

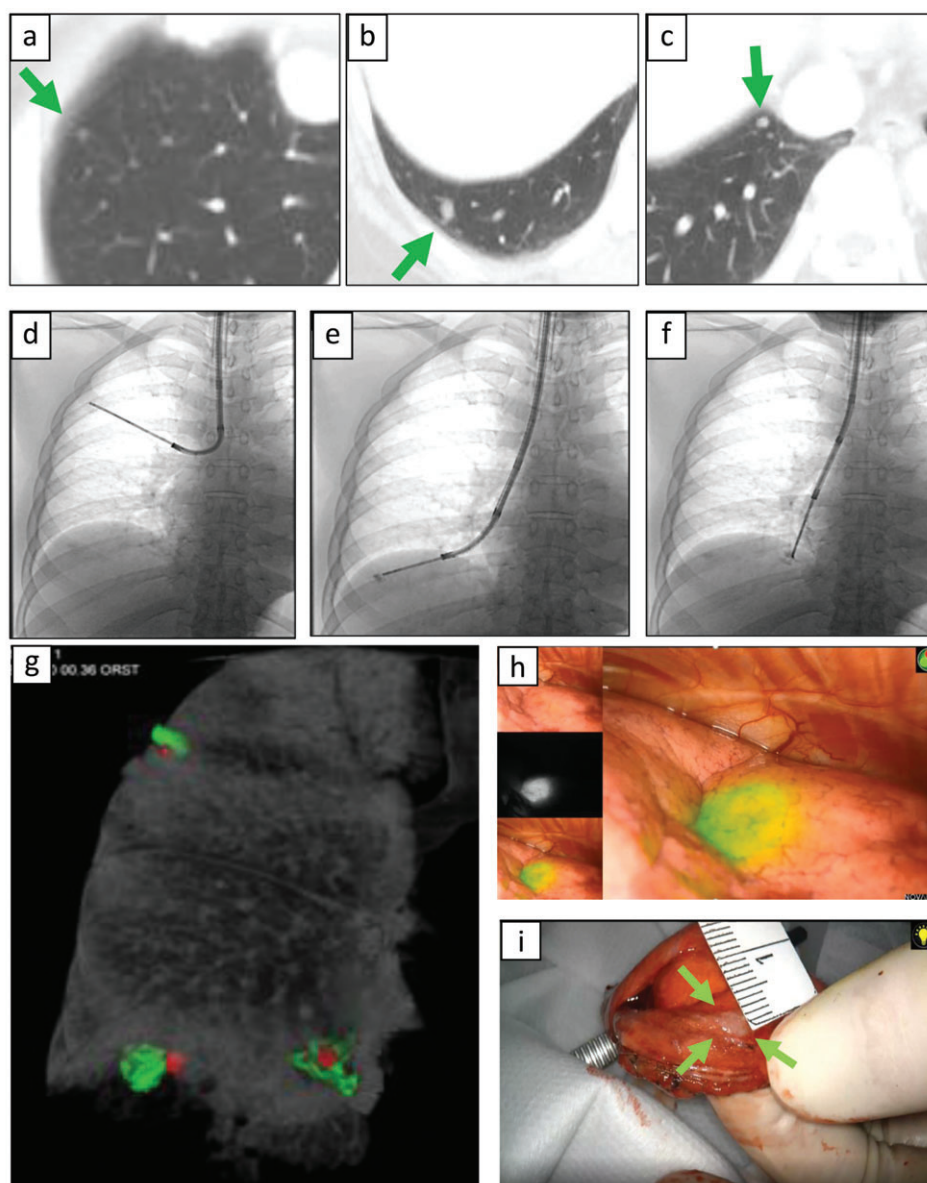
Figure 1 Bronchoscopic video-assisted thoracoscopic surgery (VATS) marker injection under cone beam computed tomography (CBCT)-augmented X-ray fluoroscopy guidance. (a) CBCT is performed to obtain three-dimensional positions of multiple pulmonary nodules. (b) Bronchoscopic fluorescent marking after introduction of general anesthesia in a hybrid operating room. (c) X-ray fluoroscopic image with the transbronchial aspiration cytology needle inserted into the peripheral lung. (d) The X-ray-invisible pulmonary nodule is indicated as "+" on X-ray fluoroscopy (red arrow). (e) VATS marker solution is injected near the target. (f) The VATS marker is placed successfully.

