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Video-Assisted Thoracoscopic Surgery: A Model Global Learning Framework

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Background: Video-assisted thoracoscopic surgery (VATS) is a minimally invasive approach for the treatment of lung cancer and other lung diseases. Although VATS is associated with better outcomes compared with open surgery, the extensive skill and knowledge requirements may prolong the learning curve and limit adoption.

Objective: The objective of this work was to develop a training model that optimizes skill acquisition while shortening the learning curve of novel surgical procedures, with a specific application to VATS training.

Methods: A seven-step training method was developed. A board of thoracic surgeons was then surveyed by a Delphi process to validate the method within the context of a VATS curriculum.

Results: The Delphi consensus established the following: *1*) there is a need for a standardized, stepwise training approach for VATS lobectomy; *2*) the seven-step method can be locally adapted and applied to VATS training and maximizes the chances of success for both the individual and the institution; *3*) the framework is universal and can be adapted for other novel devices and procedures; *4*) the model covers the elements needed to make it safe and provide good outcomes for patients; and *5*) the training method has the necessary requirements to be established as standard practice.

Conclusion: This paper presents the educational components that are needed to form a standardized curriculum for VATS, as agreed by a panel of established thoracic surgeons through a Delphi process. The training framework considers both individual and team-specific skills along the learning curve to optimize outcomes for patients.

Keywords:
Delphi technique; minimally invasive surgical procedures; professional competence; video-assisted thoracoscopic surgery; training programs

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The new generation of thoracic surgeons is now being introduced to video-assisted thoracoscopic surgery (VATS) procedures as the standard approach to the thoracic cavity instead of open thoracotomy. Both minor procedures (i.e., wedge resections, pleural biopsies, or operations for pneumothorax) and major resections performed by VATS are associated with fewer postoperative complications, less pain, better postoperative quality of life, and equivalent oncologic outcomes compared with open surgery (1, 2).

Despite these advantages, many thoracic procedures worldwide are still performed by open approaches, with rates varying by country and institution (3). Both small-volume open surgery centers and established cardiothoracic surgeons in mixed-practice settings may feel challenged by the pressure to acquire VATS skills despite little support. The learning curve of performing a familiar procedure with an unfamiliar technique remains a significant barrier (4). Thus, there is a need to train surgical teams on the skills required to perform VATS safely with the shortest learning curve and the best outcomes for patients and healthcare professionals.

This article proposes a seven-step learning framework that can be locally adapted to reproducibly, effectively, and efficiently train surgeons and surgical teams on new procedures and medical devices. A Delphi consensus was used to validate the model and apply it to VATS training.

METHODS

This study describes the survey-based development of a training model. It is not a clinical study, no patients were enrolled, and no trainees were involved; therefore, institutional review board approval is not applicable.

Development of the Generic Framework

A generic seven-step training framework was first developed by the authors based on their collective expertise and a nonsystematic review of the literature from diverse training fields. The purpose of the proposed model was to provide a framework that can be locally adapted and applied to the training of proficient surgeons and surgical teams on the acquisition of a new surgical technique. The seven steps described below are the outcome of that process.

The Delphi Method

The generic seven-step model was presented to a group of established VATS surgeons for validation within the context of a VATS training curriculum to explore areas of consensus within each step. The surgeons were from Europe (Denmark, Spain, Germany, Italy, and France) and the United Kingdom and were selected based on their expertise and experience both as trainees and trainers in VATS. Each surgeon had performed over 500 minor and major VATS procedures annually with over 5 years of experience in training and mentoring trainees within their own departments as well as serving

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as mentors for clinical immersion training for other units.

The Delphi process consisted of two rounds of questions in which surgeons were asked to define the standards for each step as applied to VATS training. The first round occurred during a face-to-face meeting (November 2018) with answers documented anonymously. Each surgeon was subsequently interviewed individually by phone to avoid peer influence, with answers again documented anonymously. Finally, a second face-to-face meeting (October 2019) occurred to stimulate discussion and refine the model with respect to both the overall structure and the specific elements required for VATS training. Each surgeon was asked the same eight questions about the criteria for each step (Table 1, top row), such as how many procedures should be undertaken before moving onto the next step, the case volume required to become proficient, and the role of new training technologies such as simulation and wet and dry laboratory models. As experienced trainers and mentors, the Delphi participants also shared insights into the requirements and success factors for individual training, team clinical immersions, and advanced procedure training, which contributed to the framework model in addition to the eight prespecified questions.

