconstruction algorithm may also be responsible in part for the reduction in spiral artifact which we observed.

The use of overlapping reconstructions could yield further improvement in the quality of virtual bronchoscopy reconstructions<sup>19-21</sup>. Slice overlap of up to 50% has been shown to improve the quality of three-dimensional CT bronchoscopy reconstructions<sup>22</sup>. Increased slice overlap comes at a cost, however, since the number of images increases proportionately. Greater computer memory is required and processing time increases. Frame rates for virtual bronchoscopy "fly-throughs" also decrease as the number of images increases. The technique we used for MS-CT produces 200 to 300 axial images through the airways, depending on patient size.

Although virtual bronchoscopy reconstructions with the MS-CT scanner are improved compared to those from the SS-CT scanner, artifacts are still present and need to be recognized. For example, the nature of the spiral artifact is different with the MS-CT data but the artifact is still present. The artifact appears as a slight rippling in the wall of the airways. Motion artifact from cardiac pulsation can still blur the lingular bronchi. Visualization of bronchi that are oriented within the plane of section will still be somewhat limited (e.g., right middle lobe and lingular bronchi). Respiratory artifact is reduced but not completely eliminated. Since the chest must be scanned in more than one breathhold, there will still be a gap and an offset where the clusters of CT data meet.

## **ACKNOWLEDGMENTS**

We thank Dr. Andrew Dwyer for review of the manuscript.

