Virtual Bronchoscopic Navigation

Fumihiro Asano, MD, FCCP

KEYWORDS

- Virtual bronchoscopy
- Lung neoplasms and solitary pulmonary nodule/diagnosis
- Transbronchial biopsy • Three-dimensional imaging
- Endobronchial ultrasonography • User-computer interface

In recent years, solitary peripheral pulmonary lesions are being encountered more frequently because of the widespread use of CT scanning.[1] For the diagnosis of these lesions, bronchoscopy is routinely considered because it is safe and minimally invasive. However, its overall diagnostic yield is inadequate. The guidelines of the American College of Chest Physicians (ACCP) in 2007 showed a diagnostic yield of 57% for all lesions and 34% for lesions less than 2 cm in diameter.[2] The lesion-associated factors affecting the transbronchial diagnosis of solitary peripheral pulmonary lesions includes the lesion size,[3,4] its location,[3] the presence/absence of bronchial involvement,[5] and its malignant/benign status.[4] The bronchoscopist-associated factors include the apparatuses used and the bronchoscopist's skills and experience.[6]

At present, bronchoscopy for peripheral pulmonary lesions is performed using a bronchoscope with an external diameter of approximately 5 to 6 mm under x-ray fluoroscopy. Bronchoscopists mentally reconstruct the three-dimensional (3D) bronchial arrangement based on two-dimensional (2D) planar axial slices of CT, performed before the procedure, and select a bronchial path. A major problem with this method is difficulty in the guidance for the bronchoscope and its accessories. Bronchial path selection during the examination and at the same time maintaining the position of the bronchoscope along with its accessories in desired location under fluoroscopic guidance require time and skills. In addition, because the range of bronchoscope advancement is limited to around the subsegmental branches, biopsy instruments must be guided by fluoroscopy for a long distance from these proximal branches to the peripheral lesion. Therefore, the diagnostic yield depends on the bronchoscopist's experience and skill.[6]

To overcome these challenges, the use of a bronchoscope with a reduced external diameter (ultrathin bronchoscope) could be beneficial. In particular, because the ultrathin bronchoscope [7] can be advanced close to the lesion, guidance of the biopsy instruments is easier. In addition, the ultrathin bronchoscope can be negotiated to the difficult-to-reach areas of the endobronchial tree,[8] thus, it could be useful for the diagnosis of small peripheral pulmonary lesions.[9,10] However, because the number of bronchial branching increases as the bronchoscope advances further into the periphery, the path to the lesion is difficult to identify within the limited examination time even if bronchial branching is directly visible. In addition, endobronchial examination by itself does not provide the direction to the peripheral lesion. Intuitive bronchial path selection based on CT data is inaccurate even at the third- to fourth-generation bronchus levels,[11] and therefore cannot be applied to the levels of bronchi reached and observed by the ultrathin bronchoscope. In recent years, CT fluoroscopy has allowed real-time confirmation of the positions of the bronchoscope, sampling instruments, and the lesion, and has been useful for the diagnosis of small

Department of Pulmonary Medicine and Bronchoscopy, Gifu Prefectural General Medical Center, 4-6-1 Noishiki, Gifu, 500-8717, Japan
E-mail address: asano-fm@ceres.ocn.ne.jp

Clin Chest Med 31 (2010) 75–85
doi:10.1016/j.ccm.2009.08.007

peripheral lesions.[10,12,13] However, because the radiation exposure dose and the procedure time are significantly increased, path selection before the bronchoscopy is important.

Virtual bronchoscopic navigation (VBN) is a method in which bronchial path to the peripheral lesion is produced from virtual bronchoscopy (VB) images and used as a guide to navigate the bronchoscope. Because the bronchial branching pattern on VB images is similar to real bronchoscopic images, the bronchoscope can be advanced close to the target lesion according to the bronchial path to the lesion displayed on VB images. In addition, a system has been developed and applied that allows the automatic production of VB images of the bronchial path and their simultaneous display with real bronchoscopic images for navigation. VBN has been used in combination with CT-guided ultrathin bronchoscope, x-ray fluoroscopic bronchoscopy, and endobronchial ultrasonography with a guide sheath (EBUS-GS), and has been reported to reduce the examination time and increase the diagnostic yield. Its clinical application has also been reported. In this report, the author discusses VBN and the automatic VBN system, reviews the published literature, and describes its usefulness and limitations.

VIRTUAL BRONCHOSCOPY

Helical CT provides 3D serial volume data. VB is a method for a 3D fly-through display of the border between the bronchial lumen and the bronchial wall viewed from the bronchial lumen, as if it were observed using a bronchoscope.[14]

There are various 3D display methods. MPR (Multi Planner Reconstruction) can display any cross-sectional image. In addition to 2D planar axial slices, 3D observation of sagittal and coronal MPR images is useful in gaining an understanding of the lung structure including the airway.[15,16] However, branching structures along the bronchial path to the target are difficult to show in a single cross-sectional image. In addition, although cross-sectional images of the path can be displayed by curved multiplanar reconstruction (CMPR), the direct use of this data for the guidance of the bronchoscope is difficult. CT bronchoscopy is a method for the 3D display of the external appearance of the bronchial tree, but cannot be directly used for bronchoscopy. On the other hand, VB images reflect the actual anatomic findings[17] and provide useful data for the guidance of the bronchoscope, such as the bronchial branching pattern viewed from the bronchial lumen (ie, the size and shape of the entrance to the bronchi at the branching site, the branching angle, and bronchial arrangement after branching).

Compared with real bronchoscopy, VB is noninvasive and has no adverse effects except radiation exposure. VB allows the display of areas peripheral to stenotic areas, and also the display of extramural structures simultaneously with endobronchial images using the volume rendering method.[18] Therefore, VB has been used for the evaluation of airway stenosis,[19,20] tracheal/bronchial injury, endobronchial malignancy,[21] airway lesions in children with attention to exposure dose,[22] foreign bodies in the airway,[23] and postoperative bronchial complications.[24] VB is also used for the education of bronchoscopists,[25,26] transbronchial needle aspiration (TBNA),[27] stent placement,[28] and the planning of interventions,[14,29] such as brachytherapy and laser photoresection.

