Virtual-assisted lung mapping: outcome of 100 consecutive cases in a single institute

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Abstract

OBJECTIVES: We developed virtual-assisted lung mapping (VAL-MAP), a bronchoscopic multispot dye-marking technique using three-dimensional (3D) virtual imaging, for precise thoracoscopic sublobar lung resection with safe surgical margins. We herein review the results of 100 consecutive cases of VAL-MAP in our institute to identify types of tumours or resections that benefit from VAL-MAP.

METHODS: Markings were bronchoscopically made within 2 days preoperatively using virtual 3D images. Post-VAL-MAP computer tomography (CT) scans localizing the actual markings were reconstructed into 3D images for intraoperative navigation. All data on patients, markings and outcomes were prospectively collected, and the contribution of VAL-MAP to the operation was graded by the surgeon.

RESULTS: Resections of 156 lung lesions in 100 consecutive patients were planned from July 2012 to March 2014. The lesion diameter was 8.3 ± 4.9 (range, 2–24) mm. The total number of actually conducted markings was 380 (3.83 ± 1.07 markings/patient). Eighty-four lesions were resected by 71 wedge resections using 158 markings (2.1 ± 0.1/resection; range, 1–3). Seventy lesions were resected by 63 segmentectomies using 224 markings (3.6 ± 0.1/resection; range, 2–6). Markings were identifiable on post-VAL-MAP CT mostly as ground-glass opacities (87.7%) and/or bronchial dilatation (56.1%). During the operation, 357 of 380 markings (93.9%) were visible on the pleural surface and significantly associated with marking visibility on CT. Multiple markings that were complementary to one another appeared to have contributed to the high rate of successful resection (99.3%) with satisfactory resection margins. The contribution of VAL-MAP to the operation as graded by surgeons demonstrated that VAL-MAP is most effective during wedge resection or complex segmentectomy for hardly palpable, small tumours, while VAL-MAP still plays an important role in simple segmentectomy or resection of palpable tumours by providing higher confidence levels to surgeons during the operation. Minor pneumothoraces were found on post-VAL-MAP CT images in 4 patients without symptoms or a need for treatment.

CONCLUSIONS: The present study further demonstrated the efficacy and safety of VAL-MAP. VAL-MAP is likely to benefit a broader range of patients than are conventional marking techniques by assisting with both accurate tumour identification and precise determination of resection lines.

Keywords: Virtual bronchoscopy • Marking • Ground-glass opacity • Navigation

INTRODUCTION

The introduction of computer tomography (CT) screening for lung cancer is likely to increase the incidence of finding early-stage small lung tumours [1]. However, expansion of thoracoscopic surgery has made palpation of such tumours challenging. As such, a preoperative or intraoperative lung marking technique may play an important role in thoracoscopic resection of such hardly palpable tumours [2, 3]. However, conventional marking techniques such as CT-guided percutaneous marking using a hook wire have multiple limitations including limited access to the lung apex, areas facing the diaphragm, and interlobar fissure as well as complications including frequent pneumothorax (up to 30%), haemorrhage, dislodgement and, most importantly, potentially fatal air embolisms [4–6].

To overcome these limitations, we developed a novel technique termed virtual-assisted lung mapping (VAL-MAP) and reported our experience with our initial 30 cases [7]. Beyond conventional techniques of lung marking, we call this new technique lung ‘mapping’ instead of marking because it enables not only tumour identification, but intraoperative navigation for precise thoracoscopic sublobar lung resection [7, 8].

Nevertheless, further data accumulation was desired for better evaluation of the efficacy and safety of this new technique. For
example, although we experienced no clinically evident complications associated with VAL-MAP, we identified 2 cases of minor pneumothoraces on post-VAL-MAP CT scans among the first 30 cases (6.7%) [7]. However, whether this lack of major complications occurred because the number of cases was small remains unclear. Technical refinement might reduce the complication rate even further and improve the outcome of the technique.

The purpose of the present study was to review the results of 100 consecutive cases of VAL-MAP in our institute and identify types of tumors or resections that benefit from VAL-MAP. We also describe improvements in the technique of VAL-MAP over time that appear to have contributed to further establishment of the safety and efficacy of this technique.

MATERIALS AND METHODS

Patients

One hundred consecutive patients were enrolled in this study to undergo VAL-MAP followed by lung resection from July 2012 to March 2014. The inclusion criteria were (i) a requirement for sublobar resection (i.e., wedge resection or segmentectomy) to resect a pulmonary lesion or (ii) lesions that were either anticipated to be hardly palpable intraoperatively or in which the resection margin needed to be carefully selected regardless of the palpability of the lesion. The exclusion criterion was past or present bronchial asthma. Data were prospectively collected with some exceptions (described later). The study was approved by the ethics committee of Kyoto University Hospital.

Virtual-assisted lung mapping planning

The VAL-MAP procedure was designed to identify hardly palpable lesions and/or indicate the resection lines in wedge resection or segmentectomy. In wedge resection, two to three markings were used to surround the lesion and indicate resection lines [8], while in segmentectomy, three to six markings were used to indicate the resection lines (i.e., intersegmental planes) [7]. Virtual bronchoscopy (Aquarius iNtuition Client Viewer; TeraRecon, Inc., Tokyo, Japan or Synapse Vincent; Fuji film Medical, Tokyo, Japan) was used to identify target bronchi reaching the designed marking points. The software was selected based on the bronchoscopist’s or surgeon’s preference.

Virtual-assisted lung mapping procedure

The dye injection technique of VAL-MAP is shown in Videos 1 and 2. Briefly, within 2 days preoperatively, the patient was brought to the bronchoscopy suite and mildly sedated using 2–3 mg of midazolam. A metal-tip catheter (PW-6C-1; Olympus, Tokyo, Japan) was preloaded with 1 ml of indigo carmine (Daiichi-Sankyo, Inc., Tokyo, Japan). A regular flexible bronchoscope (BF 260; Olympus) was orally inserted, and the catheter was then inserted through the working channel of the bronchoscope into a target bronchus, usually aiming at an 8–11 branching level. Fluoroscopy was used to visualize the tip of the catheter reaching the visceral pleura. Once the catheter tip was wedged in the peripheral lung, the plunger of the syringe connected to the catheter was gently pushed while the catheter was slightly withdrawn until the plunger could be easily withdrawn by 1 cm, until the plunger could be easily pushed. Injection of dye was followed by injection of air (20–90 ml/mark; see below, ‘Technical changes over time’). This marking procedure was repeated for all target bronchi.

Technical changes over time

The techniques of the bronchoscopic mapping procedure were modified during the study period. In the first period (Cases 1–20,
the amount of air injected after the injection of dye was 90 ml/mark. In the second period (Cases 21–40), this amount of air was reduced to 30 ml/mark because of the 2 cases of pneumothoraces that developed in the first period (see the ‘Results’ section). In the third period (Cases 41–80), the amount of injected air was further reduced to 20 ml/mark, and the use of a stylet in the catheter was omitted in the theoretical interest of further safety. In the fourth period (Cases 81–100), we introduced a grading system for each mark for better quality control. The details of the grading system are described in the ‘Materials and Methods’ section.

Post-virtual-assisted lung mapping CT scan

An additional CT scan was performed to confirm the location of markings within 2 h after the mapping procedure. All CT findings were recorded, including the presence of ground-glass opacities (GGOs), bronchiectasis, pleural changes such as thickening, and bulla formation. The ease of identifying each marking on the CT scans was given one of four grades from ‘easy’ to ‘not identifiable’ by the surgeon or bronchoscopist. Post-VAL-MAP CT images were reconstructed into three-dimensional (3D) images including the target lesion, markings and other geometric information such as the interlobar fissures. A representative CT and constructed 3D image after VAL-MAP are shown in Fig. 1.

