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Image-guided techniques for localization of pulmonary nodules during video-assisted thoracoscopic surgery lobectomy

Danilo Coco[1], Silvana Leanza[1], Sebastiano Angelo Bastone[2], Massimo Giuseppe Viola[1], Vincenzo Ambrogi[2]

[1]Department of General Surgery, Giglio Hospital Foundation,Cefalù (PA), Italy
[2]Ph.D. Program in Applied Medical-Surgical Sciences, Department of Surgical Science, PTV Policlinico Tor Vergata University, Rome, Italy

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Abstract

In the modern era when screening and early surveillance of pulmonary nodules are increasing in importance, the management of the pulmonary nodule represents a different challenge to thoracic surgeons. The difficulty lies in the merging of sound surgical and oncological principles with more minimally invasive and appropriate lung-sparing surgery. The success rates of video-assisted thoracoscopic surgery (VATS) resection for smaller as well as subsolid nodules have increased as a result of radiologists' preoperative localization tools. Fast tracking in thoracic surgery is promoted by proper postoperative care for patients having lobectomies in combination with the VATS technique. Image-guided surgery refers to the application of a real-time correlation of the surgical field to preoperative imaging data collection that reflects the precise placement of a chosen surgical instrument in the adjacent anatomic structures. Among the cross-sectional digital imaging techniques the most widely utilized imaging modalities for image-guided therapy are computed tomography and magnetic resonance imaging. Additionally, surgical navigation devices, tracking tools, integration software, ultrasound, and angiography are used to support these procedures. For people who are thinking about implementing or optimizing a nodule localization program in view of workflow patterns, surgeon preferences, and institutional resources in a certain facility, this review provides in-depth, unbiased evaluation and offers useful information.

Key words: video-assisted thoracoscopic surgery (VATS) lobectomy, video-assisted thoracoscopic surgery, magnetic resonance imaging, computed tomography, pulmonary nodules.

Introduction

With increasing availability and accessibility of advanced radiological investigations, as well as with the advent of lung screening programs, the incidence of newly diagnosed pulmonary nodules is on the rise. A far cry from the days when patients often presented with advanced disease, thoracic surgeons are now receiving more referrals concerning management of incidental findings of pulmonary nodules on various modalities of imaging. Consequently, the demand for diagnostic and therapeutic thoracic procedures to manage these nodules is equally on the rise. The management of pulmonary nodules is very much dependent on the nature of the lesion, although ethnic and regional variations in what the nature of the lesion may entail can be quite variable. Malignant lung lesions have to be staged accordingly and if deemed resectable should be dealt with surgically according to oncological principles. The importance of obtaining good histology is paramount for appropriate management of lung nodules; for suspicious nodules, patients should be offered options of image-guided biopsy or surgical biopsy. However, the prospect of undergoing major surgery with lengthy incisions for the sole purpose of diagnosis often deters patients from surgery. This disregards the fact that surgical biopsy can yield more reliable and representative tissue for diagnosis, and also deprives patients of the possibility of same session completion lobectomy for primary malignant disease. Furthermore, in the current era when identification of the subtype and specific characteristics of adenocarcinomas can have significant prognostic and clinical importance, surgical excisional biopsy may more readily and accurately provide this information. Recent advancements in thoracic anaesthesia, minimally invasive surgical access, intra-operative identification techniques and the increasing evidence for sublobar resections in selected cases have all contributed to a paradigm shift in surgical management of small pulmonary

