Three Dimensional Computed Tomography Lung Modeling is Useful in Simulation and Navigation of Lung Cancer Surgery

Norihiko Ikeda, MD, PhD,1 Akinobu Yoshimura, MD, PhD,2 Masaru Hagiwara, MD,1 Soichi Akata, MD, PhD,3 and Hisashi Saji, MD, PhD1

The number of minimally invasive operations, such as video-assisted thoracoscopic surgery (VATS) lobectomy or segmentectomy, has enormously increased in recent years. These operations require extreme knowledge of the anatomy of pulmonary vessels and bronchi in each patient, and surgeons must carefully dissect the branches of pulmonary vessels during operation. Thus, foreknowledge of the anatomy of each patient would greatly contribute to the safety and accuracy of the operation.

The development of multi-detector computed tomography (MDCT) has promoted three dimensional (3D) images of lung structures. It is possible to see the vascular and bronchial structures from the view of the operator; therefore, it is employed for preoperative simulation as well as navigation during operation. Due to advances in software, even small vessels can be accurately imaged, which is useful in performing segmentectomy. Surgical simulation and navigation systems based on high quality 3D lung modeling, including vascular and bronchial structures, can be used routinely to enhance the safety operation, education of junior staff, as well as providing a greater sense of security to the operators.

Keywords: lung cancer surgery, 3D CT, navigation, simulation

Introduction

Since computed tomography (CT) is commonly used in routine practice, we can detect early stage lung cancers more easily. Minimally invasive surgery is now widely performed, mainly for early stage lung cancers. In Japan, more than half of lung cancer operations are performed using the VATS technique.1) Minimally invasive operations, such as VATS lobectomy or segmentectomy, require precise knowledge of the anatomy of pulmonary vessels and bronchi in each patient, and surgeons should carefully dissect the branches of pulmonary vessels during surgery.

Anatomic variations of pulmonary vessels make lung resection more difficult, especially when the separation of the interlobular fissure is incomplete.

Segmentectomy is a more complicated operative procedure than standard lobectomy because of its anatomical complexity, including vascular and bronchial structures and its variability in segmental levels.

Thus, preoperative knowledge of the surgical anatomy of each patient would contribute greatly to the safety of operations.
The development of multi-detector computed tomography (MDCT) has enabled three dimensional (3D) images of lung structures. Currently, 3D displays of anatomic structures have become feasible for the decisions on surgical methods and preoperative planning. Especially, in the field of hepatic surgery, preoperative simulation has been widely employed using high resolution 3D fusion images. Several software programs currently used were developed to analyze detailed 3D vasculature and bile duct structure as well as to predict liver resection volume.\(^2\)\(^-\)\(^5\)

In this manuscript, we review recent advances and clinical applications of 3D images of pulmonary vessels and the tracheobronchial tree.

### Usefulness of 3D CT for Lung Cancer Surgery

Watanabe reported the usefulness of 3D angiography using MDCT for preoperative identification of the branching pattern of the pulmonary artery. Most pulmonary arteries were imaged and identified successfully, but some of the branches less than 1.5 mm in diameter were not correctly imaged. Among 86 branches of pulmonary artery imaged by preoperative 3D CT, 84 were identified during operation (Concordance rate: 97.7%).\(^6\)

Fukuhara performed preoperative 3D CT for stage I lung cancers which were scheduled for VATS lobectomy. A total of 49 patients were studied, and 139 pulmonary arteries were imaged by preoperative 3D CT. All 49 cases were successfully operated by VATS, and 149 pulmonary artery branches were identified during the operation, which showed a preoperative identification rate of 95.2% for pulmonary artery branching by 3D CT.\(^7\)

Oizumi used the “OsiriX” software for the reconstruction of 3D images and applied the technique supporting of VATS segmentectomy for 52 patients. The operative procedure was successful in all cases, and 3D image was useful in identifying the intersegmental vein, which was the key structure to identify the intersegmental plane (resection line).\(^8\)

Akiba analyzed preoperative 3D CT in 27 consecutive patients who underwent surgery for lung cancer. Among 62 pulmonary artery branches imaged by 3D CT, 60 were correctly identified during the operation. The missing 2 branches were considered to be compressed due to swollen metastatic lymph nodes.\(^9\)

Representative reports of preoperative 3D CT of lung cancer are shown in Table 1.

### Software Technology

There are several software programs for 3D angiographic imaging. Most software programs employ volume rendering methods, which consist of a set of techniques used to display a 2D projection of 3D volume visualization.

Matsumoto compared the performance of three software programs, AW, OsiriX and CTTRY. OsiriX and CTTRY are free software programs.\(^10\) AW and OsiriX are based on a volume-rendering technique and require contrast enhancement during CT examination, while CTTRY is based on a surface-rendering technique and does not require enhancement. AW and CTTRY require one hour for obtaining 3D images, while OsiriX needs only 10–20 minutes. Most pulmonary vessels are reported to be correctly imaged by all programs. It was also concluded that AW produced images most similar to the actual object, but branches unnecessary for surgery were also depicted.

The quality of images and the time required for image acquisition are most important for surgeons.

We have extensively used a newly-developed high speed 3D image analysis system (Synapse Vincent, Fuji Film Co., Ltd., Tokyo, Japan) to convert digital imaging and communication in medicine (DICOM) data of contrast-enhanced CT images of the chest to 3D images. This system extracts pulmonary vessels and the tracheobronchial tree, and then displays 3D images automatically with single click within a few minutes.