RESULTS

The seven steps of the generic framework are shown in Figure 1. The model is divided into two halves. Steps 1 through 4 describe the training of individuals, whereas Steps 5 through 7 describe training of the theater team. Team training can begin when the individual surgeon has completed simulation training, has gained experience with basic VATS procedures, has assisted with advanced VATS procedures, and has had case-based discussions with a mentor.

Each framework step as well as the Delphi consensus on the specific parameters applicable to a VATS curriculum will be described in turn below. Overall, there was 100% agreement on the seven-step framework shown in Figure 1 following the two rounds of Delphi discussion. The model steps were also considered appropriate to deliver a safe and integrated VATS training curriculum. There was 80% agreement between the seven surgeons on the eight Delphi method questions shown in Table 1.

The Delphi participants also evaluated the progression between certain steps to ensure proficiency had been attained, as will be described below. Two surgeons was decided as the ideal number to be trained (Table 1, Question 1). It was felt the training process would require approximately 12 months to fully train an open surgeon and team to comfortably perform VATS lobectomy independently (Table 1, Question 2). Another essential consensus of the Delphi process was the absolute need for a VATS surgeon to be able to safely perform an open thoracotomy in cases of uncontrolled bleeding. Recognizing when complications arise and quickly deciding when to convert is critical to outcomes and was considered by the panel to be an important part of early training.

Step 1: Self Study

The Delphi participants identified self-study and self-assessment as an essential first step in the learning framework. Although the panel agreed it would be difficult to standardize e-learning (Table 1, Question 3), it was agreed that e-learning is particularly suited to assessments and

Table 1. VATS lobectomy Delphi survey questions and results

	Question 1: Ideal Number of Surgeons to Be Trained	Question 2: How Long Would it Take to Train an Open Thoracic Surgeon to VATS?	Question 3: Development of E-learning across EMEA for VATS Procedures	Question 4: Number of Major Lung Resections that Should Be Done by Unit Already	Question 5: Number of Minor VATS Procedures to Be Done before Embarking on Major VATS	Question 6: The Number and Requirement of Simulation Animals/Cadavers in Training	Question 7: What Are the Current Challenges with Simulation Training?	Question 8: The Value of Nonintubated VATS as a Procedure?
Surgeon 1	2 Surgeons	Full-time 12 mo	Difficult to standardize	52/year	52/year	Animal and cadaver essential; open conversion essential	Simulation access	There is a place for it on selected cases
Surgeon 2	2 Surgeons	Full-time 12 mo	Difficult to standardize	50/year (difficult in small units)	100 minor VATS before VATS lobectomy	50 on simulator, pigs poor anatomy resemblance to human; cadaver ethical issues	Objective assessment via simulation	Not necessary
Surgeon 3	2 Surgeons	Full-time 4–5 mo	Difficult to standardize	30/year	50 minor VATS	10 simulations before; pig training essential	Simulation not possible for 5 lobes and lymph node dissection	Not necessary

(continued on following page)

Table 1. *Continued.*

	Question 1: Ideal Number of Surgeons to Be Trained	Question 2: How Long Would it Take to Train an Open Thoracic Surgeon to VATS?	Question 3: Development of E-learning across EMEA for VATS Procedures	Question 4: Number of Major Lung Resections that Should Be Done by Unit Already	Question 5: Number of Minor VATS Procedures to Be Done before Embarking on Major VATS	Question 6: The Number and Requirement of Simulation Animals/ Cadavers in Training	Question 7: What Are the Current Challenges with Simulation Training?	Question 8: The Value of Nonintubated VATS as a Procedure?
Surgeon 4	2 Surgeons	Full-time 12 mo	Difficult to standardize	50/year (difficult in small units)	50 minor VATS before vessel dissection	50 simulations, if no experience then animal lab and cadaver use needed	Simulation not possible for 5 lobes and lymph node dissection	Concerns with bleeding; dangers in wrong hands
Surgeon 5	2 Surgeons	Full-time 12 mo	Difficult to standardize	150/year (difficult in small units)	52/year VATS lobectomy; 100–150/year minor VATS	100 simulated minor VATS	Simulation access	Concerns with bleeding; dangers in wrong hands
Surgeon 6	2 Surgeons	Full-time 12 mo	Difficult to standardize	150/year	Depends on individual and team workstreams	Simulation and/or animal and/ or cadaver	Simulation essential to training	Not safe
Surgeon 7	2 Surgeons	Full-time 12–24 mo	Difficult to standardize	150/year	500/year	150 minor VATS, and/or animal, and/ or cadaver	Simulation access	Not safe

Definition of abbreviations: EMEA = Europe, Middle East, Africa; VATS = video-assisted thoracoscopic surgery.

