Asian Journal of Surgery (2019) 42, 488–494

Available online at www.sciencedirect.com

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ORIGINAL ARTICLE

Combined virtual-assisted lung mapping (VAL-MAP) with CT-guided localization in thoracoscopic pulmonary segmentectomy

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Received 13 June 2018; accepted 14 June 2018
Available online 20 July 2018

KEYWORDS
VAL-MAP;
CT-Guided localization;
Segmentectomy;
Lung cancer

Summary *Background/Objective:* Virtual assisted lung mapping (VAL-MAP) is a bronchoscopic lung marking technique developed to assist in navigational lung resection. It can be used for nodule localization and segmental identification. This article presents our initial experience of thoracoscopic pulmonary segmentectomy using combined VAL-MAP and computed tomography (CT)-guided localization.
Material and methods: Markings with India Ink were made bronchoscopically, before surgery, using a virtual bronchoscopy system (LungPoint® Planner) without fluoroscopy guidance. Post VAL-MAP CT scans localized the actual markings. All data on patients, markings, and outcomes were retrospectively collected, and the contribution of VAL-MAP to the operation was graded by the surgeon.
Results: From March 2017 to September 2017, 24 consecutive patients received the VAL-MAP marking procedure before thoracoscopic segmentectomy. Nineteen patients also received pre-operative CT-guided percutaneous localization after VAL-MAP; fifteen patients received CT-guided localization with dye (patent blue V) and microcoil, and four patients received with dye only. Of the 101 marking attempts made in all the patients, 71 (70.3%) were identified as contributing to the surgery. No clinically evident complications were associated with the procedure. A total of 24 segmentectomies were thoracoscopically conducted for 18 cases of lung

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https://doi.org/10.1016/j.asjsur.2018.06.005

cancer and six cases of benign diseases.
Conclusion: The combination of VAL-MAP and CT-guided percutaneous localization contribute to precise thoracoscopic pulmonary segmentectomy.

1. Introduction

Growing numbers of small-sized lung cancers have been detected by low-dose computed tomography (LDCT) screening, and anatomical segmentectomy has gradually been demonstrated to be the favorable surgical treatment, with comparable oncological outcomes to lobectomy, allowing for optimal preservation for pulmonary function.[1] To identify these impalpable lesions during the operations, CT-guided localization in conjunction with percutaneous transthoracic procedures were the most widely used localization techniques.[2,3] In addition to localization of the target lesion, determination of the boundary of the segment to be resected is critical to the performance of anatomical segmentectomy.

The virtual-assisted lung mapping (VAL-MAP) system, developed by Sato et al, combines virtual bronchoscopy and dye-localization techniques and has been widely used in Japan. This system provides "geometric information" with multiple markings on the lung surface, which can be reached through the extension of the endobronchial pathway.[4–9] In addition to direct localization of the lesion site, VAL-MAP guides the surgeon to identify the bronchial territory and facilitates anatomical segmentectomy, especially when doing stapler-based segmentectomy.[6]

The author's institution had well-developed techniques using CT-guidance. When the institution began using the VAL-MAP system, we presented our initial experiences of navigational thoracoscopic segmentectomy using the combination of a bronchoscopic marking technique and CT-guided percutaneous localization.

2. Material and methods

2.1. Study design and patients

The consecutive cohort of patients who underwent VAL-MAP followed by thoracoscopic pulmonary segmentectomy in National Taiwan University Hospital Hsin-Chu Branch from March 2017 to September 2017, were reviewed. The inclusion criteria for segmentectomy were: (i) small sized lesions (<2 cm) that were anticipated to be malignant, wherein complete resection with adequate margins could be achieved by anatomic segmentectomy (including uni-, bi-, and tri-segmentectomy) (ii) lesions larger than 2 cm, but with impaired pulmonary function necessitating segmentectomy. Patients received additional CT-guided localization if the lesions were anticipated to be difficult to identify intraoperatively. The study was approved by the Research Ethics Committee of National Taiwan University Hospital, Hsin-Chu Branch (approval number: 106-063-E).

2.2. Modified VAL-MAP technique

Virtual bronchoscopy (LungPoint® Planner; Broncus Technologies, Mountain View, CA, USA) based on thin-cut CT images were used to identify target bronchi of the segment to be resected. Marking plans were modified for different segments. For example, all the segmental bronchi were marked if the target segment was centrally located (left segment 3), whereas only the inferior border was marked for the superior segment of the lower lobe (segment 6). In our institution, VAL-MAP was performed on the same day as the operation. The patient was brought to the bronchoscopy room and light sedated using intravenous midazolam and fentanyl.

During the procedure, a thin flexible bronchoscope (BF P260F; outer diameter 4.0 mm; working channel, 2.0 mm; Olympus, Tokyo, Japan) was inserted trans-nasally and navigated by virtual bronchoscopy until visualization of the target bronchial orifice was achieved. A regular guide sheath catheter (GuideSheath Kit, K-201; Olympus, Tokyo, Japan) with radial probe endobronchial ultrasonography (RP-EBUS; UM-S20-17S; Olympus, Tokyo, Japan) was inserted into the orifice through the working channel. Once the operator felt resistance to further advancement of the probe, the insertion would be stopped with mild blocking force and the RP-EBUS was removed while keeping the catheter tip with motionless, followed by the standard dye injection method[7] with 1.5 ml diluted (0.5 ml pure dye in 20 ml saline) black dye (BD India Ink Reagent Droppers, Becton Dickinson, USA) and 10 ml air per marking. The marking procedure was repeated for the planned target bronchi.

2.3. Post-mapping CT & percutaneous localization procedures

After the VAL-MAP procedure, a CT scan was routinely performed to confirm the location of markings,[8] and CT images were reconstructed into three dimensional (3D) images including the target lesion and the markings, which usually presented with ground-glass opacities (GGOs) at the anticipated injection sites. During this period, additional CT-guided percutaneous procedures were also performed if needed. If the lesion was centrally-located, microcoil placement with PBV dye (patent blue V 2.5%; Guerbet, Aulnay-sous-Bois, France) injection on the pleural surface was performed. If the lesion not centrally-located, but would be intraoperatively unidentifiable, only blue dye injection was performed (Fig. 1).

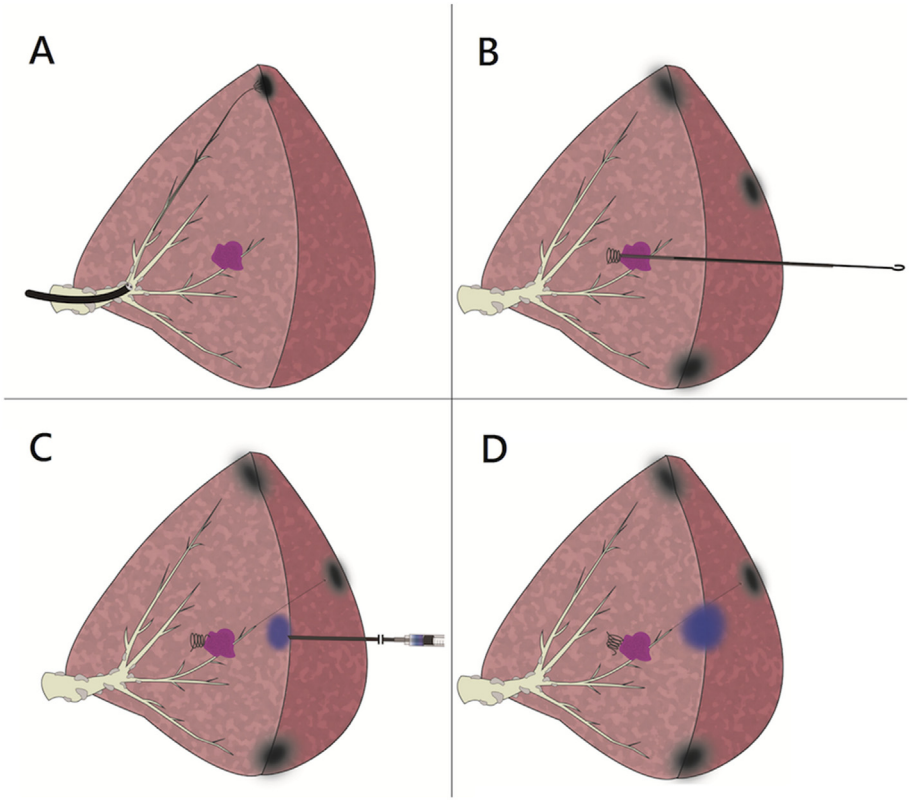

Fig. 1 Localization strategy of combined VAL-MAP with CT-guided procedures. (A) Place markings close to the intersegmental line by VAL-MAP; (B) after VAL-MAP, a microcoil was placed near the lesion through the CT-guided needle localization; (C) withdrawal of the needle under the lung surface then injection of blue dye; (D) completion of combined VAL-MAP with CT-guided localization.

2.4. Image-guided segmentectomy

For segmentectomy, the hilar structures were dissected and resected according to the preoperative plan and the intersegmental borders were cut by endo-stapler. Our procedure for segmentectomy was generally derived from the technique of stapler-based navigational segmentectomy, which was developed by Sato, et al[6] However, there were several modifications: (i) The lesion sites were directly marked using CT-guided dye localization, and the resection margin from the lesion could be assessed with confidence while engaging the stapler; (ii) After dividing the target bronchus, separation of the bronchus stump and its neighboring tissue was performed using blunt dissection and an energy device, instead of using electrocautery, allowing us to go one centimeter deeper; (iii) During the "most central" stapling, intraoperative fluoroscopy was used to confirm the adequate inclusion of microcoil, which was placed during the CT-guided procedure for centrally located lesions. After segmentectomy, lymphadenectomy was routinely performed if the lesion proved malignant.

2.5. Data collection and analyses

The clinical data, operative findings, and pathologic characteristics of the lung tumors were collected from the medical records. Measurements of the lesions were performed using preoperative CT images. The lesion size was defined as largest diameter observed on axial view, and the lesion depth was defined as the nearest distance from the center of the lesion to the pleura. Data are expressed as the median with interquartile range (IQR) and range, as appropriate. No statistical analyses were performed during the study.

3. Results

Twenty-four consecutive patients received VAL-MAP marking procedures before thoracoscopic segmentectomy from March 2017 to September 2017. The characteristics of the patients and lesions are presented in Table 1. All the patients received post-mapping CT confirmation, except for the first case because the VAL-MAP procedure was performed under general anesthesia in the operating room. Nineteen patients received additional CT-guided percutaneous localization after CT-confirmation of VAL-MAP. Among those receiving additional CT-guided procedures, 15 patients received localization with microcoil placement followed by dye injection, and four patients with peripheral lesions received dye injection only.

The results of VAL-MAP and CT-guided procedures are reported in Table 2. The total number of planned markings was 101. Of the 101 marking attempts made in all the patients, 71 were identified as contributing to the surgery. The successful rates of marking increased throughout the

Table 1 Characteristics of patients and pulmonary lesions.

Variables	Values (N = 24)
Sex Female	16
Age (y)	54.0 ± 12.9 (36–74)
Lesion size (cm)	1.1 ± 0.5 (0.6–2.8)
Location	
Right upper lobe	8
Right lower lobe	5
Left upper lobe	11
Appearance on CT	
Pure GGO	5
Part-solid	9
Solid	9
Cavitation	1
Pathology	
Primary lung adenocarcinoma	16
Metastatic cancer	2
Granulomatous inflammation	4
Cryptococcus	1
Intrapulmonary lymph node	1

CT = computed tomography; GGO = ground-glass opacity. Continuous data are shown as mean ± standard deviation and range.

course of our practice. For the first six cases, the visible markings were 46.6% of all planned markings and this number increased to 65.5% for the next six cases. After applying the knowledge gained from hands-on experience and video demonstration, the successful marking rate was 85.7% for the following 12 cases. The median mapping time and CT-guided localization time were 25 and 22 min. The median time from VAL-MAP to CT room and VAL-MAP to operating room were 36 and 61 min, respectively.

Table 2 Results of localizations and surgeries.

Variables	Values (N = 24)
VAL-MAP	
Mapping time (min)	22.9 ± 7.6 (4–48)
Planned marks/patient	4.2 ± 1.7
Visible marks/patient	2.9 ± 1.1
Total planned marks	101
1^{st}–6^{th} cases	30
7^{th}–12^{th} cases	29
13^{th}–24^{th} cases	42
Total visible marks	71 (70.3%)
1^{st}–6^{th} cases	14 (46.6%)
7^{th}–12^{th} cases	19 (65.5%)
13^{th}–24^{th} cases	36 (85.7%)
VAL-MAP to CT (min)	44.5 ± 36.5 (2–124)
VAL-MAP to OR (min)	93.4 ± 96.2 (8–443)
Combined CT-guided procedure	19
Dye only	4
Dye with microcoil	15
Localization time (min)	23.8 ± 13.6 (6–53)
Surgical procedure	
Uni-segmentectomy	14
Bi-segmentectomy	9
Tri-segmentectomy	1

VAL-MAP = virtual-assisted lung mapping.

Segmentectomies were performed according to the intraoperative findings of VAL-MAP together with post-mapping CT reconstruction. In total, 14 uni-segmentectomies, nine bi-segmentectomies, and one tri-segmentectomy were performed. No clinically evident complications were associated with the procedure. Final pathology reports showed 16 primary lung adenocarcinomas, six benign lesions, and two metastatic cancers.

4. Discussion

For the surgical management of small impalpable lesions, many institutions in different countries, have their preferred localization methods in accordance with the existing facility and specialty processes. CT-guided lung biopsy had been a regular practice for many years in our institution and the proficiency of this technique has certainly been passed on to the localization procedures.[10] As with biopsy, CT-guided needle localization of lung lesions is mostly "lesion-oriented" and its localization results usually lead surgeons to perform lesion-centered resections.[6] However, based on increasingly clear evidence, anatomy-oriented localization for anatomical resection for lungs should be adopted.[11,12] Based on the bronchial anatomy, VAL-MAP can delineate the segmental territory through multiple markings, thus reducing the limitations of our prior routine for lesion localization.

For most of the VAL-MAP cases in Japan, combined CT-guided procedures had not been considered because VAL-MAP was initially designed as an alternative to CT-guided localization, with the goal of reducing lethal complications.[13,14] However, in our institution, CT-guided localization had a high success rate, with only few minor complications.[2] Post-mapping CT-confirmation is strongly recommended[15] and salvage localization with CT-guided procedures can be useful if the VAL-MAP results are less than satisfactory. Typical VAL-MAP markings present with GGOs and/or bronchial dilation on CT scans,[5] and are supposed to interfere the identification of the lesion during CT-guided localization, especially for GGO lesions. However, when carefully comparing the previous CT images, slice by slice, authentic GGO lesions can be recognized by shape and surrounding bronchovascular structures.

In our marking strategy (Fig. 1), we used blue dye for the lesion and black dye for the segmental border, which outlined the spatial relation of the lesion and the segment during the surgery. This allowed for the planned resection margin between the segmental border and the lesion to be evaluated easily during application of the stapler to lung parenchyma. As previous reports described, microcoil placed during CT-guided localization could be enhanced under fluoroscopy to confirm the deep margins were sufficient before making staples.[16,17]

In the standard setting of VAL-MAP, real-time fluoroscopy was used to visualize the catheter tip reaching the pleura,[4] however, most hospitals in our country were not equipped with fluoroscopy in the bronchoscopy room. After

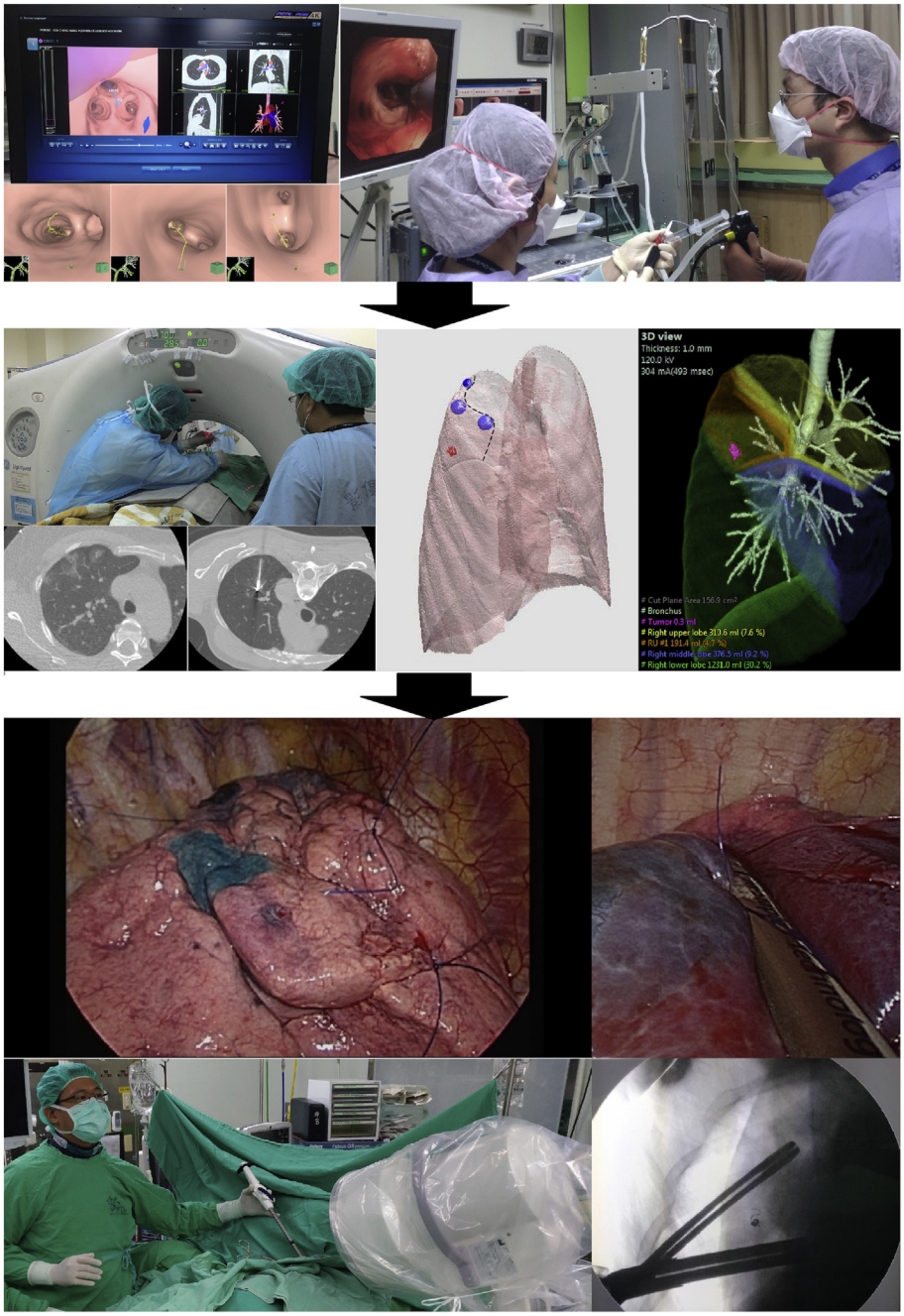

Fig. 2 Steps in combination of VAL-MAP, CT-guided localization, and image-guided surgery.
Step 1 (VAL-MAP): A set of target bronchi can be selected using virtual bronchoscopy. According to the preoperative plan, bronchoscopic marking with black dye is conducted.
Step 2 (CT confirmation & localization): Post-mapping CT is performed to confirm the locations of the markings and additional CT-guided localization procedures (blue dye with/without microcoil) were performed. The images are reconstructed into 3-dimensional images for surgical planning. **Step 3 (Image-guided surgery):** Thoracoscopic surgery would be performed according to the intra-operative findings. Marking sutures were placed along the planned resection lines, and the microcoil was used to check for the deep margin under fluoroscopy.

going through the learning curve of the first six cases with only a 46.6% successful marking rate, our marking technique was continuously refined by referring to the online video demonstrations[18] and directly learning from the experts. Without fluoroscopy, the successful marking rate had reached 85.7% in the second half of our cases. These marking procedures were performed while relying solely on hands-on experience, although far from the average performance in Japan. Fluoroscopy also provided real-time visualization. If the catheter moves in the wrong

direction, it would be obvious, recognized, and then re-inserted. To overcome the lack of fluoroscopy to guide the insertion of catheter, we used thinner bronchoscopy to reach two to three times more distal bronchial divisions than standard bronchoscopy, thus reducing the possibility of insertion into the wrong area.[19] Penetration of visceral pleura may be easy when perform the VAL-MAP procedure without using fluoroscopy. Not only pneumothorax but also decreased the effect of marking may be happened. We used the smaller size RP-EBUS with soft tip as a stylet to reduce the pleura penetration. In the present study, no significant complication was noted. Conclusively, our procedure could be an alternative to performing VAL-MAP if fluoroscopy is not the standard in another hospital's bronchoscopy room.

Hybrid operating rooms (OR), defined as surgical workspaces that combine multifunctional imaging equipment with integrating image workstations, can provide real-time image guidance during procedures and also reduce the inconvenience of patient transportation between examination rooms and the operating theater. Modern hybrid ORs are equipped with a robotic C-arm cone-beam CT (CBCT) which can provide C-arm fluoroscopy guidance during VAL-MAP, followed by CBCT for post-mapping confirmation and additional CT-guided localization when needed in a single location.[20] Many institutions throughout the world have reported their experiences with the use of image-guided thoracic surgery in the hybrid OR, and most use percutaneous localization procedures under guidance of CBCT,[21–23] but bronchoscopic procedures performed in the hybrid room had only limited reports.[24,25] Our workflow provided a prototype of multimodality image-guided thoracic surgery in the hybrid OR. A specialized work station with an image-processing technician is necessary for the post VAL-MAP CT confirmation with 3D-reconstruction, which is essential for precise surgical planning (Fig. 2). Rushing through any steps in the process while in the hybrid room could compromise the contribution of the VAL-MAP procedure.

There several limitations of VAL-MAP technique. Patients with diffused emphysematous lung were not the ideal candidate for bronchoscopic dye localization, because the dye marking were hardly visible. For the patients with risk of poor visibility, the duration between VAL-MAP and surgery should not be too long because of the negative relationship between the marking intensity and duration.[9] Also, prominent pulmonary anthracosis would mislead the recognition of markings, especially when using black-colored dye.

5. Conclusion

The combination of VAL-MAP and CT-guided localization worked in harmony in our series, and it also demonstrated a pattern of transition from lesion-directed to anatomy-directed localization for the management of small lung lesions.

Conflicts of interest

None of the authors has any potential financial or nonfinancial conflicts of interest.

Acknowledgements

The authors want to thank all members of the department of thoracic surgery in the University of Tokyo Hospital, where we learned the technique of VAL-MAP.

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