## REFERENCES

1. D. J. Vining, K. Liu, R. H. Choplin and E. F. Haponik, "Virtual bronchoscopy. Relationships of virtual reality endobronchial simulations to actual bronchoscopic findings," *Chest* **109**, pp. 549-53, 1996.
2. H. U. Kauczor, B. Wolcke, B. Fischer, P. Mildenerger, J. Lorenz and M. Thelen, "Three-dimensional helical CT of the tracheobronchial tree: evaluation of imaging protocols and assessment of suspected stenoses with bronchoscopic correlation," *Am J Roentgenol* **167**, pp. 419-24, 1996.
3. G. R. Ferretti, J. Knoplioch, I. Bricault, C. Brambilla and M. Coulomb, "Central airway stenoses: preliminary results of spiral-CT-generated virtual bronchoscopy simulations in 29 patients," *Eur Radiol* **7**, pp. 854-9, 1997.
4. W. E. Higgins, K. Ramaswamy, R. D. Swift, G. McLennan and E. A. Hoffman, "Virtual bronchoscopy for three-dimensional pulmonary image assessment: state of the art and future needs," *Radiographics* **18**, pp. 761-78, 1998.
5. H. P. McAdams, S. M. Palmer, J. J. Erasmus, E. F. Patz, J. E. Connolly, P. C. Goodman, D. M. DeLong and V. F. Tapson, "Bronchial anastomotic complications in lung transplant recipients: virtual bronchoscopy for noninvasive assessment," *Radiology* **209**, pp. 689-95, 1998.
6. R. M. Summers, D. H. Feng, S. M. Holland, M. C. Sneller and J. H. Shelhamer, "Virtual bronchoscopy: segmentation method for real-time display," *Radiology* **200**, pp. 857-62, 1996.
7. H. P. McAdams, P. C. Goodman and P. Kussin, "Virtual bronchoscopy for directing transbronchial needle aspiration of hilar and mediastinal lymph nodes: a pilot study," *AJR Am J Roentgenol* **170**, pp. 1361-4, 1998.
8. R. M. Summers, W. S. Selbie, J. D. Malley, L. Pusanik, A. J. Dwyer, N. Courcousakis, D. E. Kleiner, M. C. Sneller, C. Langford and J. H. Shelhamer, "Computer-Assisted Detection of Endobronchial Lesions Using Virtual Bronchoscopy: Application of Concepts from Differential Geometry," *Conference on mathematical models in medical and health sciences* pp. , Vanderbilt University, Nashville, TN, 1997.
9. R. M. Summers, W. S. Selbie, J. D. Malley, L. M. Pusanik, A. J. Dwyer, N. Courcousakis, D. J. Shaw, D. E. Kleiner, M. C. Sneller, C. A. Langford, S. M. Holland and J. H. Shelhamer, "Polypoid lesions of airways: early experience with computer-assisted detection by using virtual bronchoscopy and surface curvature," *Radiology* **208**, pp. 331-337, 1998.
10. R. M. Summers, L. M. Pusanik and J. D. Malley, "Automatic detection of endobronchial lesions with virtual bronchoscopy: comparison of two methods," *Medical Imaging 1998: Image Processing* **3338**, pp. 327-335, SPIE, San Diego, California, 1998.
11. H. Hu, "Multi-slice helical CT: Scan and reconstruction," *Medical Physics* **26**, pp. 5-18, 1999.
12. C. H. McCollough and F. E. Zink, "Performance evaluation of a multi-slice CT system," *Medical Physics* **26**, pp. 2223-2230, 1999.
13. M. C. Sneller, "Wegener's granulomatosis [clinical conference] [see comments]," *Jama* **273**, pp. 1288-91, 1995.
14. W. E. Lorensen and H. E. Cline, "Marching Cubes: A High Resolution 3D Surface Reconstruction Algorithm," *ACM Computer Graphics* **21**, pp. 163-169, 1987.
15. J. Wernecke, *The inventor mentor: Programming object oriented 3D graphics with Open Inventor, release 2*, Addison-Wesley, Reading, Mass., 1994.
16. R. M. Summers, "Navigational aids for real-time virtual bronchoscopy," *AJR Am J Roentgenol* **168**, pp. 1165-70, 1997.
17. F. H. Netter and S. Colacino, *Atlas of human anatomy*, CIBA-GEIGY Corp., Summit, N.J., 1989.
18. R. M. Summers, D. J. Shaw and J. H. Shelhamer, "CT virtual bronchoscopy of simulated endobronchial lesions: effect of scanning, reconstruction, and display settings and potential pitfalls," *Am J Roentgenol* **170**, pp. 947-50, 1998.
19. G. Wang and M. W. Vannier, "Stair-step artifacts in three-dimensional helical CT: an experimental study," *Radiology* **191**, pp. 79-83, 1994.
20. C. J. Kasales, K. D. Hopper, D. N. Ariola, T. R. TenHave, J. W. Meilstrup, R. P. Mahraj, D. Van Hook, S. Westacott, R. J. Sefczek and J. D. Barr, "Reconstructed helical CT scans: improvement in z-axis resolution compared with overlapped and nonoverlapped conventional CT scans," *AJR Am J Roentgenol* **164**, pp. 1281-4, 1995.
21. W. Luboldt, R. Weber, M. Seemann, M. Desantis and M. Reiser, "Influence of helical CT parameters on spatial resolution in CT angiography performed with a subsecond scanner," *Investigative Radiology* **34**, pp. 421-426, 1999.
22. K. D. Hopper, T. A. Iyriboz, R. P. Mahraj, S. W. Wise, C. J. Kasales, T. R. TenHave, R. P. Wilson and J. S. Weaver, "CT bronchoscopy: optimization of imaging parameters," *Radiology* **209**, pp. 872-7, 1998.