<table>
<tr><th>Step</th><th colspan="2">TRAINING MODEL</th></tr>
<tr><td>1</td><td>Self Study
Anatomy, disease state, evidence base, classical reading, e-learning, e-books, etc.</td><td rowspan="7">Audit Review and Improve Outcomes
Integrated into every step of the program.</td></tr>
<tr><td>2</td><td>Theatre Exposure, Masterclass, and Clinical Immersions</td></tr>
<tr><td>3</td><td>Hands-on Training (Simulation)
e.g., stapling and energy devices, VATS techniques, robotics</td></tr>
<tr><td>4</td><td>Hands-on Training (Animal Laboratories)
e.g., product-specific training</td></tr>
<tr><td>5</td><td>Hands-on Primary Training for the Entire Team
Surgeon, anesthesiologist, surgical nursing staff
On-site or at training centers</td></tr>
<tr><td>6</td><td>Non-Technical Skills Training
Patient and healthcare provider safety, device safety</td></tr>
<tr><td>7</td><td>Hands-on Advanced Training and Practice
e.g., VATS advanced resections, advanced bronchoscopy, robotics</td></tr>
</table>

Figure 1. Training framework and the skill development pathway in thoracic surgery. Steps 1–4 address the training of the individual with a focus on procedure and device skills. Steps 5–7 address the training of the team with a focus on technique refinement and patient outcomes. Integrated into every step of the program is an audit review to assess progress and improve outcomes. VATS = video-assisted thoracoscopic surgery.

self-examination, as tests can easily be integrated into electronic platforms and allow trainees to assess their progress, review their performance against their peers, and obtain feedback before progressing to the next step of the training. The Delphi participants also agreed that Step 1 allows for flexibility and can be incorporated around residents' clinical commitments and at a time when trainees are receptive to training, such as in the fallow time between operations.

Step 2: Theater Exposure, Masterclass, and Clinical Immersions

The Delphi group discussed the number of prior major lung resections that the unit should have already completed before embarking on VATS training (Table 1, Question 4). Responses ranged from 30/year to 150/year. The panel also addressed the number of minor VATS resections to be done by the surgical unit before embarking on major VATS training (Table 1, Question 5), most commonly 50–100 minor VATS procedures.

Step 3: Hands-On Training—Simulation

The Delphi participants agreed that simulation is a pivotal tool that allows surgeons to train in a fully immersive environment without risk of adverse outcomes for patients. As experienced trainers, the Delphi participants also emphasized that simulation provides the trainee with experience in making clinically important decisions in a safe environment, such as conversion to open surgery.

The Delphi consensus was that 50 simulated VATS lobectomy cases should be required before moving on to the next stage (Table 1, Question 6). Simulation availability was identified as the most common challenge to simulation training by the Delphi participants (Table 1, Question 7). It was also agreed that simulation on its own will not guarantee competent surgeons but that it is a crucial component of a structured curriculum. Although the seven steps are primarily conducted sequentially, simulation would be ideally combined with mentor-based live case observation in Step 2, progressing to assisting and then performing minor VATS procedures (e.g., wedge resections and pleural biopsies) to maximize acquisition of the surgeon's skills in parallel.

Step 4: Hands-On Training—Animal Laboratories

Training on live animals offers highly realistic conditions, with demonstrated teaching benefits for both basic and complex surgical procedures. The value of training on animal and cadaveric models was discussed during the Delphi process (Table 1, Question 6). There were discrepant opinions on whether animals and cadavers should be used in training; some felt this was an essential component of effective training, whereas others consider animals and cadaver models unrepresentative of human anatomy and tissue quality and potentially unethical. The only consensus on the value of animal models was to provide a realistic model for controlling bleeding. Bleeding is uncommon in VATS procedures but can be catastrophic when it happens. Thus, there could be value in training to manage this complication. There are also legal, financial, and ethical concerns in the use of animals for training purposes. The Delphi panel agreed that with the rapid development of simulation technology, the need for wet laboratories may diminish with time.

Step 5: Hands-On Primary Training for Entire Team

The Delphi panel agreed unanimously that two trained surgeons (Table 1, Question 1), a trained scrub or floor nurse, and a trained thoracic anesthetist would be required for successful institutional adoption. As experienced mentors of clinical immersion sites, the Delphi participants added insights into the criteria and success factors for team training. Clinical immersion visits to an established high-volume VATS lobectomy unit can initiate training effectively. The involvement of hospital administration is also crucial at this stage to gain agreement on the benefits of the new procedure for patients and the hospital and to support the necessary corporate and financial changes. Inclusion of a management representative in the clinical immersion can communicate the vision and impact of the new procedure and help achieve buy-in. Clinical team immersion also puts the body of skills and knowledge acquired up to this stage into context for the whole team and provides a more global view of the procedure as it affects the whole team.

