Virtual bronchoscopy versus bronchofiberoscopy — a comparison of diagnostic value in assessment of central lung tumours

Porównanie wartości diagnostycznej bronchoskopii wirtualnej i bronchofiberoskopii w diagnostyce centralnego guza płuc

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Abstract

Introduction: Virtual bronchoscopy (VB) is a new, noninvasive diagnostic technique that allows visualization of the trachea and bronchi. Virtual images are created based on scans from helical multidetector computed tomography (CT) scans using a special protocol. The obtained reconstructed virtual image of the bronchial tree reflects pictures seen under conventional fibre-optic bronchoscopy (FOB). The aim of the study was to compare VB images of the bronchial tree with findings from FOB and to evaluate the diagnostic value of VB in the examination of central lung tumours.

Material and methods: The studied group consisted of 40 patients with suspected central lung tumours, detected first on chest X-ray. Each patient underwent routine CT and FOB, followed by VB. Physicians performing FOB were blinded to VB results and vice versa. The presence of tumour, bronchial stenosis, and widening of the carina were the analysed features. Lung cancer was confirmed by histopathological examination in all patients, including 32 cases of non-small cell lung cancer (80%), 2 cases of small cell lung cancer (5%), 5 cases of squamous cell carcinoma (12.5%), and one case of carcinoid (2.5%).

Results: Virtual bronchoscopy for bronchial tumour detection had a sensitivity of 79.5% and specificity of 95.5%. When bronchial stenosis was assessed, sensitivity was 58.6% and specificity was 98.1%, whereas detection of widening of carina had a sensitivity of 60.7% and specificity of 97.7%.

Conclusion: The results indicate that virtual bronchoscopy is a highly sensitive and specific diagnostic method, of high clinical importance in the evaluation of lung tumours with central location.

Key words: lung tumour, bronchofiberoscopy, computed tomography, virtual bronchoscopy


Introduction

Lung cancer is the second most common malignancy detected in men and the third most common in women. It accounts for 17% of all new detected tumour cases and 23% of malignancy-related deaths. According to published data [1, 2], in 2008 1,095,200 cases of lung cancer were detected in men (47.4 cases/100,000 persons in the general population) and 513,800 cases in women (18.6/100,000). The same year, 951,000 deaths of lung cancer in men (mortality rate of 39.4/100,000) and 417,000 in women (13.6/100,000) were registered [2]. Incidence and mortality rates due to lung cancer in Poland are among the highest in Europe. In 2007, 20,360 new cases of lung cancer were registered in the country (15,742 men, 4,618 women) [3]. The disease is the most common malignancy...
in Polish men, and the third most common (after breast cancer and colorectal cancer) in women.

The above presented epidemiological data points to the importance of lung cancer diagnostics. For detection of lung tumours, various imaging techniques are used, including chest X-ray and computed tomography (CT), followed by fiberoptic bronchoscopy (FOB), fluorescent bronchoscopy, and biopsy. Virtual bronchoscopy (VB) is another diagnostic modality, introduced recently for the evaluation of lung tumours.

Virtual bronchoscopy is a radiological procedure involving the creation of three-dimensional pictures of the bronchial tree based on data obtained through helical computed tomography. Special software is used for 3D image creation, and the generated pictures are similar to those observed during bronchoscopy. Two algorithms are used for image processing: surface shadow display (SSD) or perspective volume rendering (PVR). The picture generation procedure is based on the existence of the natural contrast between air-filled bronchial lumen and surrounding tissues [4, 5], which have different X-ray attenuation in CT.

Virtual bronchoscopy permits visualization of the respiratory tract anatomy and assessment of anatomic variations. The obtained reconstruction pictures can be viewed many times, and the location of pathological lesions (tumours, stenoses) can be assessed. With the aid of VB, the area of bronchial stenosis can be accessed and passed through, with inspection of the potential tumour from behind. Using a partial bronchial wall translucence preset (depending on the software version), extrabronchial lesions such as tumours or enlarged lymph nodes can be evaluated. It also permits visualization of the bronchial tree, its patency, and the evolution of potential changes in patients after chemo/radiotherapy, examination of the anastomosis site after lung transplantation, as well as diagnostics of bronchial fistulae. Moreover, VB is a unique diagnostic modality available for instruction and training in bronchofiberscopy. Its noninvasiveness is the main advantage of this technique, permitting evaluation of patients in poor general condition or having advanced cardiorespiratory failure. The lack of a need for contrast medium administration is another great advantage as potential contrast-related complications can be avoided. There is no necessity of sedation, either.