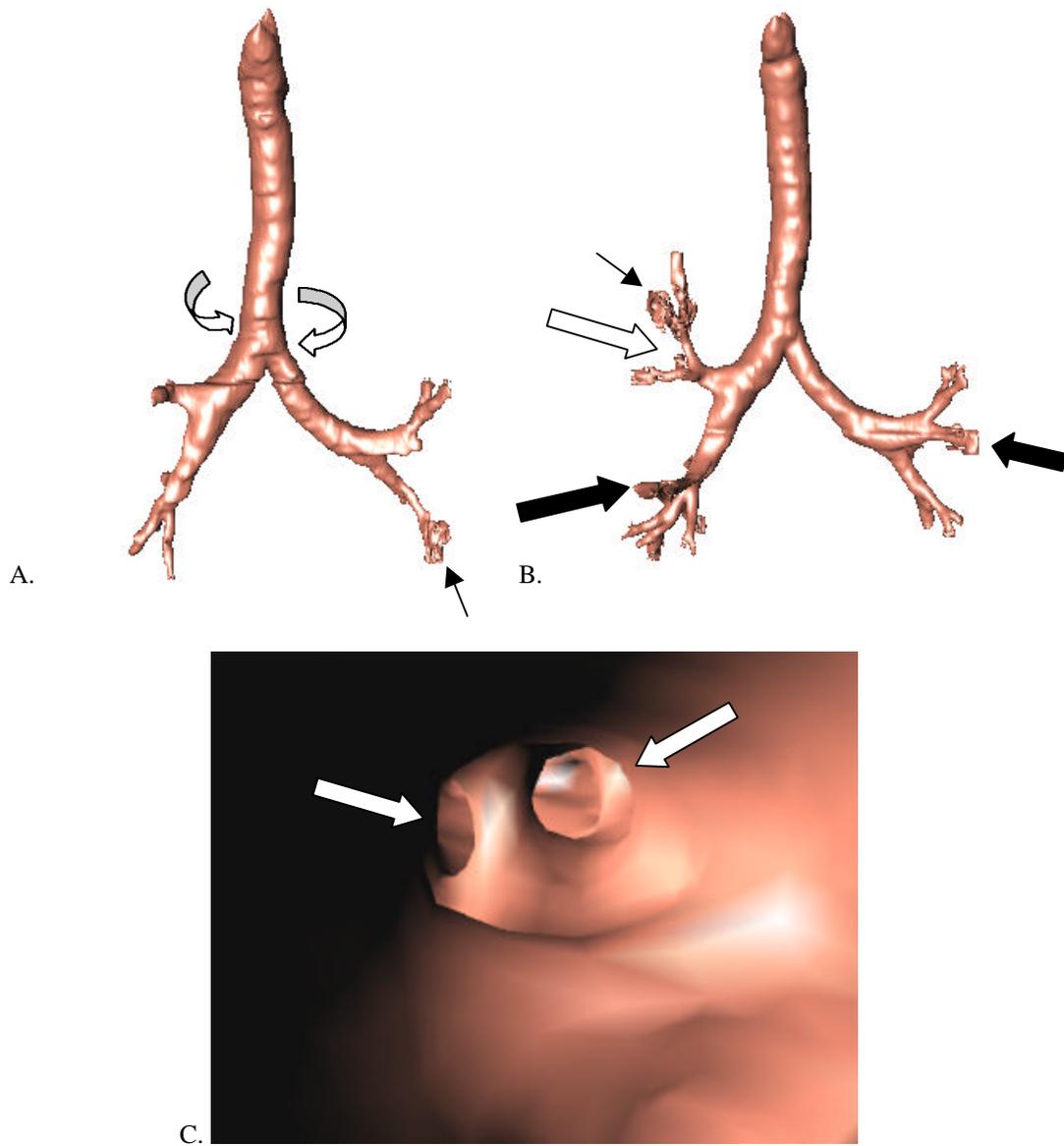


Figure 1. Virtual bronchoscopy surface reconstruction of the same patient scanned with (A) single-slice helical CT scanner and (B, C) nine months later with a multi-slice helical CT scanner. (A, B) External (“exoscopic”) view of the 3-dimensional surface model. Many more small bronchi are visualized in (B) [17 segmental and 11 subsegmental bronchi] than in (A) [9 segmental and 5 subsegmental bronchi]. Spiral artifacts (curved arrows in (A)) are also less prominent in (B). Note that right middle lobe (long black arrow) and lingular (short black arrow) bronchi are seen in (B) but not in (A). Right middle lobe and lingular bronchi are oriented within the plane of section and are difficult to segment unless z-axis spatial resolution is adequate. A small amount of segmentation leakage (an artifact) is visible at the periphery of some bronchi in both (A) and (B) (small, thin black arrows). (C) Perspective virtual bronchoscopy image taken within the posterior segmental bronchus of the right upper lobe (open arrow in (B)). Two subsegmental bronchi are visible (arrows). These subsegmental bronchi could not be seen at virtual bronchoscopy on the single-slice CT scanner.