Address for correspondence: Danilo Coco MD, Department of General Surgery, Giglio Hospital Foundation, Cefalù (PA), Italy,
phone: +393400546021, e-mail: webcostruction@msn.com
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nodules. The emergence of video-assisted thoracoscopic surgery (VATS) more than two decades ago perhaps started this evolution. Compared to thoracotomy, VATS is associated with advantages such as less post-operative pain, shorter hospital stay, less impairment of lung function and better preserved immune function postoperatively. Furthermore, VATS has been shown to result in at least comparable if not better long-term survival than traditional open approaches following major lung resection for early stage non-small cell lung carcinoma. More recently, advances in instrumentation, anaesthesia technique and perioperative imaging have provided new opportunities for further refinement of VATS. The efficiency and accuracy of localization mechanisms in hybrid operating rooms have been the subject of recent research. The different localization methods that are currently available use a variety of guidance systems and localized materials, each having its own advantages and disadvantages. Computed tomography (CT) as well as bronchoscopy are two common imaging instruments used in image-guided localization techniques. Different localized materials, such as dyes, hookwires, microcoils, metallic fiducial markers, contrast media, and radiotracers, may be used with these various techniques. Lung lesions can also be located intraoperatively using near-infrared imaging and ultrasonography. In this review, we investigate the current standard localization techniques as well as novel technologies for VATS lung nodule excision and analyze their advantages and disadvantages [1].

As highlighted by Galloway and Peters, an image-guided procedure comprises five distinct steps, namely, the acquisition of preoperative data, generally in the form of tomographic images; the localization as well as tracking of the position of the surgical tool or therapeutic device; registration of a localized volume with the preoperative data; intuitively displaying the position of the tool with respect to medically significant structures visible in the preoperative data; and taking into account the differences between the preoperative data and the patient during surgery [1, 2]. These procedures must be integrated into a single platform for an image-guided surgical platform to be implemented successfully. Intraoperative imaging, whose broad definition includes the acquisition of electrophysiological data in addition to conventional "imaging" modalities, is used to supplement preoperative images during surgery.

Techniques for localizing pulmonary nodules: CT-guided techniques

1. Methylene blue injection.

2. Technetium 99m (99mTc)–MAA*.

3. Hookwire placement – The oldest and perhaps most popular method of nodule localization is localization with placement of hookwires. The traditional mammographic hookwire system is most frequently employed. In order to prevent discomfort for the patient and complications such as wire dislodgment and pneumothorax, the wire is usually put right before the patient is sent to the operating room. This method has the benefits of an acceptable successful localization rate (93.6–97.6%) and a brief localization time. Other difficulties have included subcutaneous emphysema (5%), lung parenchyma hemorrhage (13.9–36%), and minor pneumothorax (7.5–40%). Rare reports include massive air embolism and a large amount of hemothorax (20–26). Apical localization, diaphragmatic localization, as well as positioning close to the major vessels are a few anatomical locations that would pose limitations for the procedure. For such nodules, surgeons should take alternative localization techniques into consideration.

4. Microcoil placement – In contrast to localization using a hookwire, CT-guided localization with metallic microcoils and fiducial markers leaves no wire protruding extracorporeally, which may minimize patient discomfort while they wait to enter the operation theater. The sizes of gold fiducial markers are 1.2 mm to 3 mm, whereas the dimensions of platinum microcoils range from 15 to 80 mm in length and 4 to 5 mm in diameter. The procedures are the same as for hookwire localization. A coaxial needle is used to deploy the microcoil into the lung parenchyma distal to the needle. This localization method requires fluoroscopic supervision throughout the VATS procedure, which increases radiation exposure for surgeons compared to direct visualization of the localized site utilizing a hookwire and dye localization.

5. Fiducial marker placement.

6. Radiotracer-guided localization – For the purpose of localizing lung nodules using CT-guided needle injection, radiotracer-guided localization employs gamma-emitting radioisotopes (technetium 99, Tc99m) bound to large albumin molecules. Usually, post-procedure scintigraphy is performed to verify where the radiotracer was located. Intraoperatively, gamma-ray emissions can be picked up by a probe that converts them into digital counts and auditory signals. The lesion site can be determined by locating the region with the strongest signal. Chella and associates published the first report on this technique in 2000 [3]. Thirty-nine patients were investigated, and the outcomes showed a 100% success rate for resection. For up to 24 h, the radiotracer can remain stable.

