Three-dimensional imaging navigation during a lung segmentectomy using an iPad

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Abstract

OBJECTIVES: The requirement for anatomical lung segmentectomies has increased in recent years but this surgical procedure is relatively difficult. We herein present the benefits of using three-dimensional (3D) imaging navigation during a lung segmentectomy via the intra-operative use of an iPad.

METHODS: Fourteen patients who had undergone an anatomic segmentectomy for a primary lung cancer or a metastatic lung tumour between 1 October 2010 and 30 April 2011 were included in this study. Contrast-enhanced scanning was performed twice on each patient, and 3D images were constructed using a workstation. These images were then transferred to an iPad and analysed during the operation using DICOM image viewer software.

RESULTS: The study group included 3 men (21%) and 11 women (79%) ranging in age from 57 to 83 (mean 69 ± 7.8 years). The operative procedure involved a resection in one case each of the right S1, the right S2, the right S2 + S6a, the right S3, the right S6, the left S8 and the left S8 + 9. The left S1 + 2 and the left basal segment were resected in two cases. The left upper division was resected in three cases. All segmentectomies were successful and no major post-operative complications developed in any patient during or after their procedures. No positive margins were detected pathologically.

CONCLUSIONS: A 3D computed tomography navigation using an iPad enhances the ability to perform a safe and secure segmentectomy.

Keywords: Lung segmentectomy • Three-dimensional imaging • iPad

INTRODUCTION

Lung screening using computed tomography (CT) has recently become widespread, and many small lung lesions have been detected using this method. In particular, non-solid lung tumours with a ground-grass opacity and a good prognosis have been increasing in incidence, and limited resection has achieved a measure of legitimacy as a treatment approach [1–3]. The risk of developing a second primary lung cancer after treatment for an initial lung cancer is high [4], and patients with a better preserved pulmonary function via a sublobar resection show an enhanced ability to withstand further resections [5]. The requirement for anatomical lung segmentectomies has also therefore increased.

Because there are a wide variety of possible segmentectomies that can be performed and there are many variations found in the structures of the pulmonary vessels and bronchi [6], it is relatively difficult to develop the experience and skills required for this surgical procedure. We herein present the benefits in this regard of using three-dimensional (3D) imaging navigation during a lung segmentectomy via the intra-operative use of an iPad.

PATIENTS AND METHODS

Our institutional ethics committee approved this retrospective study. Fourteen patients who had undergone an anatomic segmentectomy for a primary lung cancer or a metastatic lung tumour between 1 October 2010 and 30 June 2011 were included in the study cohort. The selection criteria for the performance of a segmentectomy were as follows: (i) a non-solid tumour of <2 cm in diameter which was a suspected primary lung cancer with no lymph node swelling evident on a chest CT scan; (ii) patients who were considered to be poor candidates for a lobectomy because of their limited cardiopulmonary reserves, including those with synchronous bilateral lung cancers

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or a second primary lung cancer; and (iii) lung metastatic tumours for which a wedge resection was considered to be inappropriate because of the tumour size or its location in the deep parenchyma. Patients with a non-solid tumour in the subpleural parenchyma of \(<1\) cm in diameter were excluded and underwent a wedge resection.

Three-dimensional imaging navigation

Images were obtained using a multi-detector CT (MDCT). A contrast agent was injected at a rate of 5 ml/s (total dose, 1.2 ml/kg) and this was followed by a 40-ml injection of normal saline to wash the contrast agent from the pulmonary artery (PA). Contrast-enhanced scanning was then performed twice, at \(7\) s after the start of the injection for enhancement of the PA and at \(18\) s after the injection for enhancement of the pulmonary vein (PV). 3D images were constructed from 1.0 mm data slices using a workstation (Ziostation, Amin, Tokyo, Japan). Images of the PA, PV, airway (from the trachea to the subsegmental bronchus) and of the tumours to be resected were constructed separately and subsequently merged. The process of generating the 3D images by radiology technicians took \(\approx 1\) h. These 3D images were then transferred to an iPad (Apple Inc., Cupertino, CA, USA) and analysed during surgery using DICOM image viewer software (OsiriX; Pixmeo SARL, Bernex, Switzerland) (Fig. 1).

Operative procedure

Preoperatively, the branches of the PA, PV and bronchus in the affected or adjacent segment were identified using 3D images. This information was used to determine whether the branches should be divided or preserved during the resection. We preserved the resection margin over the diameter of the tumour. If the surgical margin could not be sufficiently preserved in a single segment resection, a combined segmentectomy was planned involving the adjacent segments. In addition, if it was determined that a single segmentectomy could not be performed safely and securely because of an abnormality in the pulmonary vessels or bronchus, a combined segmentectomy procedure was selected.
The surgical approach used in the segmentectomies we performed was a muscle-sparing thoracotomy with an ~10-cm skin incision made adjunctively using a thoracoscope. We first ligated and cut the branches of the PA that were associated with the segment to be dissected. The segmental bronchus was then divided. In lobectomy cases, we utilize a stapler to divide a lobar bronchus. In cases of segmentectomies involving a right basal segment, left basal segment or left upper division, in which the size of these segmental bronchi is similar to that of the lobar bronchi, these were cut using a stapler. However, other segmental bronchi were simply ligated and cut. Subsequently, we identified the intersegmental veins and the pulmonary parenchyma along the veins was dissected using electrocautery or stapling devices. The intersegmental veins were usually preserved, but we sometimes ligated the veins that were not sufficiently distal to the tumour. Before the parenchymal resection, a temporary infla

Utilization of an iPad during operation

In the operating room, the iPad was placed inside a sterile bag (Ziploc, Asahi Kasei, Tokyo, Japan). The surgeons in the operative field could then easily review, zoom in or out and rotate the 3D image by direct manipulation. To perform an anatomical segmentectomy, the identification of unusual branches of the pulmonary vessels and bronchi is important to avoid intra-operative bleeding, post-operative impediment of blood flow or ventilator defects. Moreover, it is also essential to identify the intersegmental veins to enable the appropriate dissection of the pulmonary parenchyma with a sufficient margin from the tumour. In our methodology, the surgeons confirmed the anatomical structures by reviewing the 3D images using an iPad with the following timing: (i) before the dissection and division of the PAs, or bronchi, to determine whether the branch should be divided or not and (ii) before the dissection of intersegmental plane, to verify an adequate margin from the tumour (Fig. 2).

