A novel intra-operative navigation system for resection of small lung nodules by video-assisted thoracoscopic surgery (VATS) using three-dimensional image construction in real time and on site with a tablet computer

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Abstract: Precise imaging modalities are necessary during pulmonary resection to assess nodules that are otherwise difficult to diagnose. Studies have demonstrated that partial lung resection can completely cure adenocarcinoma *in situ* and minimally invasive adenocarcinoma. The important considerations for partial lung resection are: (I) to accurately identify the location of a small tumor intraoperatively and (II) to ensure a sufficient resection margin and preserve the remaining lung function. Hence, precise detection of hardly palpable or invisible tumors is essential. Although some reports describe methods for marking tumor locations, these processes are both invasive and complicated. Here, we describe a novel intraoperative navigation system that easily feeds image information to the operator on-site and evaluated its feasibility in three cases of partial lung resection. Implementing the software developed by Amin Inc. allowed three-dimensional scaling, rotation, transparency display, and calculation of tumor volumes in real time using a tablet computer (TC) interfaced with a hand tracking and voice control device. The surgeon, assistant, and digital imaging assistant can preoperatively verify the image using a TC by simulating the virtual resection line and insertion angle of the endoscopic stapler. During surgery, the tumor was assessed with a thoracoscope in comparison with the constructed three-dimensional image. Partial resection was successfully performed and pathological excision margins were negative in all cases. Other than prolonged air leakage in one case, no other complications were encountered. This novel navigation system appears to be safe and effective for less invasive partial lung resection.

Keywords: Intraoperative navigation system; small lung nodules; partial lung resection

Introduction

Improved accuracy of imaging modalities, such as computed tomography (CT), is needed for resection of small lung nodules that are otherwise difficult to detect. In such cases, qualitative diagnosis is difficult because of the small size of the tumor; thus, a pathological diagnosis is usually made intraoperatively. If performed appropriately, partial lung resection leads to complete cure of adenocarcinoma *in situ* and minimally invasive adenocarcinoma. Therefore, in order to ensure an adequate resection margin, it is necessary to accurately identify the tumor site, which is difficult to do during partial lung resection. In addition, identification of the tumor site leads to maximum preservation of the vessels and bronchi in the remaining lung to avoid reduced respiratory function.

While thoracoscopic surgery is advantageous in terms of being less invasive and achieving better cosmesis, several

problems, such as the difference between the surgical view and monitor image because of the narrow two-dimension (2D) view of a monitor versus an ordinary 2D-CT image, must be addressed.

Recently, several studies have reported the usefulness of identifying the tumor site using such as virtual-assisted lung mapping (VAL-MAP); however, most methods are often invasive and complicated (1-5). Therefore, a simple intraoperative navigation system that can be accessed in the operating room (OR) is required to reduce the invasiveness of the surgery while maintaining curability.

Here, we describe a novel intraoperative navigation system using a software (Amin Inc., Tokyo, Japan) that can easily obtain an image desired by the surgeon and can be controlled using a tablet computer (TC) (6). We evaluated the utility of the proposed intraoperative navigation system with that of conventional visual inspection and palpation.

Patient selection and workup

In total, 53 patients with suspected malignant tumors underwent partial lung resection via video-assisted thoracoscopic surgery (VATS) between July 2017 and April 2018 at the Department of Surgery, Division of Thoracic Surgery, Jikei University School of Medicine, Tokyo, Japan. Of these 53 patients, three were selected for this study because their tumor position was in the vicinity of the visceral pleura. In addition, 1-mm slice enhanced CT examinations of all three cases were performed for comparison with the virtual images created using the proposed three-dimensional (3D) image system. For all three cases, the American Society of Anesthesiologists physical status was class 1 or 2, which was judged as sufficient for the patients to endure the procedure in accordance with preoperative criteria of our hospital. Ground glass opacity was observed in two cases, whereas a thin-wall cavitary lesion was observed in the third.

Intraoperative imaging of the tumor via thoracoscopy was confirmed by visual inspection and palpation. The monitor angle and direction were traced using the TC, and an appropriate 3D image was created on site by the digital imaging assistant. The image was fed back in real time to the surgeon who was able to easily compare between the monitor and the 3D views. The resected specimen was diagnosed by pathological examination. No tumor cells were observed at the excised end. One case was complicated with prolonged air leakage.

Preoperative preparation

The tumor volume and mass and the lung surface and vessels were created using axial data [Digital Imaging and Communications in Medicine (DICOM)] obtained via 1-mm slice enhanced CT using a workstation dedicated for the creation of 3D images (Ziostation 2; Ziosoft, Inc., Belmont, CA, USA).

Further, we made two highlighted concentric spheres of 150 and 200 mm from the outer edge of the tumor, respectively. The highlighted concentric spheres between 150 and 200 mm were considered as virtual resection lines (*Figure 1*).

Because of the high volume, it is difficult to handle data using a general-purpose computer in the OR. The 3D viewing software developed by Amine Inc. recognizes only the shape displayed and does not include the CT value. In addition, the amount of data is compressed from gigabytes to megabytes, which makes data easily controllable and sufficient enough to enlarge, reduce, and/or rotate the 3D image, and delete the volume or render it transparent even on a general-purpose TC. Surgical simulation was performed before surgery, and the image was confirmed by the surgeon, assistant, and digital imaging assistant using the TC. The role of the digital imaging assistant was to operate the TC in the OR.

Equipment preference card and procedure

All surgeries were performed under general anesthesia and differential pulmonary ventilation with the patient in the lateral position. An epidural catheter was inserted for postoperative pain relief. Partial lung resection was performed using a 3-port VATS with a 10-mm 30-degree thoracoscope and a "Forest River" (Midorija Sugiura, Nakano, Tokyo, Japan) instrument invented by Dr. Morikawa.

The digital imaging assistant instantaneously visualized the 3D image as desired by the operator while orally interacting with the surgeon in real time via a Leap Motion® hand gesture tracking system (Leap Motion, Inc., San Francisco, CA, USA) and a telephone headset to enlarge, reduce, rotate, make transparent, or delete the image. The surgeon comprehensively took in to consideration both the image obtained from this system and the thoracoscopic image and subsequently identified the tumor and simulated the resection line (*Figure 2*). Following partial lung resection using an endoscopic stapler, the specimen was
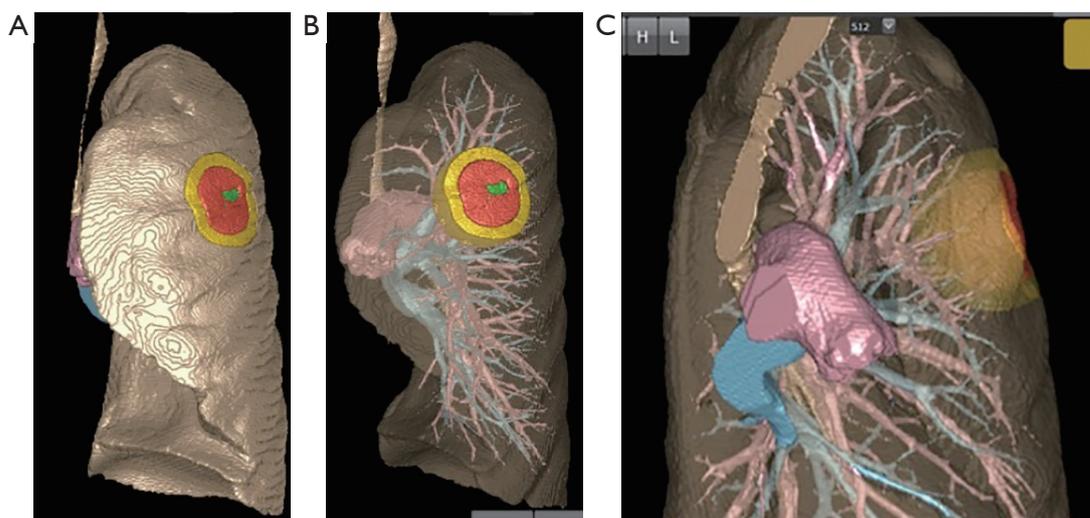
Figure 1 Surface rendering model displayed on a tablet computer (TC). The highlighted areas are 150 mm (red area) and 200 mm (yellow area) from the outer edge of the tumor with the highlighted concentric spheres as virtual resection lines (A). Volume rendering model on TC with a transparent lung volume. On-site observation of the 3D image is possible from any direction and the highlighted area can be traced without further changing the settings (B,C).

Figure 2 Monitor image obtained via a thoracoscope compared with the tablet computer (TC) image in the same view in the operating room (7). An appropriate 3D image is produced by the digital imaging assistant on site. Surface rendering image (A) and volume rendering image (B) as displayed on the TC.
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retrieved in a bag and a 20-Fr chest tube was inserted and the wound was closed.

Role of the team members

A surgeon, two surgical assistants, a scrub nurse, a circulating nurse, and an anesthesiologist participated in each surgery. Apart from the usual surgical preparations,

a digital imaging assistant operated the TC in the OR. The digital imaging assistant wore a telephone headset and operated the Leap Motion® hand gesture tracking system. The telephone headset follows the digital imaging assistant's voice commands to enlarge, reduce, rotate, make transparent, delete, or display an image. The Leap Motion® system digitally senses the imaging assistant's hand motion from the telephone headset (*Figure 3*).

Postoperative management

The postoperative management regimen was the same as that for standard thoracoscopic partial lung resection. Our protocol for removing the chest tube ensures that there is no air leakage from the chest tube and no problem with X-ray image diagnosis. All patients were discharged three to four days after the surgery.

Tips, tricks, and pitfalls

The proposed navigation system is based on the 1-mm slice enhanced chest CT and requires no other examination. Therefore, preoperative inspection is less invasive than the other marking methods. Moreover, matching images using the TC is both easy and quick, which is a remarkable point of this novel intraoperative navigation system. This system allows the surgeon to easily compare the monitor and 3D

Figure 3 The digital imaging assistant is wearing the telephone headset, which is operated using the Leap Motion® system (8). The telephone headset follows the voice of the digital imaging assistant to enlarge, reduce, rotate, make transparent, delete, and/or display the image. The Leap Motion® system senses the hand motions of the digital imaging assistant's hand to enlarge, reduce, rotate, make transparent, delete, and/or display the image from a telephone headset.
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views to smoothly conduct surgical procedures.

Conclusions

The proposed navigation system allows for a less invasive procedure because it requires only preoperative CT before surgery and also because of the use of a TC in the OR.

Acknowledgements

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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