7. Dual localization – The majority of institutions might only utilize one technique for localization of lung nodules. For needlescopic resection of minor lung nodules, Kang and colleagues described their experience utilizing dual localization with a hookwire and radiotracer/lipiodol [4]. Dual localization is applied to increase the success rate of resections and prevent failure due to hookwire dislodgement.

8. CT-guided localization in a hybrid operation room – In the radiology department, common localization techniques are usually performed prior to operations. Patients complain about the difficulty of having to undergo an invasive operation under only local anesthetic or without any anaesthesia at all. The operation's subsequent commencement time is frequently unpredictably scheduled. The duration between localization and surgery may lengthen as a result of patient transportation, and complications including pneumothorax and hemothorax may become more frequent. In a hybrid operating room, preoperative localization of lung nodules

was first documented in 2013 [5]. In a hybrid operating room, Zhao *et al.* presented their image-guided single-port VATS experience in 2016 [6].

9. Bronchoscopy-guided techniques includes electromagnetic navigation bronchoscopy. Other techniques include intraoperative ultrasonography and intraoperative near-infrared imaging.

Common components of image guidance platforms

Medical imaging modalities – Medical images are typically acquired for diagnostic purposes and often their value is minimal during the treatment of the condition should a surgical intervention be required. The role of high-quality tomographic scans such as computed tomography (CT) or magnetic resonance imaging (MRI) is twofold: to assist in the planning of the procedure and to provide the larger anatomical context during the procedure [1].

1. Computed tomography – Based on the density of the tissues that the X-rays meet, CT provides 3D images of the internal anatomy [7]. Latest generation CT scanners can acquire high-resolution 3D volumetric images of the abdomen and thoracic cavity in several seconds, and also allow for "cine" imaging and dynamic visualization of the beating heart. However, given the rather similar density, most soft tissues cannot easily be differentiated and so radiopaque contrast agents are typically used to enhance these structures [1].

2. Magnetic resonance imaging – MRI provides maps of the anatomy by imaging the response of protons present in different types of tissues to magnetic excitations of variable duration across different spatial directions [8]. Furthermore, given that the water molecules in different tissues are exposed to a slightly different magnetic environment, the MRI soft-tissue imaging capabilities are superior to those of traditional CT without the use of contrast enhancement. Given their high resolution, soft-tissue imaging capabilities and large field of view, these tomographic image datasets are pre-processed to extract the patient-specific anatomy in the region of interest (i.e., the surgical target to be treated), to determine the optimal path to reach that target, and to provide the "bigger picture" of the anatomy to interpret the intraoperative images [1].

X-ray imaging – Because of its ability to show surgical instruments such as guidewires, catheters, and other implantable devices, e.g. stents and valves, X-ray fluoroscopy has been employed in percutaneous catheter-navigation procedures almost for 20 years. However, it has inherent limitations when it comes to the visualization of soft tissue [1].

Ultrasound – Ultrasound makes images of the anatomy by mapping the amplitude and arrival time of the reflected sound waves to image intensity and axial distance, respectively. Although used mainly for diagnostic purposes, ultrasound has been adopted more recently for intraoperative monitoring and guidance, because of its non-invasive, versatile, portable, low-cost, and real-time capabilities [1].

Nuclear imaging – A somewhat different class of medical images is represented by nuclear imaging modalities, such as positron emission tomography and single photon emission CT. Both of these modalities are typically used to image metabolic processes in regions of interest, and for more intuitive interpretation they are typically registered (or intrinsically coregistered by means of dual imaging systems such as positron emission tomography-CT or positron emission tomography-MRI) to morphological images such as CT and MRI [1].