However, conventional CT and software have demonstrated limitations in the visualization of the bronchi peripheral to the segmental bronchi, showing reduced consistency with actual anatomic findings.[19,30] Therefore, the clinical use of VB is limited to the central bronchi.

In recent years, multidetector CT has allowed physicians to obtain finer isotropic voxel data, reduce respiratory and cardiac motion artifacts, and facilitate more detailed and accurate three-dimensional CT reconstruction. In addition, because of recent advances in computers, real-time display of arbitrary endobronchial images has become possible.[31,32]

VIRTUAL BRONCHOSCOPY NAVIGATION

Virtual bronchoscopy navigation is a VB method clinically applicable to arrive at the peripheral lesions. Virtual images of the bronchial path to the lesion are produced and used for navigation at the time of advancing the bronchoscope.[33] In the case that the author first reported, virtual images up to the tenth-generation bronchus comprising the bronchial pathway to the target were displayed simultaneously with real images, and an ultrathin bronchoscope (external diameter, 2.8 mm) could be advanced along the path to the target. Since this report, various studies on the usefulness of VBN have been published. Note that in articles published using Japanese nomenclature, including this article, all subsegmental bronchi, even those after repeated branchings as in the lower lobe, are regarded as third-generation bronchi and the number of further peripheral branchings is added to calculate the bronchial generation.[34,35] Therefore, when articles in Japan are compared with those in Western countries, attention should be paid to the fact that the generation of the bronchi is seemingly lower in the former group of studies.

VBN can be performed using software attached to the CT system in each institution, but there are certain issues that need to be addressed. First, the level of anatomic detail visualized by VB depends on the obtained volume data. Therefore, performing CT imaging under conditions appropriate for each purpose is important. CT conditions (ie, parameters associated with good volume data) differ among CT systems. However, in general, good volume data are obtained by minimizing collimation and overlapping the image reconstruction by at least 50%.[16,32]

The second issue is that VB findings depend on the threshold value selected to differentiate between the airway wall and lumen. In particular, in the peripheral airway, inappropriate selection of the threshold leads to a lack of bronchial branchings or holes in the bronchial wall imaging, resulting in apparent branchings where there are none.[20,36] Therefore, inappropriate thresholds may cause the bronchoscope to be guided to the wrong bronchi. It is important to select appropriate threshold values while confirming the presence or absence of branchings on axial, sagittal, and coronal images, and this requires experience. Because the production of VB images also depends on experience,[32] it is desirable that bronchoscopists themselves produce VB images or compare them with each cross-sectional image for confirmation.

The third issue is that caution should also be taken regarding the rotation procedure at the time of bronchoscope insertion. Unlike the virtual bronchoscope, the tip of the real bronchoscope can only be moved up or down, so that appropriate rotation is always necessary at the time of insertion. When the bronchoscope is rotated, the real image shifts slightly from the virtual image. The bronchial branching pattern includes many bifurcations into two bronchi of similar sizes. When the bronchoscope is rotated 90° or more, mistakes tend to be made identifying the bronchus into which the bronchoscope should be advanced. Such a bifurcation pattern continues to the peripheral area. Therefore, unless both images are made to be consistent at each branching as the bronchoscope is advanced, the risk of disorientation is high.[37]

VIRTUAL BRONCHOSCOPY NAVIGATION SYSTEM

To overcome the issues mentioned earlier and for the widespread use of the system, a VBN system (Bf-NAVI; KGT, Olympus Medical Systems, Tokyo, Japan) was developed and introduced for clinical use. This system is characterized by the automatic production of VB images along the bronchial path[38] and the display of VB synchronized with real images for bronchoscopic navigation.[39]

Bronchoscopists perform the following functions: (1) Input of digital imaging and communication in medicine (DICOM) data of CT into the system. A slice thickness of CT less than or equal to 1 mm (0.5 mm if possible) is desirable. (2) Setting of the starting point in the trachea. An appropriate threshold is automatically adjusted, and bronchi to peripheral areas are extracted. (3) Setting of the target and the terminal point. While observing short-axis, sagittal, and coronal images, bronchoscopist select the lesion and the bronchus closest to it as the target and terminal point, respectively. Because the extracted bronchi are indicated in blue, the bronchi involved with the lesion are clearly observed all the way up to the proximal area on the monitor confirming that each branching is extracted. When the extraction is inadequate, manual extraction of the bronchi can be added (**Fig. 1**). When the target and terminal point are determined, the path to the terminal point is automatically searched and displayed. (4) Path confirmation. When the point in the path is moved from the starting to the terminal point, each corresponding cross-sectional image is displayed and the branching and extraction status in the path are reconfirmed. The path is also displayed in the bronchial tree (**Fig. 2**). When the path is determined, VB images along the path are automatically produced. (5) Thumbnail registration. While VB images are moved from the starting to terminal point, the bronchus for the insertion of the bronchoscope at each bronchial branching is marked and registered as a thumbnail (**Fig. 3**). The time required from the insertion of DICOM data of CT into the system to the completion of thumbnail registration is approximately 15 minutes, of which 6.5 minutes are used for manual setting and confirmation. The median range of the production of VB images using this system is the sixth-generation bronchi.[40]

VBN is performed while displayed VB images of the target bronchus are synchronized with real images by image rotation, advancement, and retreat. Concretely, the VB image that diverges from the real image because of the rotation at the time of bronchoscope insertion is made consistent with the real image using the rotation function. Subsequently, the VB image is advanced to the next bronchial branching and the bronchoscope is similarly advanced. This procedure is repeated. Because the bronchus to which the bronchoscope is advanced is displayed on the VB image at each branching, the bronchoscope is advanced to the target based on this display