Step 6: Nontechnical Skills Training

Based on their experience as trainers and mentors, the Delphi participants emphasized that "nontechnical skills" are critically important. Nontechnical skills refer to the building of mutual respect between team members and an understanding of roles within the operating team. The panel agreed that each team member must have clearly defined and differentiated roles and responsibilities while holding task-relevant knowledge. To achieve a successful outcome, each team member must understand not only their own role but also their impact and interdependence with the rest of the team.

The Delphi participants agreed that after the initial clinical immersion, a follow-up visit at 2–3 months by the trainer to the team's hospital provides an independent review of the implementation of the surgical technique and the teams' comfort level with the new procedure, in effect, a more global debriefing of the team training to date.

Step 7: Hands-On Advanced Training and Practice

Although the current framework is focused on multiportal VATS for simplicity, physicians at this advanced stage of training will have the tools and expertise to refine their VATS technique for the best and safest outcomes.

The Delphi participants recommended that the process for introducing advanced procedures mirror the entire curriculum from start to finish, addressing each of the steps of knowledge acquisition, simulation, mentored team and operator training, and continual audit of outcomes. Advanced training also requires a thorough and ongoing evaluation of the current evidence-based medical literature. For example, in relation to VATS training, up-to-date evidence on the adequacy of segmentectomy in lung cancer treatment informs the need to train in the best techniques for that procedure.

The Delphi process also explored the value of nonintubated VATS (Table 1, Question 8). The consensus was that this procedure was unnecessarily risky and that only expert teams should consider these procedures in carefully selected and fully consented patients (5).

Audit Review and Improve Outcomes

Integrated into every step of the program should be an assessment audit that reflects on improving patient outcomes and satisfaction before, during, and after the procedure (Figure 1). This step continuously evaluates the outcomes after the adoption of a new technique and quickly identifies the impact of change implementation and areas for continued improvement.

As the scope widens to improving the patient pathways, new skills are required. A holistic, team-based understanding of the patient–provider journey with a focus on continuous improvement will improve the experience for all.

DISCUSSION

Surgical training has for a long time adopted Halsted's model of "see one, do one, teach one." However, this model of training is now considered both unsafe for patients and outdated (6). Successfully implementing new techniques with good outcomes requires more than just motor skills. It requires the staged and safe acquisition of technical competency, infrastructure, team training, and sustained growth. The framework proposed herein encompasses complex learning and organizational research concepts such as e-learning, simulation, situational awareness, teamwork, decision-making, communication, leadership, and change management to maximize successful implementation with sustained adoption. The focus is on effective and efficient training in both the knowledge base and the staged acquisition of technical skills, with an emphasis on competency rather than time-based progression through the stages (7).

There are many challenges when developing a globally applicable VATS curriculum given variations in cultural, institutional, and economic values between hospitals, regions, and countries. The proposed model is therefore broad in its description but specific in its aim at each step, lending itself adaptable to local prevailing practices. Furthermore, the framework is flexible to incorporate new innovations into surgical training, providing a structure and foundation but allowing for growth. As this structure is presented to different regions around the globe, trainers will be able to see which steps are achievable locally and which may require collaborative support from other established surgeons and institutions.

Critical to the early phases of the training model are self-study, e-learning, and simulation. Reading, procedure videos, digital lectures, and animations provide a broad factual understanding of the surgical procedure methodology, surgical instruments, anatomical orientation and variations, patient positioning, port placement, team members, and required skill sets. E-learning allows for access across multiple devices and is easily updated to remain contemporaneous and relevant. This reduces the learning threshold and can be tailored to the individual's routine and learning pace. Simulation (8, 9) not only develops technical and motor skills but also provides experience in making clinically important decisions in a safe environment, such as conversion to open surgery. Simulation enables performance metrics (e.g., predefined benchmarks, completion times, and accuracy) for effective feedback and provides the ability to individualize the pace of skill acquisition to enhance long-term retention and skill refinement (10) and prevent cognitive overload. Simulation can also objectively assess readiness for progression and identify areas for improvement (11, 12).

There was discrepancy in the opinion on whether animals and cadavers should be used in training, reflecting the current deficiencies and inaccessibility of innovative simulation models to replace animal and cadaver models. At present, there is likely some technical experience to be gained in handling and dissecting live tissue. However, simulation is a rapidly evolving area, and the authenticity of the experience is constantly improving. As simulation becomes more widely available, a sufficiently powered and controlled study would be valuable to evaluate its training effectiveness.

A significant proportion of surgical mortality is due to a lack of nontechnical skills (13, 14). Therefore, