



# Future strategy of surgical simulations in video-assisted thoracic surgery

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**Abstract:** Video-assisted thoracic surgery (VATS) has come to be the primary operative procedure in thoracic surgery as the method of choice for the treatment of a variety of lung diseases. As VATS has acquired widespread favor with the development of techniques and instrumentation, indications for VATS have further expanded. However, many facilities have yet to adopt this approach for anatomical lung resections. In terms of building VATS educational platforms, standardization of the training programs that is based on risk-free based teaching strategies is essential. Today, surgical simulations have a pivotal role in increased patient safety and reduction of the risk of surgical errors as a desired part of the training model for not only residents but also consultants who need to acquire new techniques. There are two different categories of surgeons requiring skills of thoracoscopic procedure who must be considered: (I) surgeons who had experienced a period of transition from open thoracotomy to VATS, and (II) the new generation of surgeons being trained after the exponential development of VATS. The evolution of simulation programs such as cadavers, live animals, black-boxes, and three-dimensional virtual reality simulators can compensate for their limited-operating room-based training opportunities and aid them in the acquisition of necessary skills in a brief time. We will discuss the types of simulators focusing on the desired programs to allow the new generation of surgeons to master VATS lobectomy with a shorted learning curve and a future strategy of surgical simulations in VATS.

**Keywords:** Simulation; video-assisted thoracic surgery (VATS); training; virtual reality; three dimensional (3D)

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## Introduction

Video-assisted thoracic surgery (VATS) has come to be the primary operative procedure in thoracic surgery and is gradually substituting open thoracotomy as the method of choice for the treatment of lung cancer, metastatic lung tumors, mediastinum tumors, and benign lung diseases (1-7). Established evidence of several advantages in VATS presents faster operative recovery, fewer complications, and quicker return to daily life preserving quality of life without interfering with oncological and survival outcomes when compared to thoracotomy (8-13). As VATS has acquired widespread favor with the rapid development of techniques and instrumentation, indications for VATS have further expanded. However, many medical facilities have yet to

adopt the thoracoscopic approach for anatomical lung resections because learning and mastering this technique is a real challenge due to the technical demand of being get used to a two-dimensional surgical field being viewed on monitors and the use of long specialized devices. Moreover, the new variant, uniportal VATS, also emerges as a one-step-forward approach toward the same minimally invasive direction (14-16).

In terms of building VATS educational platforms today, standardization of the training programs that is based on risk-free based teaching strategy is essential and would involve structural and functional alterations. Unstructured traditional apprenticeship of unlimited duration used to be the most common trend available for surgical residents wanting to acquire major surgical skills and dexterity with

supervision tailored to their needs. Although this confers experience in dealing with a wide range of operative approaches and complications from basic skills such as knot-tying or suturing to the execution of fearsome steps such as controlling bleeding by unexpected vessel injury on trainees over many years, these types of training should be usually learnt only inside the operating room. Duty-hour restrictions and decreased clinical exposure of trainees in many countries and recent radical changes in the prevalence of minimally invasive surgery produce new challenges and might require additional resources without causing a deterioration of required surgical residency's experience (17-19). Moreover, an increased chance of legal disputes and strong ethical imperatives also attribute reduced surgical training opportunities on patients to young surgeons (20,21). More efficient educational curriculums than the traditional apprenticeship design is therefore warranted for novice surgeons to improve their cognitive and procedural skills in a stepwise manner. Today, surgical simulations have a pivotal role in increased patient safety and reduction of the risk of surgical errors as a desired part of the training model for not only residents or fellow surgeons but also experienced consultant who need to acquire new techniques (22-30).

When thoracic surgeons work with simulators that are used for training individuals by imitating situations they encounter in real life, there are generally two different categories of surgeons requiring skills of thoracoscopic procedure (or already reaching a higher proficiency level to accomplish VATS) who must be considered in the community; (I) surgeons who had experienced a period of transition from open thoracotomy to VATS, and (II) surgeons being trained after the exponential development of VATS. Surgical simulations work differently between these two cohorts according to their surgical skills and experience. Majority of the current leaders and pioneers with VATS expertise are the former and had seen the whole evolutionary process from thoracotomy to VATS. They were usually self-taught and gained experience and confidence over the years. On the other hand, most of current young surgeons are the latter and this new generation have usually initiated their surgical specialty trained mostly in thoracoscopic or laparoscopic procedures under guided supervision whereas they have not so many experiences of open chest surgery. The evolution of advanced technologies including a variety of simulation programs such as human cadavers, live animals, black-boxes, and three-dimensional (3D) virtual reality simulators can compensate their limited-operating

room-based training opportunities and inexperience that may cause intraoperative complications and aid them in the acquisition of necessary thoracoscopic skills in a brief time (26-29,31,32).

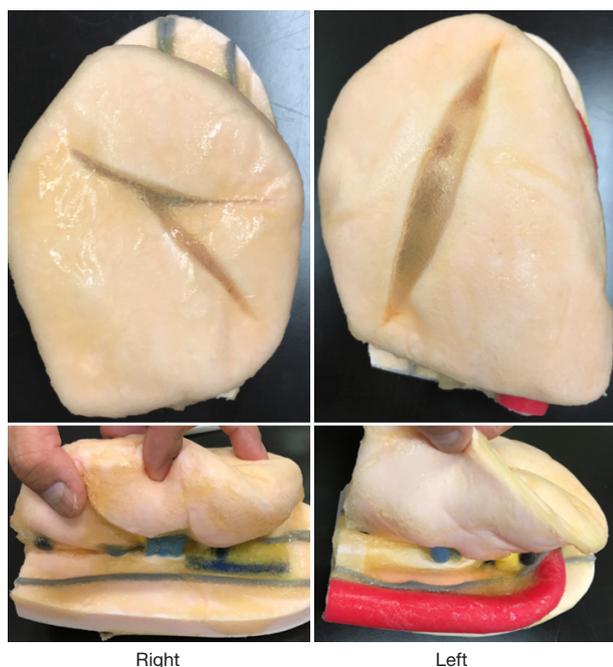
Here, we will discuss the types of simulators currently available focusing on the desired programs to allow the coming generation to master VATS lobectomy with a shortened learning curve and future strategy of surgical simulations in VATS.

### Advantages of simulation-based training

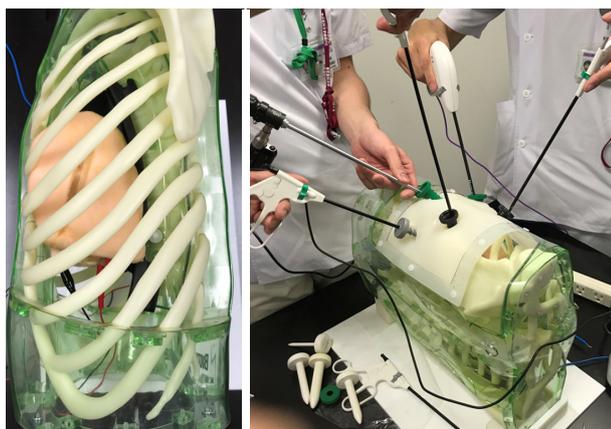
Not only surgeons but also other professions such as pilots and soldiers practice and learn in real-time interactive simulations. Pilots log hundreds of hours learning to fly new planes in simulators before they ever enter the real plane, so that they already know how to operate it in a wide range of conditions on taking the real plain up. Likewise, surgical simulation is a very important aspect of training in learning counterintuitive techniques and promote repetitive practices in a setting that forgives failure before doing operation for real patients. A key question here is whether thoracoscopic skills learnt on simulators translate to improve actual performance on patients and make the learning curve of VATS lobectomies shorter.