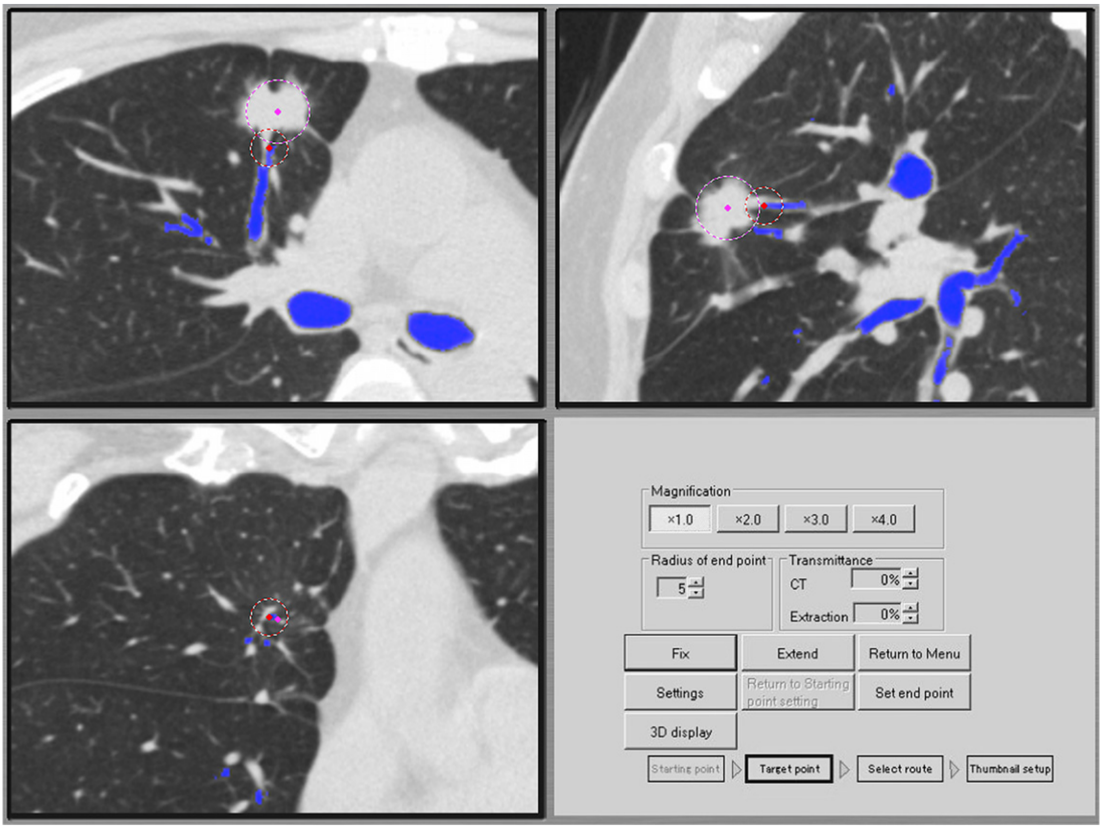

Fig. 1. VBN system setting of the target and terminal point. A small solitary lesion in the peripheral area of the right S3 is shown. The lesion is set as a target (*large circular dotted line*) while observing axial, sagittal, and coronal images. The terminal point (*small circle*) is set at the peripheral end of the extracted involved bronchus indicated in blue.

(**Fig. 4**). When branchings are lost during bronchoscopic advancement, VB images are redisplayed, or a thumbnail at each branching is provided as a reference. The direction of the lesion is displayed on the image and can also be referred to. Because the bronchoscope is advanced according to VB images indicating the target, even inexperienced bronchoscopists can guide the bronchoscope to the target in a short time. The time required for the guidance to the target bronchus is approximately 2 minutes.[39] This system can also be used for educational purposes, such as for illustrating the bronchial branching pattern.

VALIDATION STUDIES FOR THE DIAGNOSIS OF PERIPHERAL LESIONS

In VBN, biopsy instruments reaching the lesion itself cannot be confirmed; therefore, VBN is used in combination with CT, x-ray fluoroscopy, or EBUS. In the published studies on VBN and its system for the diagnosis of peripheral pulmonary lesions, the outline and characteristics of each combination were found to be as follows (**Table 1**).

CT-guided Ultrathin Bronchoscopy

CT-guided bronchoscopy allows the accurate confirmation of biopsy instruments even in the lesions that cannot be observed by fluoroscopy and is useful for the diagnosis of peripheral pulmonary lesions.[10,12,13]

Asano and colleagues[37] performed CT-guided ultrathin bronchoscopy under VBN in 36 peripheral pulmonary lesions. Using VB images produced to the 6.1-generation bronchi (on average), the 6.9-generation bronchi (on average) could be observed using the ultrathin bronchoscope. Because VB images accurately reflected the actual bronchial branching pattern, the ultrathin bronchoscope could be guided along the planned path toward the lesion in 30 (83.3%) of the cases without using x-ray fluoroscopy.

Shinagawa and colleagues[41] used a similar method for 26 peripheral pulmonary lesions less