There are, however, several limitations to the virtual bronchoscopy technique, of which no possibility of tissue sampling or mucosa evaluation are the most serious ones [6]. Virtual bronchoscopy can nevertheless be applied for assessment of both central and peripheral lung tumours [5, 7]. Published data show that sensitivity of VB for lung tumour detection ranges between 83 and 90.9% [5, 8], and for bronchial stenosis detection between 92.8 and 95% [7, 9]. This technique can also be used for diagnostics of Wegener granulomatosis, bronchial stenoses due to non-malignant diseases, in patients after lung transplantation, in William-Campbell syndrome, for assessment of endobronchial endometriosis, tracheal glomus tumours (Latin: glomangioma), tracheal stenosis in advanced kyphosis, or examination of developmental anomalies, with the latter indication being of great value in paediatrics [10–20].

Aim

The aim of the study was to compare pictures obtained through VB with findings from FOB as well as to assess the efficacy of VB in diagnostics of lung tumours in different locations and of bronchial stenoses. Three features that can point to the presence of a tumour in central bronchi were evaluated: the presence of tumours in bronchial lumen, bronchial stenosis, and dilatation of carina. Furthermore, the probability of obtaining the right diagnosis in different parts of the bronchial tree was assessed.

Material and methods

The study group included 40 patients with suspected central lung tumours, who were hospitalized in the 1st Clinic of Lung Diseases, National Research Institute for Tuberculosis and Lung Diseases between late November 2004 and early February 2007. Central tumours were defined as lesions originating from the main, lobar, or segmental bronchus, visible in chest X-ray as widened hilus or mediastinum-related mass [21]. There were 22 men (55%) and 18 women (45%) in the study group, aged between 43 and 83 years (mean age 62.7 ± 8.7 years).

Most patients in the studied group admitted smoking (37 persons, 92.5%), with only 3 non-smokers (7.5%). Diagnosis of lung cancer was made in all patients through histopathological examination of tissue samples obtained during FOB, with diagnostic cytological specimens (spumum and/or bronchial secretion) available in some of them. Histopathological diagnoses included: non-small cell lung cancer not otherwise specified (NOS) in 32 patients (80%), squamous cell carcinoma in 5 patients (12.5%), small cell lung cancer in 2 patients (5%), and carcinoid in one person (2.5%). Radiological pictures showed right-sided lesions in 25 patients (62.5%) and left-sided masses in 15 persons (37.5%).
In all the studied patients diagnostics began with chest X-ray, and findings suggesting a centrally located tumour were inclusion criteria. Further diagnostic procedures included routine computed tomography in all patients, with the obtained data used later for virtual reconstruction of the bronchial tree. Tomography was performed using a multidetector Somatom Sensation 16 device (Siemens AG). All the CT scans were assessed by one experienced radiologist.

The next routine diagnostic step was FOB, performed by one physician. The time span between the two investigations was 1–5 days, which was related to the capacities of the bronchoscopic service.

After completion of both investigations in a single patient, the results were announced to both involved physicians, and the findings from all diagnostic modalities were compared.

When comparing the results of FOB and VB, the following features were evaluated:
— presence or no signs of a pathological mass in bronchus/obstruction of the bronchus lumen,
— presence or no signs of bronchial stenosis,
— presence or no signs of widening of main bronchial, lobar, or segmental carina (table 1).

### Bronchoscopy technique

All bronchoscopic procedures were performed in the Endoscopic Service of the Department of Thoracic Surgery of the National Research Institute for Tuberculosis and Lung Diseases. Written consent was obtained from each patient prior to the procedure. The following Pentax bronchoscopes were used: EB 1830, EB 1830T2, EB 1830T3, and EB 1530T3, with respective external diameters of 6.0 mm, 6.0 mm, 6.0 mm, and 5.1 mm and diameters of working channel of 2.0 mm, 2.6 mm, 2.6 mm, and 2.0 mm. The procedure was performed according to the local standard and current guidelines [22]. Local anaesthesia with 2% lignocaine solution (Braun) and 10% lidocaine solution (Egis Pharmaceuticals Ltd) was applied. Premedication was not administered, based on the authors’ earlier experience. Bronchofiberoscopes were introduced perorally.

The entire bronchial tree was evaluated, including the trachea, both main bronchi, lobar and segmental bronchi, as well as carinae. All the visible endobronchial lesions were assessed. Routine sampling included bronchial secretion for cytological and bacteriological assessment as well as 2–4 tumour samples, taken using biopsy forceps with smooth edged cups (Olympus or Pentax, depending on the type of fiberoscope used). Tissue samples were assessed by a histopathologist on a routine basis. All the procedures were archived on S-VHS tapes.

### Computed tomography technique

Computed tomography was performed 1–4 days prior to FOB, using a multidetector (16-detector-row) Somatom Sensation 120 kV 175 mA device (Siemens AG). Five-millimetre thick layers were used for picture reconstruction and 2 mm layers for VB. Pitch value was 1.125, collimation 1.5. All procedures were archived on CDs. Patients fasted for at least 6 hours before the procedure. 90 ml of non-ionic contrast medium (Ultravist, Schering AG; Visipaque 320, Nycomed Imaging AS; or Optiray 350, Tyco Healthcare) was administered. Each procedure was continuously supervised by a technician, a nurse, and a radiologist. The entire procedure duration was 5–10 minutes, and X-ray exposure lasted several to some ten seconds. Scans were taken with patients in supine position, holding a deep breath; scans were taken from head to toes.