Intraoperative findings

All operations were conducted under thoracoscopy or with the aid of thoracoscopy and were recorded by a thoracoscopic video system. The quality of each marking was graded using the grading system shown in Fig. 2. This grading system was introduced from Case 81 onwards, and these data were collected in a prospective manner. From Case 1–80, grading was conducted in a retrospective manner, while after Case 81, each marking was graded by the bronchoscopist or surgeon and feedback of the result was facilitated. The operation types were reported as wedge resection; conventional segmentectomy (i.e. segmentectomy guided by intersegmental vein); and unconventional segmentectomy, which included subsegmentectomy, pulmonary artery-guided segmentectomy [9] or extended segmentectomy that extends beyond the anatomical segment into an adjacent segment [10].

The contribution of VAL-MAP to the operation was graded by the surgeons as follows: Grade A, the same level of operative precision was judged to be impossible without VAL-MAP; Grade B, a similar level of precision was judged to be possible, but VAL-MAP enabled confident performance of the operation and Grade C, the same operation was judged to be possible without VAL-MAP.

Data analysis and statistics

All data were collected in a prospective manner with the exception of the grading of the CT and intraoperative findings, which were introduced from Case 41 onwards and from Case 81 onwards, respectively. Grading of previous cases was retrospectively conducted using post-VAL-MAP CT and intraoperative video recordings. The relationship between the grade of the contribution of VAL-MAP to the operation and the type of operation or tumour characteristics (size, depth, CT characteristics and palpability during operation) was examined using Pearson's χ² test. In cases where multiple resections were conducted or multiple tumours were resected, the most representative operation type and tumour were used for analyses. With respect to tumour characteristics, tumour size was categorized as ≤5, >5–10 and >10 mm; tumour depth was categorized as ≤10 and >10 mm; CT quality of the tumour was categorized as pure GGO, GGO with solid component, solid/nodule and cavity; and palpability during the operation was categorized as easy, difficult, impossible and not attempted.

Data are expressed as the mean ± standard deviation as appropriate. Statistical analysis was conducted using the JMP software (SAS Institute).

RESULTS

One hundred patients were enrolled in this study from July 2012 to March 2014. The patients’ characteristics and radiographic characteristics of the lesions are given in Table 1. In total, 156 lung lesions were targeted by VAL-MAP. The preoperative diagnosis included primary lung cancer (90 lesions in 71 patients) and metastatic lung tumours (66 lesions in 29 patients). For these lesions,
wedge resections were planned for 84 lesions (30 suspected primary lung cancers and 54 suspected metastatic tumours), while segmentectomies were planned for 72 lesions (60 suspected primary lung cancers and 12 suspected metastatic tumours).

The total number of planned markings was 382 (3.83 ± 1.07 markings/patient). The number of planned markings for wedge resection was 158 (2.1 ± 0.1/resection; range, 1–3), while that for segmentectomy was 224 (3.6 ± 0.1/resection; range, 2–6).

Table 1: Radiological characteristics of targeted pulmonary lesions according to preoperative diagnosis

<table>
<thead>
<tr>
<th>Preoperative diagnosis</th>
<th>Primary lung cancer</th>
<th>Metastatic lung tumour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>72</td>
<td>28</td>
</tr>
<tr>
<td>Sex (F/M)</td>
<td>42/30</td>
<td>12/16</td>
</tr>
<tr>
<td>Age in years (range)</td>
<td>62.5 ± 16.2 (37–85)</td>
<td>62.9 ± 11.0 (32–76)</td>
</tr>
<tr>
<td>Operation side (R/L/both)</td>
<td>39/32/1</td>
<td>17/10/1</td>
</tr>
<tr>
<td>Number of lesions</td>
<td>90</td>
<td>65</td>
</tr>
<tr>
<td>Number of lesions/patient (range)</td>
<td>1.3 ± 0.6 (1–4)</td>
<td>2.2 ± 1.5 (1–7)</td>
</tr>
</tbody>
</table>

CT quality

<table>
<thead>
<tr>
<th>Pure GGO</th>
<th>GGO with solid component</th>
<th>Solid/nodule</th>
<th>Cavity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter [mm (range)]</td>
<td>9.3 ± 4.8 (4–22)</td>
<td>13 ± 4.9 (8.7–24)</td>
<td>9.9 ± 5.1 (2.9–22)</td>
</tr>
<tr>
<td>Depth [mm (range)]</td>
<td>6.0 ± 6.5 (0–30)</td>
<td>8.0 ± 8.4 (0–35)</td>
<td>8.6 ± 9.2 (0–34)</td>
</tr>
</tbody>
</table>

GGO: ground-glass opacity.

*GGO component of the lesions was 52.8% ± 23.0% in the cross-sectional CT at the largest diameter of the lesion.
The marking procedure was conducted following the mapping plan except in the following cases: in 3 patients, one of the target bronchi could not be entered because of the anatomical angle of the bronchial orifice; two markings were totally abandoned and the remaining marking was conducted through another bronchus anatomically close to the original plan. Thus, 380 markings were conducted in total. The average bronchoscopice time (from insertion of the bronchoscope to the end of mapping) was 20.1 ± 5.65 min, while the average time spent on actual mapping (from identification of the first target bronchus to the end of mapping) was 15.0 ± 5.1 min (3.7 ± 1.0 min/mark).

All patients underwent post-V AL-MAP CT scans as per protocol. Fifty patients were placed in the decubitus position, while 49 patients were placed in the supine position; 1 patient was placed in the prone position (a case of bilateral mapping). The average time from mapping to the CT scan was 59.2 ± 53.2 min. CT scans in the decubitus position generally provided better distinction of markings in the posterior region of the lung because of the weaker effect of gravity in the area (Fig. 3). The CT findings are shown in Fig. 4. Approximately 75% of markings were easily identifiable on post-V AL-MAP CT, while ~5% of markings were not identifiable (Fig. 4A). Markings were typically identified on CT scans as GGOs and/or bronchial dilation (Fig. 4B). Among 342 identifiable markings in contact with the visceral pleura on post-V AL-MAP CT scans, 338 markings (98.8%) were visible during the operation; only 8 of 19 markings (42.1%) that were unidentifiable on CT, and 11 of 19 markings (57.9%) that were localized away from the pleura on CT were visible during the operation (Fig. 4C and D). Bulla formation was observed in 4 patients (Fig. 4E), while minor pneumothoraces were identified in another 4 patients (Fig. 4F); no chest tube drainage or other interventions were required in these patients. Minor intra-alveolar bleeding was suspected in 1 patient. No other adverse events were identified on the CT scans. Three of the 4 pneumothoraces were found in the first 40 cases.

Using the post-V AL-MAP CT scan, preoperative 3D images were made for all patients. The operation was conducted within 2 days after mapping. The timing of the operation was as follows: operation on the same day as mapping (n = 59), operation on the day after mapping (n = 36) and operation 2 days after mapping (n = 5). The intraoperative findings of markings (grades) are shown in Fig. 5A. Among all 380 markings, Grade 2 was the most frequent grade (202 markings); 357 of 380 markings (93.9%) were identified during the operation (i.e. Grades 1–5). The intraoperative marking visibility was associated with findings on the post-V AL-MAP CT scan. Markings that were not identified on the CT scan or identified in the middle of the lung parenchyma, away from the visceral pleura, were generally hardly identifiable during the operation (Fig. 5B and C). Conversely, if the markings were identifiable on the CT scan, those that reached the visceral pleura were usually well visible during the operation regardless of the difficulty of identification on the CT scan (Fig. 5D). There was no significant difference in the degree of intraoperative marking visibility among the different timings of mapping (Fig. 5E). With respect to the technical changes in the V AL-MAP procedure over time, the fourth period (after introduction of the grading system) showed the highest ratio of appropriate markings (Grades 2 and 3, Fig. 5F).

Seventy-nine tumours were palpated during the operation. Among them, 59 were palpable with variable difficulty, 18 were palpable with little confidence and 12 were not palpable at all. The remaining 76 lesions were not palpated mainly because the tumour was visible (n = 10), the location of the tumour was difficult to palpate (n = 11), the tumour was unlikely to be palpable according to the radiographic findings (n = 44) or other reasons (n = 10). After extraction, 36 tumours were easily palpable regardless of mapping, 52 were considered to be easily palpable because the mapping indicated the tumour location, 42 were hardly palpable despite mapping and 25 were not palpable at all.

Operations were conducted according to the plan in most cases. In total, 71 wedge resections were conducted for 84 lesions (29 wedge resections for 30 suspected primary lung cancers and 42 wedge resections for 54 suspected metastatic tumours), while 63 segmentectomies were eventually conducted for 70 lesions (52 segmentectomies for 58 suspected primary lung cancers and 11 segmentectomies for 12 suspected metastatic tumours). In 1 patient, the

Figure 3: Patient position and post-V AL-MAP CT scan. (A and B) Post-V AL-MAP CT scan of the same patient taken in the supine position. (C) Post-V AL-MAP CT scan of another patient taken in the decubitus position. White arrows indicate markings made by V AL-MAP. Black arrows indicate gravity effect, showing ground-glass-like appearance.
The operation plan was changed from segmentectomy to lobectomy after VAL-MAP but before the operation at the patient’s request. In another patient, segmentectomy was conducted after VAL-MAP according to the plan; however, the resection margin was considered to be insufficient, and completion lobectomy was added.

The contribution of VAL-MAP to the operation was graded by the surgeons, and the relationships of the grade with operation types and tumour characteristics were examined (Fig. 6). Overall, grades A, B and C were assigned to 58/100 (58%), 36/100 (36%) and 6/100 cases (6%), respectively (Fig. 6A). Grade A occurred significantly more frequently in wedge resection and unconventional segmentectomy than in conventional segmentectomy (Fig. 6B). No significant differences were found in tumour size, depth or CT characteristics (Fig. 6C–e), although tumour size (especially < 5 mm) and pure GGO tended to be associated with Grade A. Intraoperative palpability showed a statistically significant relationship with grade (Fig. 6F).

The final pathological results are given in Table 2. In total, 155 of the targeted 156 lesions were successfully resected (99.4%). In 1 patient, two metastatic lung sarcoma lesions were planned to be resected by two wedge resections. During the operation, two lesions were resected, but one of the originally targeted lesions was found to be unresected on a follow-up CT scan obtained 3 months postoperatively. A retrospective review of the operation video revealed that one resected lesion that was visible on the pleural surface during the operation had not been identified on the preoperative CT scan (i.e. the lesion was mistakenly resected, leaving a target tumour unresected). The patient underwent a second VAL-MAP, and the tumour was successfully resected.

**DISCUSSION**

We have herein reported the results of 100 consecutive cases of VAL-MAP conducted in a single institute. We previously reported the details of this technique in our first 30 cases of VAL-MAP, and that experience suggested the novel role of multiple lung markings or lung ‘mapping’ not only in identification of a hardly palpable lung tumour, but also in determination of precise resection lines to obtain secure resection lines during thoracoscopic sublobar lung resection [7]. We also recently described special techniques such as utilization of anatomical landmarks and auxiliary lines as part of the lung map [8]. These new techniques further reinforced the utility of VAL-MAP, practically covering all areas of the lung surface [8]. In the present study, to further examine the efficacy and safety of VAL-MAP, we examined the data of 100 consecutive patients who underwent VAL-MAP-assisted lung resection.

Compared with conventional marking techniques [2, 3, 11–13], VAL-MAP is characterized by two unique features that support a high rate of successful resection: concurrent multiple markings and 3D images constructed from post-VAL-MAP CT scans. First, because multiple markings are conducted, even if one of them fails, the others work as ‘insurance’, complementing the failed marking. In other words, the locations of both the failed markings and the tumour can be estimated to some extent from the successful markings. Secondly, post-VAL-MAP CT with reconstruction into 3D images allows for adjustment of the lung map and operation plan according to the actual location of the markings. Thus, unlike conventional marking techniques that are totally
dependent on a single marking, the VAL-MAP system is resistant to errors that may occur for multiple reasons.

Another important finding is the association between post-VAL-MAP CT findings and intraoperative findings. Markings in contact with the pleura that are identifiable on the post-VAL-MAP CT scan are also likely to be identifiable during the operation. This is important because, for example, if four markings are made and only three are visible during the operation, which one of the four markings is missing may not be readily apparent. However, if the marking that might be invisible during the operation is predictable by CT, this further reinforces the error resistance of VAL-MAP.

The CT findings in this study also suggest the causes of the marking failures that occurred in <10% of the markings. A major reason for these failed markings was ‘central injection’ (Fig. 4D), which tends to happen when the injection catheter is withdrawn too far after the first wedging of the catheter [7]. To avoid this, slow and gradual withdrawal is critical. For educational purposes, we created instructional videos that are now being both internally distributed and externally distributed to institutions participating in our ongoing multicentre trial (parts of the videos are shown in Videos 1 and 2). Other explanations for the failed markings include severely anthracotic lungs and/or emphysematous lungs, the latter of which do not have sufficient lung parenchyma to hold the dye. Improved marking strategies are needed for these pathological lungs.

Safety is the primary concern in the conduction of lung marking. Indeed, previously reported potentially fatal air embolism [4–6, 14] was our initial motivation for development of the present VAL-MAP technique. Among the 380 markings of the 100 consecutive patients in this study, we experienced 4 pneumothoraces that required no further treatment. This number is much smaller than that reported using a hook-wire method (>30%) [11]. Conversely, to our knowledge, no pneumothoraces were reported in association with previous bronchoscopic marking methods. This might be because of the relatively small number of lung markings (20–30 markings) in previous reports [15–17]. Notably, the first 3 pneumothoraces were experienced in our first 40 patients, suggesting that the high volume of injected air in the initial protocol (30–90 ml/mark) and the use of a stylet in the injection catheter may have influenced the incidence of pneumothorax. Although the technical modifications throughout the case series are relatively minor, we consider they are important to enhance safety and reproducibility of the procedure.

One of the purposes of this study was to identify tumours and resection types that benefit from VAL-MAP. We found that surgeons
Figure 6: Contribution of VAL-MAP to the operation and its relationships with operation type and tumour characteristics. (A) The overall contribution of VAL-MAP to the operation was graded by the surgeons. (B) Relationship between the contribution grade of VAL-MAP and the operation type. Higher grades were assigned to wedge resection and unconventional segmentectomy. (C-F) Relationship between contribution grade of VAL-MAP and tumour characteristics including (C) tumour size, (D) tumour depth from the pleural surface, (E) tumour characteristics on CT images and (F) intraoperative palpability. Although intraoperative palpability showed a significant relationship, small tumours and pure GGO lesions tended to have higher grades. Conv seg: conventional segmentectomy; Unconv seg: unconventional segmentectomy; GGO: GGO: ground-glass opacity.

Table 2: Final pathological results of the resected lesions according to preoperative diagnosis

<table>
<thead>
<tr>
<th>Preoperative diagnosis</th>
<th>Primary lung cancer (n = 90)</th>
<th>Metastatic lung tumour (n = 65)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final diagnosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary lung cancer</td>
<td>(n = 77)</td>
<td>Metastatic tumour (n = 54)</td>
</tr>
<tr>
<td>Adenocarcinoma</td>
<td>(60)</td>
<td>Colorectal cancer (19)</td>
</tr>
<tr>
<td>Adenocarcinoma in situ</td>
<td>(11)</td>
<td>Sarcoma (11)</td>
</tr>
<tr>
<td>Squamous cell carcinoma</td>
<td>(3)</td>
<td>Lung adenocarcinoma (7)</td>
</tr>
<tr>
<td>Large cell neuroendocrine cell tumour</td>
<td>(1)</td>
<td>Uterus (6)</td>
</tr>
<tr>
<td>Atypical adenomatous hyperplasia</td>
<td>(n = 2)</td>
<td>Oesophageal cancer (4)</td>
</tr>
<tr>
<td>Inflammation and others</td>
<td>(n = 13)</td>
<td>Hepatocellular carcinoma (3)</td>
</tr>
<tr>
<td>Focal fibrosis</td>
<td>(5)</td>
<td>Laryngeal cancer (3)</td>
</tr>
<tr>
<td>Follicular lymphocytic bronchiolitis</td>
<td>(3)</td>
<td>Thyroid cancer (1)</td>
</tr>
<tr>
<td>Inflammation, non-specific</td>
<td>(1)</td>
<td>Tracheal cancer (1)</td>
</tr>
<tr>
<td>Mucoid plug</td>
<td>(1)</td>
<td>Inflammation and others (n = 11)</td>
</tr>
<tr>
<td>Hamartoma</td>
<td>(1)</td>
<td>Inflammation, non-specific (4)</td>
</tr>
<tr>
<td>Focal subpleural fibroelastosis</td>
<td>(1)</td>
<td>Intrapulmonary lymph node (4)</td>
</tr>
<tr>
<td>Amyloid nodule</td>
<td>(1)</td>
<td>Organizing pneumonia (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sclerosing haemangioma (1)</td>
</tr>
</tbody>
</table>
tended to evaluate the contribution of VAL-MAP to the operation as Grade A (the same level of operative precision was judged to be impossible without VAL-MAP) for wedge resection and unconventional segmentectomy, smaller tumours of <5 mm, pure GGO lesions and hardly palpable tumours, suggesting that these are the patient populations most likely to benefit from VAL-MAP.

Notably, however, surgeons evaluated the contribution of VAL-MAP as grade A or B (VAL-MAP enabled confident performance of the operation) in 96% of cases. This result suggests that VAL-MAP was beneficial in most patients selected based on the current inclusion criteria of the study (i.e. lesions that were either anticipated to be hardly palpable intraoperatively or for which the resection margin needed to be carefully selected regardless of the palpability of the lesion). Although many target lesions were palpable or even visible during the operation, this does not simply mean that VAL-MAP did not contribute to the operation. It is worth emphasizing that the role of the lung map drawn by VAL-MAP is not only to assist with tumour identification, but also to guide intraoperative navigation, including setting the appropriate resection lines [7].

Based on the results of this study, VAL-MAP has two specific and important roles. First, palpation with the aid of VAL-MAP is likely to increase surgeons’ confidence. The palpability of the target lesions appears to have been enhanced by VAL-MAP because VAL-MAP shows the surgeon exactly where the tumour is located. Palpation with the aid of VAL-MAP is likely to have provided high levels of confidence to surgeons, even for small tumours that would have been otherwise difficult to identify. Thus, high palpability of the tumour with the aid of VAL-MAP does not necessarily mean that VAL-MAP was totally unnecessary.

Another important role is the setting of appropriate, oncologically secure resection lines. For example, some lesions are a mixture of consolidation and GGO, the latter of which is hardly palpable intraoperatively or for which the resection margin was impossible without VAL-MAP) for wedge resection and unconventional segmentectomy, smaller tumours of <5 mm, pure GGO lesions and hardly palpable tumours, suggesting that these are the patient populations most likely to benefit from VAL-MAP.

The present study is limited by its single-centre, single-arm design. To further evaluate the reproducibility, efficacy and safety of VAL-MAP, a multicentre trial has been initiated. Notably, we developed VAL-MAP with the intention to make it a universally available system. VAL-MAP is feasible by using basic fluoroscopy, CT scan, an inexpensive reusable catheter and a 3D imaging system, for which most radiology workstations and even free software are suitable. Therefore, the ongoing multicentre trial is expected to give further information regarding the applicability of VAL-MAP in many centres.

CONCLUSION

We have herein reported the outcomes of 100 consecutive cases of VAL-MAP. The results suggest that VAL-MAP is a well-reproducible technique with satisfactory safety and efficacy in assisting thoracoscopic lung wedge resection and segmentectomy, not only in identification of hardly palpable tumours, but also in determination of the precise resection lines with which to obtain sufficient resection margins.

Conflict of interest: none declared.

REFERENCES