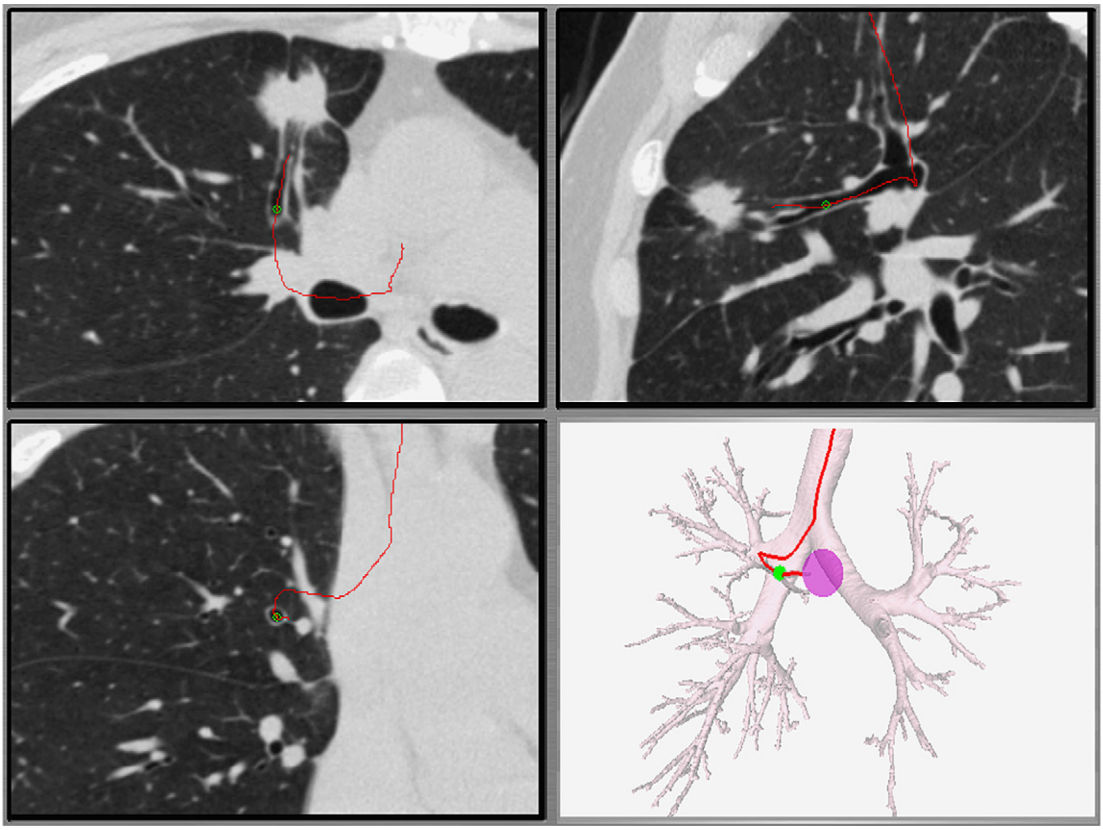

Fig. 2. Path display. After an automatic search for the path, the path (*red line*) to the terminal point is shown on each cross-sectional image. The left lower figure shows the bronchial tree, and the purple circle indicates the target.

than 2 cm in diameter, and could make a diagnosis in 17 (65.4%). The mean time to the first biopsy was 13.0 minutes, and the mean examination time was 29.3 minutes. In their study, more peripheral VB images were produced by a method[42] using the pulmonary arteries running along the bronchi.

Using the VBN system, Asano and colleagues[39] performed CT-guided ultrathin bronchoscopy in 38 peripheral pulmonary lesions less than or equal to 3 cm in diameter, and could guide the bronchoscope to the expected path without using x-ray fluoroscopy in 36 lesions (94.7%). The arrival of biopsy instruments at the lesion could be confirmed by CT in 33 lesions, and diagnosis was possible in 31 (81.6%). The median time required to use the system was 2.6 minutes, and the total examination time was 24.9 minutes. It is of note that the biopsy instrument arrival rate and diagnostic yield were high (96.4 and 89.3%, respectively) in 28 lesions showing bronchial involvement than otherwise.

Shinagawa and colleagues[43] performed CT-guided ultrathin bronchoscopy using the VBN system in 71 lesions less than 2 cm in diameter. The diagnostic yield was high (70.4%) but did not differ from the previous study at their institution. They stated that this was because of a higher percentage of benign cases considered to be associated with a low diagnostic yield. Although the comparison was retrospective, the mean time to the first biopsy was 8.5 minutes and the total examination time was 24.5 minutes, showing significant decreases in time from the previous study.

Shinagawa and colleagues[44] analyzed 85 lesions (<2 cm) by combining the two studies,[41,43] and reported that the location of the lesion (left superior segment of the lower lobe, S6) contributed to the diagnostic yield, and the diagnostic yield was high in lesions for which the ultrathin bronchoscope could be advanced to areas peripheral to the fifth-generation bronchi and those showing an involved bronchus or pulmonary artery.

When these reports are summarized, the diagnostic yield by CT-guided ultrathin bronchoscopy combined with VBN was 65.4% to 86.1% in all lesions and 65.4% to 80.8% in lesions less than 2