Supportive evidences from many studies suggested that a variety of simulation methods and dedicated dry and wet labs help to enhance psychomotor and judgement skills, hand-eye coordination, and ambidextrous surgery (33). An *ex vivo* model such as porcine heart-lung block filled with ketchup offers a low cost and high-fidelity simulation if the tissue box is prepared with bench-top models (27,28). The use of live animals such as swine proved to improve greatly the learning of basic and advanced surgical procedures (30). Live animals share many of the same features as human surgeries and provide trainees with a wide range of VATS procedural elements (30,34). Simulated environment provided by live animals is superior to other kinds of simulators in the context of the accuracy and reality. However, they are limited by the cost, single use of animal tissue, and some ethical concerns.

Having less anatomical accuracy than live animals and cadavers, another low-fidelity model such as black-box simulator allow quick and repetitive simulation of a specific skills enable to mastery of individual techniques (28,29,35). Modern 3D virtual reality simulators also offer high-fidelity and create realistic environment that capture minute anatomical details with high accuracy (31). Virtual



**Figure 1** Biotexture wet model of the bilateral lungs (Fasotec, Chiba).



**Figure 2** The Biotexture lung is installed inside the Biotexture thoracic cavity simulator to offer the realistic environment for surgical training.

simulator-based training developed for laparoscopy showed that the performance level of novice surgeons was increased to that of intermediately experienced laparoscopist in a randomized controlled trial (36). Jensen *et al.* reported that when making comparisons between virtual reality simulation and black-boxes in overall skill acquisition after

video-assisted procedure completion, surprisingly the black-box group was significantly faster than the virtual-reality group (29). The authors also demonstrated a commercially available virtual reality simulator for practicing VATS lobectomy showing good content validity in another study (31). The amount of these dry lab exercises is unlimited, and the cost is small once the systems are installed. Refined virtual reality simulators enable technical performance to be recorded, measured, and used for feedback.

Recently, 3D-printed Biotexture wet lung models for surgical training were introduced as a valid alternative to the use of animals (Fasotec, Chiba; *Figure 1*). Texture of human tissues are reproduced to enable surgical trainee enhance practicing. Being installed inside the thoracic cavity simulator, the wet model offers the realistic environment for VATS training (*Figure 2*). Such a new advanced surgical simulator provides appropriate levels of challenge and instruction.

The strength of surgical simulations in VATS as an adjunct rather than an alternative to clinical experience (37,38). The technological evolution has paralleled the evolution of surgical simulators, which offers obvious training and educational benefits.

### **VATS simulation programs of the future for the new generation**

A key challenge is to lay the formal and structured VATS training base incorporating available surgical simulations to safe VATS lobectomy completion for the next generation of thoracic surgeons. As each operation has a sequence of steps of increasing difficulty, they should focus on completing each thoracoscopic procedural element in a step wise fashion by practicing basic parts to difficult parts no matter what the level of experience of the trainees. Even though they have a wider range of surgical techniques to learn and inevitably have less experience in certain techniques including open chest procedures than the forebears had, standardized VATS lobectomy with preserved quality has to be completed without compromising patient safety, acceptable operative time, and minimum blood loss through an appropriate supervision. Surgical simulations are supposed to contribute to the shorter learning curve of VATS lobectomies and provide an adequate return on the investment of both finances and time. Here are a set of recommendations for a surgeon embarking on structured VATS lobectomy program with taking advantage of surgical

simulations even though many different better approaches to VATS lobectomy have been existed:

- (I) Dry lab exercises (virtual reality simulators and black boxes) and *ex vivo* model (porcine heart-lung blocks);
- (II) 3D printed Biotexture model;
- (III) Wet lab exercise (live animals) and VATS minor procedures;
- (IV) The introduction of VATS lobectomy in a stepwise fashion and 3D image surgical simulation.

Once trainees begin with a new step, that has to be performed repeatedly within a short period of time. Otherwise it will take a long time to complete a learning curve. On every step, surgeons have opportunities to review the video with their performance over and over, preferably along with senior surgeons in order to critically analyze it.