### Virtual bronchoscopy technique

The obtained CT scans were saved in Digital Imaging and Communication in Medicine (DICOM) format and sent for elaboration. Data were analysed using syngo Fly Through software. Threshold for X-ray beam attenuation was −520 HU (Hounsfield units), with modifications from −400 to −550 HU, as recommended by De Wever et al. [23]. For reconstruction, 512 × 512 matrix and SSD algorithm were used; the reconstruction algorithm

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**Table 1. Features evaluated in fibre-optic bronchoscopy and virtual bronchoscopy**

<table>
<thead>
<tr>
<th>Type of lesion</th>
<th>FOB findings</th>
<th>VB findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tumour in bronchial lumen</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Bronchial stenosis</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Widened carina</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
</tbody>
</table>
permits image reconstruction with analysis and interpretation of volume and surface data. Manual navigator was used during VB reconstruction, beginning from the trachea and proceeding through the main to the peripheral bronchi. The entire bronchial tree was evaluated. A single patient VB procedure took 15 to 30 minutes. Each session was archived on a CD. The result of VB reconstruction was announced to the bronchoscopist after FOB was performed, and the obtained results were interpreted.

Virtual bronchoscopy evaluation

Findings from VB and FOB from each patient were compared.

In a normal person, having no developmental anomalies, the bronchial tree consists of the trachea and 28 bronchi (main stem, lobar, and segmental bronchi), with 15 bronchial branches on the right and 13 on the left side. In 40 patients, 1,160 different levels of the bronchial tree altogether were analysed. Pathological bronchial masses were not detected in both modalities in 988 levels. Assessment of a further 172 bronchial levels was not feasible in FOB; therefore, corresponding areas visualized in VB were not included in final evaluation.

Tumour presence in bronchus was assigned in VB if a pathological mass completely occluded its lumen or when no obstruction was noted.

When evaluating bronchial stenosis, assessment of 968 of all 1,160 anatomical levels was feasible in both modalities. The remaining 192 areas were not evaluable in FOB; therefore, corresponding findings from VB were not included in final analysis. Stenosis was assigned if a pathological funnel-shaped or concentric narrowing of the bronchial lumen was visible in VB picture or if compression of the wall (e.g. in trachea) from outside was evident. Pathological mass present inside and causing narrowing of the bronchial lumen but with no complete obstruction was qualified as tumour and not as stenosis, although stenosis most often coincides with restricted bronchial lumen.

Eighteen carinae can be identified in man until the level of segmental bronchi; therefore, in 40 patients 720 carinal levels were evaluated. When assessing carinal widening, 604 carinae were evaluable in both modalities in the group of 40 patients. The remaining 116 carinal areas were not evaluable, or corresponding FOB pictures were not available for comparison.

Statistical analysis

Statistical analysis was performed using STATISTICA 6.0 software for Windows XP. The following tests were used: chi-square with Yates correction for binomial frequencies, as well as chi-square test for multinomial frequencies. As universally accepted, the level of significance was p < 0.05.

Results

Virtual bronchoscopy showed 53 cases of pathological masses/bronchial obstruction; whereas control fibre-optic bronchoscopy revealed 49 tumours. In 39 cases, the same tumour was identified in VB and FOB (full concordance). In 14 cases, VB showed a tumour that was not identified in FOB (false positive result). In 10 cases, no tumour was detected in VB, but FOB showed a pathological mass (false negative result). No lesions were found in a total of 925 analysed areas in VB, further confirmed by fiberoscopic findings. Detailed results are presented in table 2.

Virtual bronchoscopy had a sensitivity of 79.6% and specificity of 98.5% for tumour detection in the presented study, with concordant results between two methods in 97.6% of cases (CI [confidence interval] 96.4–98.4). The same lesions were assessed separately for each bronchus. The greatest discrepancies in assessment of tumour presence in corresponding areas in two modalities were noted in large bronchi, i.e. main left or right bronchus, both upper lobe bronchi, and lower lobe bronchi from the left and right side. The best concordance was observed in the upper right bronchus, where for every 10 VB-detected lesions, 8 were positively verified by FOB (80%). No exophytic lesions in trachea were found in the entire patient group (tables 3, 4).

<p>| Table 2. Tumour detection in fibre-optic bronchoscopy (FOB) and virtual bronchoscopy (VB) |
|-----------------------------------------|----------------|----------------|---------------|</p>
<table>
<thead>
<tr>
<th>FOB</th>
<th>VB</th>
<th>No tumour</th>
<th>Visible tumour</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No tumour</td>
<td>925 (98.5)</td>
<td>10 (20.4)</td>
<td>935</td>
<td></td>
</tr>
<tr>
<td>Visible tumour</td>
<td>14 (1.5)</td>
<td>39 (79.6)</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>939 (100)</td>
<td>49 (100)</td>
<td>988</td>
<td></td>
</tr>
</tbody>
</table>
The probability of tumour visualization in VB was also evaluated in bronchi of different diameters. The bronchi were classified into four groups for the purpose of this analysis, given similar diameters of bronchi at respective levels [24, 25]:

- group 1 — main right bronchus, main left bronchus, intermediate bronchus;
- group 2 — right upper lobe bronchus, left upper lobe bronchus, right lower lobe bronchus, left lower lobe bronchus;
- group 3 — middle lobe bronchus, anterior branch bronchus, lingular bronchus;
- group 4 — all segmental bronchi.

No tumours were detected in trachea in the entire patient group; therefore, this structure was not included in the analysis. Concordant tumour findings for VB and FOB were found for 7/10 cases in group 1, 19/19 cases in group 2, 4/6 cases in group 3, and for 9/14 cases in group 4. Virtual bronchoscopy failed to identify 3/10 real tumours in group 1, 2/6 tumours in group 3, and 5/14 tumours in group 4; no VB-unidentified tumours were noted in group 2 (table 5).

False positive results for VB were noted in a total of 14 cases, including one case in group 1, 3 cases in group 2, and 10 cases in group 4; no false positive results were found in group 3.

Concordance of VB and FOB results for tumour detection in respective groups was also evaluated, including cases with no pathology identified by neither VB nor FOB; data are presented in table 5.

No significant difference was found between frequency of tumours detected by VB and different bronchial levels in chi-square test (p = 0.3448). However, correlation was significant between tumour detectability and bronchial diameter (p = 0.0439).
Efficacy of VB was then assessed for detection of bronchial stenosis. Thirty-five stenoses were identified by VB, of which 17 cases were concordant with FOB and 18 were discordant (false positive result). False negative results were noted in 12 cases (table 6).

Sensitivity of VB for bronchial stenosis detection was 58.6% and specificity was 98.1%. Concordant findings between VB and FOB were found in 96.9% of cases (CI 95.6–97.8). Analogical lesions were assessed separately for each bronchus. The greatest concordance in the assessment of bronchial stenosis in corresponding areas in two modalities was noted in the trachea and main bronchi, i.e. the main left or right bronchus as well as intermediate bronchi. Complete concordance was noted in intermediate bronchus lesions, where all three lesions detected by VB were also identified by FOB (tables 7 and 8).

The probability of bronchial stenosis detection by VB was evaluated by bronchus diameter. In cases of tracheal stenosis, concordant results were found in 2 patients, false positive VB results were noted in 2 patients, and a false negative result in one patient. Bronchial stenosis was concordantly found by VB and FOB in 10/13 cases in group 1, in 2/4 cases in group 2, in 2/2 cases in group 3, and in 1/7 cases in group 4. Virtual bronchoscopy failed to detect three stenoses in group 1 (confirmed by FOB), 2 lesions in group 2, and 6 lesions in group 4; there were no undetected stenoses in group 3. Sixteen cases with VB false positive results were found in the studied population, including 4 cases in group 1, 2 cases in group 2, 2 cases in group 3, and 8 cases in group 4 (table 9).

The greatest concordance for stenosis detection between VB and FOB was found in group 1 (largest bronchi; 76.9%), with the lowest agreement

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**Table 6. Virtual bronchoscopy (VB) and fibre-optic bronchoscopy (FOB) for bronchial stenosis detection**

<table>
<thead>
<tr>
<th>Results</th>
<th>MB</th>
<th>ULB</th>
<th>SB1</th>
<th>SB2</th>
<th>SB3</th>
<th>IB</th>
<th>MiB</th>
<th>SB4</th>
<th>SB5</th>
<th>LLB</th>
<th>SB6</th>
<th>SB7</th>
<th>SB8</th>
<th>SB9</th>
<th>SB10</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No stenosis</td>
<td>921 (98.1)</td>
<td>12 (41.4)</td>
<td>933</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visible stenosis</td>
<td>18 (1.9)</td>
<td>17 (58.6)</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>939 (100)</td>
<td>29 (100)</td>
<td>968</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Table 7. Analysis of concordant results of fibre-optic bronchoscopy (FOB) and virtual bronchoscopy (VB) for stenosis detection in all right-sided bronchi**

<table>
<thead>
<tr>
<th>Results</th>
<th>MB</th>
<th>ULB</th>
<th>SB1</th>
<th>SB2</th>
<th>SB3</th>
<th>IB</th>
<th>MiB</th>
<th>SB4</th>
<th>SB5</th>
<th>LLB</th>
<th>SB6</th>
<th>SB7</th>
<th>SB8</th>
<th>SB9</th>
<th>SB10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concordant VB/FOB</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Discordant VB/FOB</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 8. Analysis of concordant results of fibre-optic bronchoscopy (FOB) and virtual bronchoscopy (VB) for stenosis detection in all left-sided bronchi**

<table>
<thead>
<tr>
<th>Results</th>
<th>MB</th>
<th>ULB</th>
<th>ABB</th>
<th>SB1+2</th>
<th>SB3</th>
<th>LB</th>
<th>SB4</th>
<th>SB5</th>
<th>LLB</th>
<th>SB6</th>
<th>SB7</th>
<th>SB8</th>
<th>SB9</th>
<th>SB10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concordant VB/FOB</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Discordant VB/FOB</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Description:**
- MB = main bronchus; ULB = upper lobe bronchus; SB1 = apical segmental bronchus; SB2 = posterior segmental bronchus; SB3 = anterior segmental bronchus; IB = intermediate bronchus; MiB = middle lobe bronchus; SB4 = lateral segmental bronchus; SB5 = medial segmental bronchus; LLB = lower lobe bronchus; SB6 = apical segmental bronchus; SB7 = medial segmental bronchus; SB8 = anterior basal segmental bronchus; SB9 = lateral basal segmental bronchus; SB10 = posterior basal segmental bronchus.
- MB = main bronchus; ULB = upper lobe bronchus; ABB = ascending branch bronchus; SB1+2 = apicolateral segmental bronchus; SB3 = anterior segmental bronchus; LB = lingular bronchus; SB4 = upper lingular bronchus; SB5 = lower lingular bronchus; LLB = lower lobe bronchus; SB6 = apical segmental bronchus; SB8 = anterior basal segmental bronchus; SB9 = lateral basal segmental bronchus; SB10 = posterior basal segmental bronchus.
in group 4 (smallest bronchi; 14.3%). Tracheal stenosis was not included in this analysis since the tracheal diameter is much bigger than that of the next order size bronchi, i.e. the main bronchi. Correlations between concordant VB and FOB findings in respective groups were also analysed, including cases where neither VB nor FOB detected any pathologies; data are presented in table 9.

No statistically significant difference was found between the number of stenoses detected by VB and the bronchial diameter (p = 0.2018). The difference was, however, significant when comparing stenosis detectability by VB with bronchial calibre (p = 0.0300), with worse detection ratio in smaller bronchi.

Carinal widening was the third analysed feature in the study. Six hundred and four carinal areas were assessed in a total of 40 patients. The remaining 116 carinae were not evaluable, or FOB pictures were not available for comparison with VB. No carinal widening was detected in 563 cases by VB, which was confirmed by FOB. Virtual bronchoscopy detected a total of 30 widened carinae, including 17 cases with concordant findings in both modalities. In 13 cases VB showed a widened carina, which was, however, not confirmed by FOB, whereas in 11 cases VB showed normal pictures but bronchoscopist described widened carina. Data distribution is presented in table 10.

The sensitivity of VB for carinal widening was 60.7% and specificity was 97.7%. Concordant results were found in 96.0% of cases (CI 94.2–97). Topographical analysis showed the most concordant findings in the main carina, big bronchial carinae, and in right-sided carina between the anterior and posterior segmental bronchi. The results agreed most often for upper lobe carina on the right side, with a lower concordance rate for main carina.

### Discussion

In the studied patient group, the presence and topographical location of tumours in respective bronchi were assessed by virtual bronchoscopy, comparing these results with findings described in fibre-optic bronchoscopy. In a total of 40 patients, VB detected 53 tumours and FOB identified 49 tumours. Concordant findings for tumour detection and localization were noted in 39 cases. Sensitivity of VB was therefore 79.6%. Identification of bronchi with no apparent lesions was also concordant between the two modalities. In the studied group, VB specificity was 98.5%, comparable with results reported by other authors.

In 1997 Fleiter et al. published one of the first papers concerning VB, analysing a group of 20 patients with histopathologically confirmed lung cancer. Seven patients had tumours causing >50% or complete obstruction of bronchial lumen, and in four patients tumours compressed bronchi from outside, with complete occlusion of lumen (mediastinal mass of enlarged lymph nodes). The remaining 9 patients had smaller tumours. The detected tumours correlated well with bronchoscopic findings, which led the authors to the conclusion

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### Table 9. Virtual bronchoscopy (VB) and fibre-optic bronchoscopy (FOB) for stenosis detection by bronchus diameter (excluding trachea)

<table>
<thead>
<tr>
<th>Stenosis detected</th>
<th>Group 1. n (%)</th>
<th>Group 2. n (%)</th>
<th>Group 3. n (%)</th>
<th>Group 4. n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VB(+)/FOB(+)</td>
<td>10 (76.9)</td>
<td>2 (50)</td>
<td>2 (100)</td>
<td>1 (14.3)</td>
</tr>
<tr>
<td>VB(-)/FOB(+)</td>
<td>3 (23.1)</td>
<td>2 (50)</td>
<td>0 (0)</td>
<td>6 (85.7)</td>
</tr>
<tr>
<td>VB(+)/FOB(-)</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>VB(-)/FOB(-)</td>
<td>100</td>
<td>141</td>
<td>99</td>
<td>547</td>
</tr>
<tr>
<td>Razem</td>
<td>117</td>
<td>147</td>
<td>103</td>
<td>562</td>
</tr>
</tbody>
</table>

---

### Table 10. Virtual bronchoscopy (VB) and fibre-optic bronchoscopy (FOB) for carina widening detection

<table>
<thead>
<tr>
<th>FOB</th>
<th>Brak poszerzenia</th>
<th>Visible poszerzenie</th>
</tr>
</thead>
<tbody>
<tr>
<td>VB</td>
<td>n (%)</td>
<td>n (%)</td>
</tr>
<tr>
<td></td>
<td>563 (97.7)</td>
<td>11 (40)</td>
</tr>
<tr>
<td></td>
<td>13 (2.3)</td>
<td>17 (60.7)</td>
</tr>
<tr>
<td>Razem</td>
<td>576 (100)</td>
<td>28 (100)</td>
</tr>
</tbody>
</table>
that VB is an effective method of spatial visualization of exophytic lesions [26]. In another report, Rapp-Bernhardt et al. described a group of 21 patients with oesophageal cancer infiltrating the bronchial tree, in whom VB detected bronchial lesions with 93.8% sensitivity and 99.7% specificity [27]. Finkelstein et al. studied 32 patients with diagnosed lung cancer of whom 9 persons had normally appearing bronchial tree in both FOB and VB. Bronchoscopy identified a total of 35 lesions in 23 patients. Virtual reconstruction of the bronchial tree permitted detection of 29 of these lesions, including 19 cases of bronchial obstruction, 9 cases of endobronchial masses, and 1 case of mucosal lesion. General sensitivity of the method was 83% and specificity was 100% [28]. Lacasse et al. noted an even lower sensitivity of VB (76%), thus resonating that this method is not reliable enough for detection of pathological lesions inside the bronchial tree. It should, however, be mentioned that collimation in the cited study was 3 mm, which is twice as much as normally applied for VB reconstruction and which possibly contributed to a higher number of discordant findings between different diagnostic modalities [29]. The first publications on this subject concerned only lesions of the trachea and large diameter bronchi, whereas later publications also dealt with more distal parts of the bronchial tree, i.e. segmental bronchi. The results of the currently presented study are in accordance with those previously published, and the sensitivity of 97.6% is similar to other reports. This is in part due to the fact that many cases with no tumour detected by VB had concordant findings also in FOB. These observations are in accordance with results published by Wojciechowski et al. [30].

In the presented study, the sensitivity of VB turned out to be lower than that shown in some publications in literature. The most commonly occurring cause of false negative results is setting the threshold value of X-ray beam attenuation too low. With too high a threshold, bronchi appear wider than they actually are. Virtual bronchoscopy often fails to visualize dynamic and discrete stenosis of segmental bronchi [31]. In the current study, there were 10 cases with false negative VB results, including 4 cases of small tumours with no bronchial lumen narrowing. All of these lesions were located in distal parts of segmental bronchi and the patients also had other, bigger lesions that were correctly detected. One patient had obstruction of the right-sided segment 1 and 3 bronchus, with widened segmental carina between bronchi 1 and 3. In this case, VB revealed obstruction of the segment 3 bronchus and carina widening. In three other cases, small tumours had the appearance of mucosal swelling. In one case, FOB clearly showed tumorous infiltrate whereas VB disclosed only bronchial stenosis but not the tumour. In another case, the lesion was visible in VB as a bronchial wall deformity, which in FOB turned out to be tumour. False negative results were noted for lesions situated in much smaller bronchi, which are probably related to the technical principles of VB, which is not reliable enough for visualization of lesions in small calibre bronchi. In the presented study there were 14 cases of false positive results, representing 26.4% of all tumours detected by VB. Further analysis of these cases showed that in 8 of them bronchial secretes was visible inside the lumen. In another 5 cases, FOB described significant stenosis (> 90%) due to submucosal infiltration, whereas VB showed bronchial obstruction. In another case, FOB disclosed a “soft” lesion, with the presence of a mass compressing the bronchial lumen from the outside but regressing under fiberoscope pressure, whereas VB showed just bronchial occlusion. Finkelstein et al. also mentioned the presence of thrombi and secretion inside the bronchial lumen as the reason for obtaining false positive VB results [8].