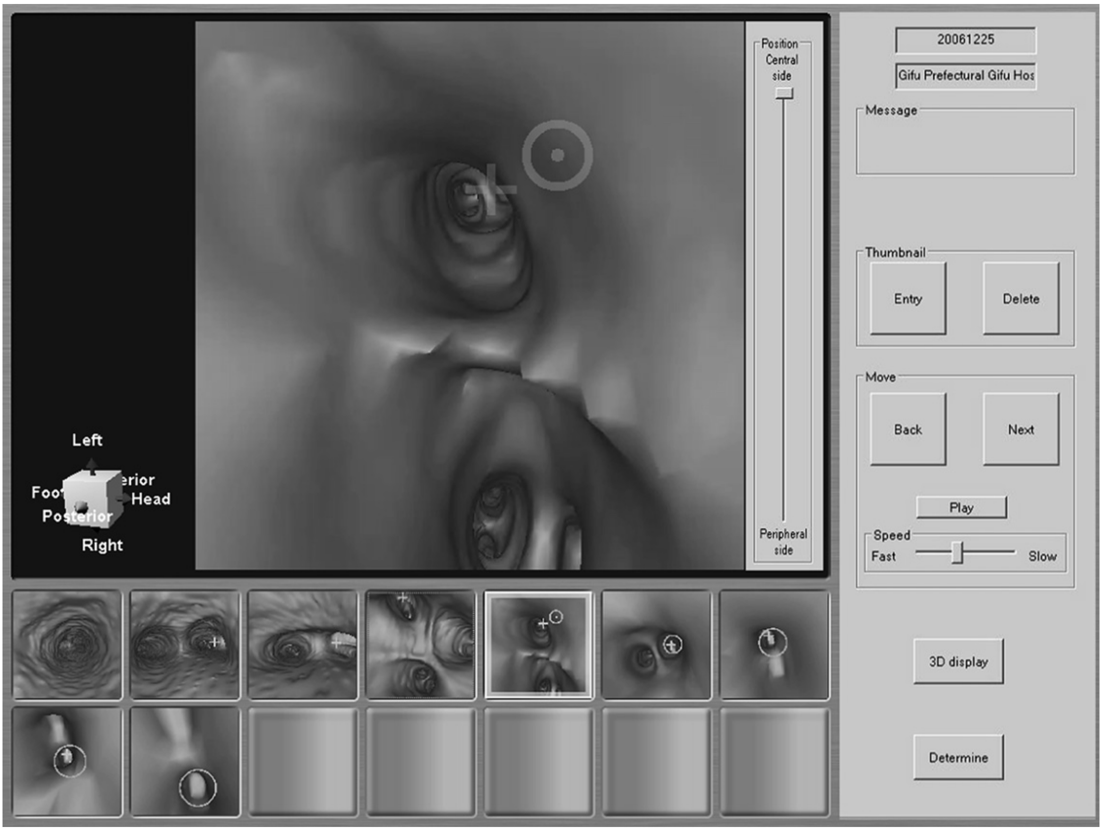

Fig. 3. VB image production, thumbnail registry. VB images of the path are automatically produced. While VB images are peripherally advanced, the bronchus for insertion is marked (*cross*) at each branching and registered as a thumbnail (lower area of the figure). The circle indicates the direction of the target.

cm in diameter. Although the comparison is retrospective, the usefulness of the VBN system has been confirmed. VBN is associated with a high-diagnostic yield and may be useful when diagnosis is impossible by other combinations of methods. On the other hand, the problems of the combination include radiation exposure caused by the CT, the cost of the use of the CT room, and the small size

Fig. 4. Navigational bronchoscopy using the VBN system. Using this system, VB images of the target bronchus are displayed in comparison with real bronchoscopic images. Based on these images, the bronchoscope is advanced to the target.

Table 1
Diagnosis of pulmonary peripheral lesions using VBN

	Authors	Years	References	VBN System	External Diameter of the Bronchoscope (mm)	Confirmation of Arrival	No. of Examined Lesions	No. of Diagnosed Lesions	Diagnostic Yield (%)	No. of Lesions <2 cm	No. of Diagnosed Lesions <2 cm	Diagnostic Yield for Lesions <2 cm (%)
1.	Asano et al	2002	[37]	Not used	2.8	CT and x-ray fluoroscopy	36	31	86.1	26	21	80.8
2.	Shinagawa et al	2004	[41]	Not used	2.8	CT fluoroscopy	26	17	65.4	26	17	65.4
3.	Asahina et al	2005	[49]	Not used	4.0, 5.3	EBUS	30	19	63.3	18	8	44.4
4.	Asano et al	2006	[39]	Used	2.8	CT and x-ray fluoroscopy	38	31	81.6	26	21	80.8
5.	Shinagawa et al	2007	[43]	Used	2.8	CT fluoroscopy	71	50	70.4	71	50	70.4
6.	Tachihara et al	2007	[45]	Used	2.8, 5.2	X-ray fluoroscopy	96	60	62.5	77	42	54.5
7.	Asano et al	2008	[38]	Used	4.0	EBUS	32	27	84.4	15	11	73.3
8.	Asano et al	2008	[40]	Used	4.0	EBUS	99	80	80.8	58	44	75.9
	Summary						428	315	73.6	317	214	67.5

of the sample collected. Therefore, proper case selection is important and the combined use of all cytologic specimens may be important.

X-ray Fluoroscopy

Tachihara and colleagues[45] used the VBN system in 96 peripheral pulmonary lesions less than or equal to 3 cm in diameter and reported diagnostic yields of 62.5% in all lesions and 54.5% in lesions less than or equal to 2 cm in diameter, respectively, and an examination time of 24.1 minutes. The diagnostic yield did not significantly differ among lesions located in the central, intermediate, and peripheral regions.

VBN under x-ray fluoroscopy was reported only in the present study. However, because bronchoscopy under x-ray fluoroscopy is readily and widely performed, further studies on its usefulness are necessary.

Endobronchial Ultrasonography with a Guide Sheath

Regarding bronchoscopy for peripheral pulmonary lesions, EBUS has recently been reported to be useful for evaluating the location of the lesion.[46,47] EBUS-GS is a method in which arrival at the lesion is confirmed using an ultrasound probe with a guide sheath, and the lesion is biopsied through the guide sheath placed at the lesion.[48]

Asahina and colleagues[49] performed EBUS-GS under VBN in 30 peripheral pulmonary lesions less than or equal to 3 cm in diameter. As a result, 24 lesions (80%) were visualized by EBUS and 19 (63.3%) could be diagnosed. The diagnostic yield did not differ among bronchoscopists.

Asano and colleagues[38] performed EBUS-GS using a VBN system and a thin bronchoscope (external diameter, 4.0 mm; forceps channel, 2.0 mm) in 32 peripheral pulmonary lesions. VB images to a median of the fifth-generation bronchi could be produced and the branchings in VB images were in agreement with those in the real images in all cases. The median observation range using a thin bronchoscope was the fifth-generation bronchi. EBUS allowed the visualization of 30 lesions (93.8%), of which 27 could be diagnosed (84.4%). In this study, unlike Asahina's study, no curette-type instrument was used to lead the guide sheath. However, even in lesions less than or equal to 3 cm, 91.4% could be visualized and the diagnostic yield was 79.2%. These results suggest that most lesions can be visualized without the guidance of the EBUS probe if the bronchi leading to the lesion are correctly selected to the fifth-generation bronchi by a thin bronchoscope.

To objectively confirm the usefulness of the VBN system, Asano and colleagues[40] performed a multicentered, joint randomized study: Virtual Navigation in Japan (V-NINJA) bronchoscopic trial. Two hundred subjects who had peripheral pulmonary lesions less than or equal to 3 cm in diameter were randomized into two groups with and without using the VBN system (VBN and non-VBN groups, respectively) and performed biopsy using EBUS-GS. A thin bronchoscope was guided using the VBN in the VBN group and axial CT images in the non-VBN group. In the VBN group, VB images could be produced to the fourth- to twelfth- (median, sixth-) generation bronchi, and the rate of agreement with real images was 98%. The diagnostic yield in the VBN group (80.8%, 80/99) was significantly higher than that in the non-VBN group (67.4%, 64/95) at $P<.05$. The time until the initiation of the biopsy and the examination time (median, 8.1 and 24 minutes, respectively) were significantly shortened in the VBN compared with the non-VBN group $P<.05$.