RESULTS

The study group included 3 men (21%) and 11 women (79%) ranging in age from 57 to 83 (mean 69 ± 7.8 years). The clinical diagnosis was a primary lung cancer in 11 cases (79%), including three cases of bilateral lung cancer, one case of a second primary lung cancer and three cases of a metastatic lung tumour (21%). The lesion was located in the right lung in five cases (36%) and in the left lung in nine cases (64%). The operative procedure was a resection in one case each of the right S1, the right S2, the right S2 and S6a, the right S6, the left S8 and the left S8 and S9 (Table 1). The left S1 + 2 and the left basal segment (S8, S9 and S10) were resected in two cases each (Table 1). The left upper division (S1 + 2 and S3) was resected in three cases (Table 1). All segmentectomies were successful and the operative times ranged from 134 to 297 min (mean 210 ± 53 min), with blood loss during the operation measured at between 5 and 57 ml.
No peri-operative blood transfusions were required and no major post-operative complications, such as massive haemorrhaging, acute lung injury, pneumonia or a bronchopleural fistula, were evident in any patient during or after their procedures. Eleven of our cases (79%) had a diagnosis of a pulmonary adenocarcinoma, and there were three cases (21%) of a metastatic lung tumour. No positive margins were found pathologically in any of these patients.

**COMMENTS**

In our present study, we focused on the usefulness of 3D imaging navigation for the safe performance of a lung segmentectomy. With the development of MDCT and 3D workstation software, 3D imaging has become relatively easier and has provided very useful visual information for the treatment of various diseases [7]. For example, some clinicians have described the usefulness of 3D imaging for lung surgery [8–11]. However, in these previous reports on 3D imaging navigation surgery, the pulmonary vessels were detected without distinguishing between arteries and veins, and the bronchi were not discerned in most of the images used. In contrast, in our present study, we have separately constructed 3D images of the PA, PV, airway and lung tumours to be resected and then merged these pictures. The 3D images generated in this way helped us properly identify these anatomical structures and thereby recognize the precise positional relationship between them and the lesions to be resected.

The iPad is a modern portable, lightweight computing device with an intuitive interface that is now being used in some clinical settings. Notably, because this tablet device can be used as a DICOM viewer [12], it can display and manipulate radiological images during an operation. Volonte et al. [13] have previously described a case in which a lung segmentectomy was performed with the assistance of 3D images generated intra-operatively using an iPad. These authors reported that they were able to review and manipulate the 3D images interactively during the surgery and that the device not only helped them to perform the procedure safely but also provided valuable learning with regard to intrapulmonary anatomy. In our institute, we started using iPads for 3D imaging navigation in October 2010 and found that this device allowed us to perform segmentectomies more safely than before as both the operator and the assistant were able to identify actual anatomical structures quite easily and concurrently and thus perform the procedures while checking for anatomical landmarks. Before the introduction of this procedure, we had performed segmentectomies that were regarded as more routine and straightforward such as the resections of the left upper division, the left lower division, the S6 or the basal segment, but tended to avoid performing other more difficult segmentectomies. Following the introduction of 3D imaging navigation with an iPad, however, these more difficult segmentectomies have been performed more often at our institution because the safety of these surgeries was increased by the availability of this imaging.

We have now utilized our imaging procedure during a thoracotomy operation involving a 10 cm incision. Oizumi et al. [11] have reported previously that anatomical segmentectomies can be performed by thoracoscopic surgery using CT angiography. Moreover, Atkins et al. [14] have described in a previous study that a thoracoscopic segmentectomy is a safe and feasible procedure compared with a thoracotomy as it reduces the length of the hospital stay and is a viable option for a lung-sparing, anatomic pulmonary resection by experienced thoracoscopic surgeons. The use of this procedure is quite new for our institute but we hope to perform more such interventions thoracoscopically in the future.

There are some noteworthy limitations to our present study. First, it takes a relatively long time to generate the 3D images and to perform segmentectomies. In generating the 3D images, some researchers have reported that only 5–15 min are required [11, 13], but we have found that ~1 h is necessary. This is because we need to construct separate images of the PA, PV, bronchus and tumour areas to generate more easily visible and intuitively understandable pictures. As for the length of segmentectomies, we have not yet become fully familiar with the 3D CT navigation surgery or with the undertaking of difficult segmentectomies and therefore have not developed a fully established protocol for this procedure. However, we hope to reduce the imaging time and the length of operation in the future through increased habituation. Second, small branches of the pulmonary vessels or bronchus may not be visualized using this method. It is therefore not yet appropriate or safe to rely completely on 3D imagery and careful surgical manipulation is still required. Third, the observation period we used was short and no prognostic evaluations were undertaken.

In conclusion, 3D CT navigation using an iPad enhances the ability of surgeons to perform a safe and secure segmentectomy. Given the increasing demand for this surgical intervention, 3D imagery is likely to become more widespread in the future.

**Conflict of interest:** none declared.

**REFERENCES**