(Fig 1a). Multiple target pulmonary lesions are identified, and the 3D coordinates of each lesion are registered in the system to make them visible on the X-ray fluoroscopic image so that the position of the lesions is consistently displayed on X-ray fluoroscopy. The thin bronchoscope (Olympus BF-P190, Olympus Corporation, Tokyo, Japan) is inserted into the sub-subsegmental bronchus following the target pulmonary nodule. A transbronchial aspiration cytology (TBAC) needle (Fig 1b) is inserted near the target by X-ray fluoroscopic guidance (Fig 1c). The TBAC needle tip is pierced into the lung parenchyma (Fig 1d) and 0.05 mL of a 0.025 mg/mL (100 times diluted from the original concentration) ICG/Iopamidol mixture is injected (Fig 1e) using a method reported previously.¹² The second CBCT is performed to confirm that the VATS marker has been injected in the vicinity of the lesion (Fig 1f). In a

representative case that had three multiple pulmonary nodules in rt. S1, S9, and S7 (Fig 2a–c), VATS markers were injected near the target pulmonary nodules (Fig 2d–f). The right lateral view of the 3DCT image of the right lung shows both target pulmonary nodules (in red) and VATS markers (in green) for reference during surgery (Fig 2g). In the representative case shown in Figure 2, the surgeon's exposure dose was 35.8 mGy as a result of X-ray fluoroscopy-guided bronchoscopic VATS marking. The patient had undergone CBCT scanning twice – before and after VATS marking – and therefore the patient's exposure dose was 245.8 mGy in total.

A bronchial blocker was inserted into the tracheal tube for one-lung ventilation and the patient was placed in the lateral decubitus position for VATS. A near-infrared thoracoscope was used to visualize the near-infrared

Figure 2 An example of the procedure in a patient with three multiple pulmonary nodules in the right lung. (a–c) The patient had three small pulmonary nodules < 3 mm in right S1, S9, and S7. (d–f) Video-assisted thoracoscopic surgery (VATS) markers were injected in each target nodule. (g) Cone beam computed tomography (CBCT) performed a second time to create a three-dimensional CT image of the right lung, including the target tumors (colored in red) and VATS markers (colored in green) for preoperative planning. The surgeon refers to this three-dimensional image and performs VATS while confirming the positional relationship between the VATS marker(s) and pulmonary nodule(s). (h) VATS marker visualized by a near-infrared thoracoscope. (i) Successful resection of the target nodule confirmed macroscopically by cross-section. The pathological diagnosis for all three lesions was consistent with pulmonary metastases from cervical squamous cell carcinoma.



fluorescence of the ICG VATS marker (Fig 2h). The lung, including the target lesion, was excised by VATS. Successful removal was confirmed using both gross observation and rapid pathological diagnosis of the excised lung specimen (Fig 2i).

Discussion

Bronchoscopic marking does not damage visceral pleura and therefore can be used to mark more than one target lesion without causing secondary pneumothorax. However, VATS markers can only be inserted along the anatomical branch of the peripheral bronchus. Factors defining marking accuracy include the positional relationship between

the bronchial branch and the lesion, the accuracy of the bronchoscopic examination technique of the operator, and the accuracy of the image guidance technique. On the basis of CT data, a bronchial route closest to the target lesion was created as a virtual bronchoscopy movie using the dedicated software Synapse Vincent (Fuji Film, Tokyo, Japan).¹² If the target lesion cannot completely be reached by the bronchoscope, a VATS marker is placed at a point as close as possible to the target, and the surgeon is able to localize the target by confirming the relative positional relationship by 3DCT (Fig 2g).

In our technique, we first perform CBCT and register the 3D position of the lesion. Even if the pulmonary nodule itself is not X-ray invisible, the position of the target