When these reports are summarized, the diagnostic yield using VBN in combination with EBUS-GS is 63.3% to 84.4% in all lesions and 44.4% to 75.9% in lesions less than 2 cm in diameter. This method requires an EBUS system, but this system is inexpensive and simple. In addition, this combination is applicable to lesions that cannot be visualized by fluoroscopy, is accurate, and allows collection of multiple samples from the lesion. It is possible that the combination of a VBN system, a thin bronchoscope, and EBUS-GS will become the routine examination method for peripheral pulmonary lesions.

APPLICATION TO TREATMENT

VBN is applicable to not only for the diagnostic purposes but it can also be used for therapeutic purposes. Asano and colleagues[50,51] performed CT-guided transbronchial marking to clarify the location of the lesion and the resection range at the time of thoracoscopic surgery. The subjects consisted of 23 individuals who had 31 lesions showing a pure ground-glass opacity pattern less than or equal to 1 cm in diameter. The lesion could not be confirmed in any case under x-ray fluoroscopy. After an ultrathin bronchoscope was guided to a median of the sixth-generation bronchus under VBN, a site near the lesion was marked using a special catheter under CT guidance. The median distance from the barium marker and lesion was 4 mm, and marking within 1 cm was possible in 27 lesions. The required time was 23.5 minutes per subject. Seven subjects had multiple lesions and three of them had bilateral lesions. However, no complication was observed in any subject. Thoracoscopic partial resection was performed after 22 days or less, and the lesion, together with the barium marker, could be resected in all subjects. This method causes no complications, such as pneumothorax and hemorrhage, which are often observed with the percutaneous method. The procedure could be readily performed and can be used for multiple lesions. In addition, the resection range can be three-dimensionally indicated by multiple markings.

ADVANTAGES AND LIMITATION OF VIRTUAL BRONCHOSCOPIC NAVIGATION

When the results of the studies discussed earlier are summarized, the diagnostic yield is 73.6% for peripheral pulmonary lesions and 67.5% for those less than 2 cm in diameter (see **Table 1**). The diagnostic yield is affected not only by the size of the lesion but also by the type of disease, location, and presence/absence of bronchial involvement. Therefore, direct comparison is difficult, but the diagnostic yield was high compared with the current diagnostic yield (34%) according to ACCP Guidelines. One advantage of VBN is the improvement in the diagnostic yield. However, to confirm that this improvement is also observed by VBN used in combination with methods other than EBUS, randomized studies are necessary. VBN facilitates the guidance of the bronchoscope to the peripheral lesions. As a result, a high diagnostic yield may be achieved irrespective of the skill or experience of the bronchoscopist. VBN is a safe method in which the bronchoscope is guided by looking at the real image and the virtual image and no complications of VBN itself have been reported. In addition, because VBN requires no special apparatus except software, the cost is not generally prohibitive.

A limitation is that arrival at the lesion cannot be confirmed by VBN itself, unlike electromagnetic navigation.[52,53] Its combination with fluoroscopy, CT, or EBUS is necessary to confirm localization of the lesion. If a thin or ultrathin bronchoscope is used, its guidance to a site near the lesion is possible. Therefore, in most patients, the guidance of biopsy instruments is not necessary.

FUTURE PROSPECTS OF VIRTUAL BRONCHOSCOPIC NAVIGATION

The VBN system currently used is simple and practical but requires manual adjustment of VB to real images. A method for automatic adjustment has been developed.[54,55] As a clinical application, McLennan and colleagues[56] used a system allowing the real-time display of VB images showing the location of the lesion and path information on real images for TBNA biopsy of the mediastinal lymph nodes, and showed its usefulness. Merritt and colleagues[57] in a phantom study reported the usefulness of this system for peripheral lesions. For peripheral lesions, there are limitations, such as respiration-associated movements and difficulty in acquiring a good visual field. However, if a function for the automatic adjustment of VB to real images is added to the VBN system, the system will become easier to use. Because VBN is a useful method to support bronchoscopy for peripheral lesions, its widespread acceptance is unavoidable.

SUMMARY

Virtual bronchoscopic navigation is a method for the guidance of a bronchoscope to peripheral lesions using VB images of the bronchial path. Irrespective of the bronchoscopist's skill level, the bronchoscope can be readily guided to the target in a short time. In addition, a system to automatically search for the bronchial path to the target has been developed and clinically applied; this system produces VB images of the path to the fourth- to twelfth- (median, sixth-) generation bronchi, and displays the VB images simultaneously with real bronchoscopic images. VBN has been used in combination with CT-guided ultrathin bronchoscopy, x-ray fluoroscopic bronchoscopy, and endobronchial ultrasonography with a guide sheath; the diagnostic yields for lesions less than 2 cm in diameter in these examinations have been reported to be 65.4% to 80.8%, 54.5%, and 44.4% to 75.9%, respectively (total, 67.5%). A randomized study showed VBN improved the diagnostic yield and decreased the total examination time. VBN is used not only for diagnosis but also for treatment, such as marking in thoracoscopic surgery. VBN is a useful method supporting bronchoscopy for peripheral lesions, and its widespread use is likely.

ACKNOWLEDGMENTS

I express deep gratitude to the late Dr Koichi Yamazaki and to Dr Naofumi Shinagawa (First Department of Internal Medicine, Hokkaido University School of Medicine), Dr Takashi Ishida (Department of Pulmonary Medicine, Fukushima Medical University), Dr Hiroshi Moriya (Department of Radiology, Sendai Kousei Hospital), Dr Masaki Anzai (Department of Pulmonary Medicine, University of Fukui, Faculty of Medical Sciences), Dr Yoshihiko Matsuno and Dr Akifumi Tsuzuku (Department of

Pulmonary Medicine, Gifu Prefectural General Medical Center) for their collaboration.