As an initial step, students and starters receive training on thoracoscopic box and virtual reality simulators as well as using the porcine blocks. Black-boxes require them to operate within the closed environment containing scopes that allow them to check their own movements (29,35). Virtual reality simulators also offer real-time haptic feedback to trainees about their performance within the simulation (31). The porcine block combined with bench-top synthetic model is a highly useful and inexpensive simulator with high fidelity (27,39). The efficacy of these dry lab exercises and *ex vivo* training in improving surgical skills in a cost-effective manner has been validated by multiple studies (40-42).

Once trainees attain significant proficiency in basic simulated thoracoscopic tasks over a relatively short period, the next step is to exploit high fidelity models such as 3D-printed wet models, live animals, and cadavers to make their acquired skills more advanced and improved. Although some ethical concerns have arisen over the use of live animals and cadavers as simulators depending on countries, VATS courses with wet labs can have a different educational focus according to the experience of the group. In the course of acquiring advanced skills using the simulation models, surgeons have to accumulate an exhaustive knowledge of their anatomical characteristics, which can foster the crucial point of views for grasping detailed surgical anatomies and 3D relationships of hilar structures on real patients. In addition to the wet lab exercises, performing a lot of minor VATS procedures such as pneumothorax operations, pleural biopsies, division of pleural adhesions, and wedge resection can be better options at this level while considering the differences in

anatomy between animal's and human's. At the same time, trainees at this level need to learn the principle of VATS scopist until they can show reproducible operative fields whenever operators ask for.

After the completion of "warm-up" period of the trainees, the introduction of VATS lobectomy procedures can be provided in a stepwise fashion; port replacements first, then dividing the pulmonary ligament, dissection of pulmonary vein, artery, and bronchus, and lymphadenectomy. Even if surgeons are get used to perform thoracoscopic procedures, surgical simulations still matter. 3D imaging techniques has come a long way since its introduction in the field of thoracic surgery. Many studies reported that surgical simulations for the assessment of chest anatomy using as variety of 3D imaging modalities are highly beneficial for the safe and efficient performance of VATS anatomical resection and for further understanding of the surgical anatomy (43-46). Moreover, preoperative understanding the anatomy of the lung and many anatomical variations beforehand by 3D images also make the learning curve shorter. Regardless of the experience of VATS lobectomies, it is crucial for surgeons to perform surgical simulation for each case.

Surgical simulators of the future are considered to move forward to "patient-specific simulations" that is similar to the underlying concept of precision medicine, in which health care is individually tailored on the basis of a person's genetics, lifestyle, and environment. If digital imaging and communications in medicine (DICOM) data that have high resolution computed tomography of a patient are transferred to virtual reality simulation modalities, then a surgeon can practice VATS anatomical resection repeatedly with reusable patient specific virtual reality lung structures. These types of simulators have already been used in other areas of operations (47-49). Patient-specific lung virtual reality models allow a surgeon to preoperatively practice VATS procedures in a virtual environment and can be one the most promising simulation tools in risk-free based teaching platforms.

## Conclusions

As long as the developments continue to be made in the field of surgical training and education for the coming generation of thoracic surgeons, further development of surgical simulation can continue. Although much has been described about the need of a balanced training in general, cardiac, open thoracotomy, laparoscopic surgery, and

VATS, limitations in work hours and increased concerns for patient safety resulted in decreased clinical exposure and increased off-patient practice in surgical training. Simulation based practice might be able to accelerate procedural progress relating VATS with the learning curve. There are possible concerns that surgeons could lose the bigger picture, misunderstand a complex reality as the oversimplification, and become fixated on events in the narrow operating field to the ignorance of wider concerns. We need to consider how structured and formal VATS training platform incorporating with surgical simulations should be built for the new generations of surgeons and hope that not only multiportal VATS but also uniportal VATS and robot-assisted surgery will be widely and safely distributed into many medical facilities in the future for saving a large number of patient's lives.

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