Most studied patients had FOB pictures of obstruction or significant bronchial stenosis, not giving passage to advancing fiberoscope, which impeded assessment of distally located bronchi. Because of that, many bronchial planes (172 bronchi in total) were not evaluable. Virtual bronchoscopy permits instead assessment of bronchi situated behind the tumour or stenosed area. In some cases, distal bronchi could be evaluated, showing close bronchial lumen. Two similar cases were described by Finkelstein et al. [32]. Four cases of false positive results were noted in large bronchi, including main left bronchus, and right or left upper lobe bronchus, with the remaining cases concerning segmental bronchi. False positive VB results can be caused by the threshold attenuation level being set too low or by the presence of secretion in bronchial lumen. Too low threshold setting results in generation of pseudo-columns of pseudo-tumours in the bronchial orifice picture [33]. Bronchial secretions as causes of false positive findings were debated by many authors [34–36]. Another reason may be an erroneous picture interpretation by the describing radiologist, which applies to all radiological diagnostic modalities, even in cases dealt with by experienced specialists.

Tumour detectability in VB was also analysed in bronchi of varying diameters. More tumours in
larger bronchi could be detected in the described material (groups 1 and 2), and significant correlation was found between probability of tumour detection and bronchus diameter ($p = 0.0439$). This finding emphasizes that VB is a good method for the detection of lesions situated in large bronchi, which is inherent with the technical principles of the technique and remains in agreement with other authors’ results [29].

Another feature analysed in the presented study was the presence or no signs of bronchial stenosis. Only the lesions not related to endoluminal bronchial tumour presence in FOB and VB were considered in analysis. Virtual bronchoscopy identified a total of 35 stenoses, of which 17 cases were confirmed by fibre-optic bronchoscopy. Sensitivity of VB for stenosis detection was 58.6% and specificity was 98.1%. Good concordance with FOB results was also observed in cases with no signs of stenosis. The best concordance was noted for lesions in the main right bronchus. There were 18 false positive and 12 false negative cases in the studied group, resulting in worse detectability rates as compared to other authors. It should, however, be emphasized that bronchial lumen narrowing caused by the presence of tumour infiltrate was classified in VB as a tumour. It is therefore possible that if tumour-related stenoses were classified differently, the sensitivity of the method would be higher.

One of the first publications concerning the diagnostic utility of VB included results of examinations performed on a single detector row scanner [37]. The authors examined 20 patients, and identified 3 cases of bronchial stenosis among other pathological lesions found in VB. One year later, Ferretti et al. [7] described 29 patients with suspected stenosis of large bronchi. In total, 39 stenoses (95%) were identified in 27 patients. Two minor stenoses (<25%) were not identified. Bronchoscopy showed 41 cases of stenosis, 30 of them malignancy-related and 11 of non-malignant causes. Most stenoses (31 cases) were caused by the presence of pathological lesions inside bronchial lumen, 3 cases were caused by submucosal infiltrates, and in 7 cases external compression to the bronchial wall could be found. The location of the lesions was concordant with FOB findings in most cases. The correctly identified stenoses were located in the trachea or large bronchi, whereas the two unidentified ones were found in segmental bronchi. The authors of the cited study could not differentiate between stenoses due to intraluminal tumour, submucosal infiltrate, or compression from the outside. This study was also performed using a single detector row scanner.

After multidetector scanners were introduced, Hoppe et al. published their study in 2002 concerning the degree of large bronchial stenosis, as mentioned here already. The authors could correctly describe 98% of stenoses in VB, with good correlation between FOB and VB results and VB sensitivity of 90.9% [5]. Two years later, the same author published another study, this time concerning detection of stenoses in segmental bronchi [34]. In the cited study, bronchoscopy detected 30 stenoses in large bronchi and 10 lesions in segmental bronchi, whereas VB identified 32 cases of main bronchial stenoses and 22 segmental bronchus lesions. Sensitivity of VB was 90%, and 96.6% for large bronchi, with 90% sensitivity and 95.6% specificity for segmental bronchi, respectively. The number of false positive results in segmental bronchi was, however, twice as high as that found in bigger bronchi (13 vs. 5), resulting in a low positive predictive value (40.9%). In the currently presented study, most false positive results (50%) were also found in segmental bronchi.

The reason for false positive results in the assessment of bronchial stenoses may be the presence of bronchial secretion, local variation of bronchial diameter, respiratory or cardiac movements, or the thickness of the layers used for reconstruction. For reconstruction purposes, layers of 1–2 mm thickness are recommended. Thicker layers can lead to irregularities and bronchial wall fluctuations described as stair-stepping artefact [38–40]. Moreover, the right attenuation threshold setting is as important as it is in the assessment of bronchial tumours. Hoppe recommends setting a lower threshold for the assessment of segmental bronchi, ranging between −500 and −800 HU, and higher values for larger bronchi [5]. In the presented study, reconstruction was performed beginning with a threshold of −400 to −550 HU (as recommended for large bronchi), with later modification for assessment of segmental and sub-segmental bronchi for optimal visualization, as recommended by Hoppe. Subjectivity in the assessment of a stenosed area can be the reason for both false positive and false negative results. False positive findings can also be related to insufficient knowledge of thoracic anatomy and erroneous interpretation of physiological narrowings, e.g. aortic arch modelling the lumen of the main bronchus. Many cases of false positive bronchial stenoses were found in the lingular or middle bronchus [41, 42], which can be explained by their anatomy. During CT scanning, these parts of the bronchial tree are situated almost perpendicularly to the transverse scan plane. Other authors suggest that bronchial secretion can be the
reason for false positive results, similarly to analysis of large bronchi [34]. In the presented study, two cases of false positive findings in lingular bronchi were noted but no middle lobe lesions were falsely interpreted. Fibre-optic bronchoscopy showed no stenosis in two cases, and a tumour was present inside the bronchial lumen in one of them. In 6 cases, bronchial secretion was present in FOB, which most likely was the reason for obtaining pictures suggesting stenosis. In two other cases, stenosis was visible in VB but not in FOB, but the reason for this could not be identified.