REFERENCES

1. Kaneko M, Eguchi K, Ohmatsu H, et al. Peripheral lung cancer: screening and detection with low-dose spiral CT versus radiography. Radiology 1996; 201(3):798–802.
2. Rivera MP, Mehta AC. Initial diagnosis of lung cancer: ACCP evidence-based clinical practice guidelines (2nd edition). Chest 2007;132(Suppl 3):131S–48S.
3. Chechani V. Bronchoscopic diagnosis of solitary pulmonary nodules and lung masses in the absence of endobronchial abnormality. Chest 1996;109(3): 620–5.
4. Baaklini WA, Reinoso MA, Gorin AB, et al. Diagnostic yield of fiberoptic bronchoscopy in evaluating solitary pulmonary nodules. Chest 2000;117(4):1049–54.
5. Naidich DP, Sussman R, Kutcher WL, et al. Solitary pulmonary nodules. CT-bronchoscopic correlation. Chest 1988;93(3):595–8.
6. Minami H, Ando Y, Nomura F, et al. Interbronchoscopist variability in the diagnosis of lung cancer by flexible bronchoscopy. Chest 1994;105(6):1658–62.
7. Tanaka M, Takizawa H, Satoh M, et al. Assessment of an ultrathin bronchoscope that allows cytodiagnosis of small airways. Chest 1994;106(5):1443–7.
8. Asano F, Kimura T, Shindou J, et al. Usefulness of CT-guided ultrathin bronchoscopy in the diagnosis of peripheral pulmonary lesions that could not be diagnosed by standard transbronchial biopsy. J Jpn Soc Bronchol 2002;24(2):80–5 [in Japanese].
9. Saka H. Ultra-fine bronchoscopy: biopsy for peripheral lesions. Nippon Rinsho 2002;60(Suppl 5): 188–90 [in Japanese].
10. Asano F, Matsuno Y, Komaki C, et al. CT-guided transbronchial diagnosis using ultrathin bronchoscope for small peripheral pulmonary lesions. Nihon Kokyuki Gakkai Zasshi 2002;40(1):11–6 [in Japanese].
11. Dolina MY, Cornish DC, Merritt SA, et al. Interbronchoscopist variability in endobronchial path selection: a simulation study. Chest 2008;133(4):897–905.
12. Wagner U, Walthers EM, Gelmetti W, et al. Computer-tomographically guided fiberbronchoscopic transbronchial biopsy of small pulmonary lesions: a feasibility study. Respiration 1996;63(3):181–6.
13. Kobayashi T, Shimamura K, Hanai K. Computed tomography- guided bronchoscopy with an ultrathin fiberscope. Diagn Ther Endosc 1996;2:229–32.
14. Vining DJ, Liu K, Choplin RH, et al. Virtual bronchoscopy. Relationships of virtual reality endobronchial simulations to actual bronchoscopic findings. Chest 1996;109(2):549–53.
15. Ravenel JG, McAdams HP, Remy-Jardin M, et al. Multidimensional imaging of the thorax: practical applications. J Thorac Imaging 2001;16(4):269–81.
16. Boiselle PM, Reynolds KF, Ernst A. Multiplanar and three-dimensional imaging of the central airways with multidetector CT. AJR Am J Roentgenol 2002; 179(2):301–8.
17. Rodenwaldt J, Kopka L, Roedel R, et al. 3D virtual endoscopy of the upper airway: optimization of the scan parameters in a cadaver phantom and clinical assessment. J Comput Assist Tomogr 1997;21(3):405–11.
18. Amorico MG, Drago A, Vetruccio E, et al. Tracheobronchial stenosis: role of virtual endoscopy in diagnosis and follow-up after therapy. Radiol Med 2006; 111(8):1064–77.
19. Hoppe H, Dinkel HP, Walder B, et al. Grading airway stenosis down to the segmental level using virtual bronchoscopy. Chest 2004;125(2):704–11.
20. De Wever W, Vandecaveye V, Lanciotti S, et al. Multidetector CT-generated virtual bronchoscopy: an illustrated review of the potential clinical indications. Eur Respir J 2004;23(5):776–82.
21. Fleiter T, Merkle EM, Aschoff AJ, et al. Comparison of real-time virtual and fiberoptic bronchoscopy in patients with bronchial carcinoma: opportunities and limitations. AJR Am J Roentgenol 1997;169(6):1591–5.
22. Sorantin E, Geiger B, Lindbichler F, et al. CT-based virtual tracheobronchoscopy in children–comparison with axial CT and multiplanar reconstruction: preliminary results. Pediatr Radiol 2002;32(1):8–15.
23. Adaletli I, Kurugoglu S, Ulus S, et al. Utilization of low-dose multidetector CT and virtual bronchoscopy in children with suspected foreign body aspiration. Pediatr Radiol 2007;37(1):33–40.
24. McAdams HP, Palmer SM, Erasmus JJ, et al. Bronchial anastomotic complications in lung transplant recipients: virtual bronchoscopy for noninvasive assessment. Radiology 1998;209(3):689–95.
25. Colt HG, Crawford SW, Galbraith O 3rd. Virtual reality bronchoscopy simulation: a revolution in procedural training. Chest 2001;120(4):1333–9.
26. Ost D, DeRosiers A, Britt EJ, et al. Assessment of a bronchoscopy simulator. Am J Respir Crit Care Med 2001;164(12):2248–55.
27. McAdams HP, Goodman PC, Kussin P. Virtual bronchoscopy for directing transbronchial needle aspiration of hilar and mediastinal lymph nodes: a pilot study. AJR Am J Roentgenol 1998;170(5):1361–4.
28. Ferretti GR, Thony F, Bosson JL, et al. Benign abnormalities and carcinoid tumors of the central airways: diagnostic impact of CT bronchography. AJR Am J Roentgenol 2000;174(5):1307–13.
29. Liewald F, Lang G, Fleiter T, et al. Comparison of virtual and fiberoptic bronchoscopy. Thorac Cardiovasc Surg 1998;46(6):361–4.
30. Lacasse Y, Martel S, Hebert A, et al. Accuracy of virtual bronchoscopy to detect endobronchial lesions. Ann Thorac Surg 2004;77(5):1774–80.
31. Summers RM, Shaw DJ, Shelhamer JH. CT virtual bronchoscopy of simulated endobronchial lesions:

effect of scanning, reconstruction, and display settings and potential pitfalls. AJR Am J Roentgenol 1998;170(4):947–50.
32. Neumann K, Winterer J, Kimmig M, et al. Real-time interactive virtual endoscopy of the tracheo-bronchial system: influence of CT imaging protocols and observer ability. Eur J Radiol 2000;33(1):50–4.
33. Asano F, Matsuno Y, Matsushita T, et al. Transbronchial diagnosis of a pulmonary peripheral small lesion using an ultrathin bronchoscope with virtual bronchoscopic navigation. J Bronchol 2002;9:108–11.
34. Oho K, Amemiya R. Anatomy of the bronchus. In: Oho K, Amemiya R, editors. Practical fiberoptic bronchoscopy. 2nd edition. Tokyo: IGAKU-SHOIN; 1984. p. 27–33 [in Japanese].
35. Fujisawa T, Tanaka M, Saka H, et al. Report by the Bronchus Nomenclature Working Group. J Jpn Soc Bronchol 2000;22:330–1 [in Japanese].
36. Seemann MD, Seemann O, Luboldt, et al. Hybrid rendering of the chest and virtual bronchoscopy [corrected]. Eur J Med Res 2000;5(10):431–7.
37. Asano F, Matsuno Y, Takeichi N, et al. Virtual bronchoscopy in navigation of an ultrathin bronchoscope. J Jpn Soc Bronchol 2002;24(6):433–8 [in Japanese].
38. Asano F, Matsuno Y, Tsuzuku A, et al. Diagnosis of peripheral pulmonary lesions using a bronchoscope insertion guidance system combined with endobronchial ultrasonography with a guide sheath. Lung Cancer 2008;60(3):366–73.
39. Asano F, Matsuno Y, Shinagawa N, et al. A virtual bronchoscopic navigation system for pulmonary peripheral lesions. Chest 2006;130(2):559–66.
40. Asano F, Yamazaki K, Ishida T, et al. Usefulness of virtual bronchoscopic navigation in transbronchial biopsy for small pulmonary peripheral lesions: a multi-center, randomized trial. In: Programs and abstracts of the 15th World Congress for Bronchology. Tokyo. 2008:32.
41. Shinagawa N, Yamazaki K, Onodera Y, et al. CT-guided transbronchial biopsy using an ultrathin bronchoscope with virtual bronchoscopic navigation. Chest 2004;125(3):1138–43.
42. Onodera Y, Omatsu T, Takeuchi S, et al. Enhanced virtual bronchoscopy using the pulmonary artery: improvement in route mapping for ultraselective transbronchial lung biopsy. AJR Am J Roentgenol 2004;183(4):1103–10.
43. Shinagawa N, Yamazaki K, Onodera Y, et al. Virtual bronchoscopic navigation system shortens the examination time–feasibility study of virtual bronchoscopic navigation system. Lung Cancer 2007;56(2):201–6.
44. Shinagawa N, Yamazaki K, Onodera Y, et al. Factors related to diagnostic sensitivity using an ultrathin bronchoscope under CT guidance. Chest 2007;131(2):549–53.
45. Tachihara M, Ishida T, Kanazawa K, et al. A virtual bronchoscopic navigation system under X-ray fluoroscopy for transbronchial diagnosis of small peripheral pulmonary lesions. Lung Cancer 2007;57(3):322–7.
46. Herth FJ, Ernst A, Becker HD. Endobronchial ultrasound-guided transbronchial lung biopsy in solitary pulmonary nodules and peripheral lesions. Eur Respir J 2002;20(4):972–4.
47. Shirakawa T, Imamura F, Hamamoto J, et al. Usefulness of endobronchial ultrasonography for transbronchial lung biopsies of peripheral lung lesions. Respiration 2004;71(3):260–8.
48. Kurimoto N, Miyazawa T, Okimasa S, et al. Endobronchial ultrasonography using a guide sheath increases the ability to diagnose peripheral pulmonary lesions endoscopically. Chest 2004;126(3):959–65.
49. Asahina H, Yamazaki K, Onodera Y, et al. Transbronchial biopsy using endobronchial ultrasonography with a guide sheath and virtual bronchoscopic navigation. Chest 2005;128(3):1761–5.
50. Asano F, Matsuno Y, Ibuka T, et al. A barium marking method using an ultrathin bronchoscope with virtual bronchoscopic navigation. Respirology 2004;9(3):409–13.
51. Asano F, Shindoh J, Shigemitsu K, et al. Ultrathin bronchoscopic barium marking with virtual bronchoscopic navigation for fluoroscopy-assisted thoracoscopic surgery. Chest 2004;126(5):1687–93.
52. Schwarz Y, Greif J, Becker HD, et al. Real-time electromagnetic navigation bronchoscopy to peripheral lung lesions using overlaid CT images: the first human study. Chest 2006;129(4):988–94.
53. Gildea TR, Mazzone PJ, Karnak D, et al. Electromagnetic navigation diagnostic bronchoscopy: a prospective study. Am J Respir Crit Care Med 2006;174(9):982–9.
54. Mori K, Deguchi D, Sugiyama J, et al. Tracking of a bronchoscope using epipolar geometry analysis and intensity-based image registration of real and virtual endoscopic images. Med Image Anal 2002;6(3):321–36.
55. Higgins WE, Helferty JP, Lu K, et al. 3D CT-video fusion for image-guided bronchoscopy. Comput Med Imaging Graph 2008;32(3):159–73.
56. McLennan G, Ferguson JS, Thomas K, et al. The use of MDCT-based computer-aided pathway finding for mediastinal and perihilar lymph node biopsy: a randomized controlled prospective trial. Respiration 2007;74(4):423–31.
57. Merritt SA, Gibbs JD, Yu KC, et al. Image-guided bronchoscopy for peripheral lung lesions: a phantom study. Chest 2008;134(5):1017–26.