### Table 1  Representative reports of preoperative 3D CT simulation of lung cancer surgery

<table>
<thead>
<tr>
<th>Author</th>
<th>No. of cases</th>
<th>Detection rate of pulmonary artery</th>
<th>Type of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akiba 2009</td>
<td>27</td>
<td>95% (59/62)</td>
<td>VATS lobectomy</td>
</tr>
<tr>
<td>Oizumi 2011</td>
<td>52</td>
<td>—</td>
<td>VATS lobectomy</td>
</tr>
<tr>
<td>Fukuhara 2008</td>
<td>49</td>
<td>95.2% (139/146)</td>
<td>VATS lobectomy</td>
</tr>
<tr>
<td>Watanabe 2003</td>
<td>14</td>
<td>97.7% (84/86)</td>
<td>lung cancer surgery</td>
</tr>
<tr>
<td>Shimizu 2012</td>
<td>42</td>
<td>—</td>
<td>VATS segmentectomy</td>
</tr>
<tr>
<td>Eguchi 2012</td>
<td>14</td>
<td>—</td>
<td>Segmentectomy</td>
</tr>
</tbody>
</table>
Most commonly used software programs used to require a much longer time (1–2 hours) and image guidance by professionals to obtain 3D images, but due to advances in software, the procedure is mostly automatic and takes only a few minutes using the new generation, Synapse Vincent software.

Using 3D volume rendering, a solid image was constructed from 1.25 mm slices of contrast-enhanced CT images. DICOM data were transferred to a workstation with volume-rendering reconstruction by the Synapse Vincent programs (Fig. 1). Virtual image analysis for anatomical recognition and simulation surgery (lung resection analysis function package) was developed in collaboration between the Department of Surgery of Tokyo Medical University and Fuji Film Company. After 3D reconstruction of the tumor, pulmonary artery and vein, bronchial tree, and lung parenchyma, we can automatically calculate the distance between the tumor and surgical margin. This function is useful in planning segmentectomy and ensuring an accurate safety margin. The 3D CT-guided segmentectomy is initiated by detaching the pulmonary arteries and veins from the pulmonary parenchyma along the shortest route to the intended segmental bronchi according to the preoperative virtual segmentectomy and intraoperative visualization guidance of an appropriate intersegmental plane surface.

**Clinical Experience with 3D CT**

**Figure 2** shows the representative preoperative simulation of left upper lobectomy (VATS lobectomy) due to lung cancer using the Synapse Vincent system.

Port placement is confirmed preoperatively by identifying pulmonary vessels and the tracheobronchial tree in the hilum as well as the interlobar fissure (Fig. 2a). **Figure 2b** shows the left upper pulmonary vein and **Figure 2c** shows the status after the stapling of the upper pulmonary vein. Type lateral middle segment artery (A4) and medial middle segment artery (A5) arising from the mediastinum deserves special attention. It should also be noted that the branch of medial middle segment artery arises from anterobasal segment artery (A8) (Fig. 2d).

**Discussion**

We set out to describe the latest imaging technology in the field of surgery for lung cancer. Advances in technology have helped to develop the most recent generation of surgery, including robotic surgery in the field of thoracic surgery. Image-guided navigation surgery using MDCT is another step forward in the field of surgery for employing simulation and navigation of operations. “Super hands” and “super eyes” are key issues for further progress in surgery.

3D CT imaging has various advantages. First, 3D CT angiography is a minimally invasive vascular imaging method that is less expensive than conventional diagnostic angiography. Also, images can be rotated freely and visualized interactively from any angle. It is important to see the vascular structures from the view point of the operator; therefore, it is employed as preoperative simulation as well as navigation during operation.

It also helps to educate students or junior doctors about surgical anatomy.
The usefulness of 3D CT angiography using MDCT for preoperative simulation has been documented. Understanding of the variation of individual anatomy of pulmonary vessels and bronchi is important for safety, especially in performing lung cancer operations. However, this technique has not spread rapidly because 3D image reconstruction required more than one hour and the assistance of diagnostic radiology specialists. Easy and quick processing, as well as accurate depiction of pulmonary vessels, are important elements for routine clinical use of this technique.

Mochizuki used the Synapse Vincent software to calculate graft volumetry in performing pediatric living donor liver transplantation, and it was capable of displaying 3D images simply, automatically, quickly (5–10 minutes), and accurately. The volumetric measurement was shown to be accurate because there were no differences between preoperative expected and actual graft weight in three cases studied. Other functions of this software are useful in performing lung segmentectomy due to lung cancer. Preoperative identification of the intersegmental pulmonary veins and its pulmonary arteries and bronchi involving resected segment using 3D CT angiography and bronchography have been demonstrated to be useful to enable surgeons to perform an accurate anatomical segmentectomy. Identifying the intersegmental plane as well as calculating the distance between the tumor and the intersegmental plane is extremely useful to help surgeons in performing segmentectomy.
Surgical simulation and navigation systems based on high quality 3D lung modeling, including vascular and bronchial structures, can be used routinely for safe operations, education of junior staff, as well as the convenience of the operators.

Acknowledgement

Supported by grant from the ministry of Education, Culture, Sports, Science and Technology (5050).

We are indebted to Associate Professor Edward F. Barroga and Professor J. Patrick Barron, Chairman of the Department of International Medical Communications of Tokyo Medical University, for their editorial review of the English manuscript.

Disclosure Statement

The authors received fixed compensation for the described intellectual property without financial interest in its production, distribution, or marketing. The authors received no outside research funding and had full control of the study design, methods used, outcome parameters, data analysis and production of the written report.

References