Twelve cases of false negative results were noted. In one case, FOB showed tracheal compression on the left wall from the outside. This was not detectable in VB, which showed instead a contralateral recessus. In 8 cases, FOB showed submucosal infiltration in various bronchial levels on the right side, with resulting stenosis < 5%; these were not identifiable in VB reconstruction. Similar issues were described by Ferretti et al. [7]. No explanation for false negative results could be found in the remaining cases in the analysed group.

Correlation of the above-described results with topographical location of the lesions was also investigated. Greatest concordance was noted for stenoses in large bronchi, lowest – for narrower bronchial structures. This observation is in agreement with the results published by Hoppe et al. [34]. In the presented study, 10 of the detected bronchial stenoses were located in the main, right-sided, or intermediate bronchus, and two lesions in the trachea. Wojciechowski compared the detectability of stenoses in main, lobar, and segmental bronchi and found similar sensitivity (92.5% vs. 89.9%) when using a multidetector scanner. Such a correlation was not observed in the presented study. The authors arbitrarily classified bronchi into 4 groups, depending on their diameters, using this classification for analysis of both tumour and stenosis detection. No significant differences were found between diagnostic accuracy and bronchus diameter between FOB and VB. Significant correlation was, however, found for VB, where the stenosis detection rate was highest for large bronchi (p = 0.03), which suggests that lesions in large calibre bronchi should be easiest to detect by VB.

Widening of carina was another feature assessed in the presented study. Carina can be distended due to submucosal infiltration, tumour presence, or mechanical pressure by neighbouring enlarged lymph nodes. The anatomy of the bronchial tree is individually variable, which might explain the lack of published data concerning this issue in VB diagnostics in literature. The authors observed widened carinae in some of the cases during the study, and hence decided to analyse this issue further. A total of 604 carinae were evaluated, and a further 116 carinal regions were not evaluable. Carinal dilatation was described in 30 cases in VB, of which 17 cases were concordant with FOB findings. There were 13 false positive and 11 false negative cases, with VB sensitivity of 60.7% and specificity of 97.7%. Concordance ratio between the two diagnostic modalities was 96.0%, and was greatest for upper lobe bronchus and main bronchus carina. In four cases, dilatation of carinae in segmental bronchi was detected. Virtual bronchoscopy could identify only major dilatations. In all false negative VB cases, FOB showed subtle dilatation due to submucosal infiltration. False positive results were found in VB when FOB showed intraluminal secretion in the respective carinal region. No explanation for false positive results could be found in 7 cases.

Virtual bronchoscopy could not explain the reason for carinal dilatation, neither could it visualize mucosal lesions. These issues were described both for older generation single detector row scanners [37] as well as for more modern ones [31]. However, the partial translucency option in VB permits identification of enlarged lymph nodes or pathological extrabronchial masses [43]. Lymphadenopathy can be observed in CT scans; however, VB reconstruction can also indirectly show such phenomena, especially in cases of widened main bronchus or upper lobe bronchus carina. The authors believe that finding a widened carina, especially if an enlarged lymph node is present underneath, can help in the identification of such lesions with partial translucency preset or axial scans taken. This, in turn, could contribute to better and more reliable diagnostics of peribronchial lesions as compared to transbronchial needle aspiration (TBNA).

**Summary**

Based on the obtained results, the authors believe that VB is a good method for visualization and topographic identification of pathological masses in bronchial lumina. The sensitivity of the method was 79.5% for tumour detection. Concordant FOB and VB results were greatest for pathologies of the largest bronchi. Where bronchus diameter was concerned, the sensitivity in group 1 was 70%, 100% in group 2, 66.7% in group 3, and 64.3% in group 4.

Much lower sensitivity (58.6%) was observed for detection of bronchial stenosis, which preclu-
des reliable assessment of this type of lesion, particularly in smaller bronchi. Overall results demonstrate that VB is of value in diagnostics of centrally located lung tumours, especially in patients in whom fibre-optic bronchoscopy cannot be performed for various reasons.

Conflict of interests

The authors have no conflicts of interests to declare.

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