Various techniques for pulmonary nodules' localization have been described, including finger palpation, intra-operative ultrasound, CT-guided insertion of localizer (hookwire, microcoils, methylene blue, lipiodol, or radionuclides) with success rates as high as 100%. The hookwire technique showed a varied success rate ranging from 58% to 97.6% in various series with a relatively high failure rate due to wire dislodgement reaching up to 47%. Minor complications such as asymptomatic pneumothorax or parenchymal hemorrhages are commonly associated, while serious events are unfrequently reported [9].

The oldest and most popular method of nodule localization is localization with installation of a hookwire. The most used system is the traditional mammographic hookwire system. The wire is usually placed just before the patient is sent to the operating room in order to avoid the patient's discomfort and complications, such as wire dislodgement and pneumothorax. Advantages of this method include an acceptable successful localization rate (93.6–97.6%) and a short localization duration. Additionally, without invasive fluoroscopy or radiation exposure during surgery, surgeons can easily visually recognize the specific site. The main disadvantage of this technique is hookwire dislodgement from a perinodular position, which could result in the loss of any intraoperative reference to the tumor location. Other complications have included minor pneumothorax (7.5–40%), lung parenchyma hemorrhage (13.9–36%), and subcutaneous emphysema (5%). Rarely reported events include significant hemothorax and significant air embolism. Moreover, there are some anatomical locations that would be a limitation for the procedure, including apical localization, diaphragmatic localization, and location near the great vessels. The preoperative assessment of patients considered for VATS lobectomy is routine, and is tailored to the indications for surgery. Preoperative imaging studies, including the use of CT and positron emission tomography (PET), are helpful to confirm the planned extent of resection and the suitability of a VATS approach [10].

Existing techniques that can be employed in the localization process include dye localization, the implantation of microcoils and fiducial markers, the injection of contrast material, radiotracer-guided localization, dual localization, and CT-guided localization in a hybrid operating room [10]. However, certain pulmonary nodules cannot be accurately detected because of the technique's limitations. VATS has been used widely for pulmonary nodules as a less invasive technique for diagnosis and therapy. Currently, a number of preoperative localization techniques have been published. Each localization technique, however, has advantages and disadvantages [11]. Despite the fact that specific radioactive tracers are more appropriate for the preoperative localization of superficial pulmonary nodules, specialized equipment, such as CT-fluorescence, is essential, and radiologists and surgeons may be exposed to radiation. Furthermore, the identification of deep pulmonary nodules is unclear, which restricts its clinical application. It is difficult to identify pulmonary nodules that are deep within the lung or that are blocked by the ribs and scapula, which can result in pneumothorax, hemorrhage, inflammation, and death from gas embolisms [12]. In 39 patients receiving preoperative localization, 5.2% of the patients had mild parenchymal hemorrhage, while 12.8% had a small pneumothorax, according to Huang *et al.* [13]. According to other research, pneumothorax occurs 7.5–40% of the time and mild parenchymal hemorrhage occurs 13.9–36% of the time.

The incidence of lobectomy complications varies according to the etiology, patient diagnosis, and resected lobe. Most complications following lobectomy happen in the early few days postoperatively (within 48 h). The major postoperative lobectomy complications are pleural empyema (1% to 3%), prolonged air leak (15% to 18%), subcutaneous emphysema, pneumonia/mucus plugging/atelectasis (6%), right middle lobe torsion (0.09 to 0.4%), persistent space (9.5%) atrial fibrillation (33%), chylothorax (0.7% to 2%), hemorrhage (2.9%), wound infection, phrenic nerve injury and recurrent laryngeal nerve injury, tumor embolization (less than 1%) and also very rarely bronchopleural fistula [14–16].

Risk-stratifying potential surgical candidates will be made simpler with information about the patients' physiological capacity to withstand lobectomy. Overall, the findings of this review indicate that VATS lobectomy is associated with decreased complication rates and better quality of life. Resection of lung cancer has moderate survival benefits compared to open lobectomy.

Disclosure

The authors report no conflict of interest.

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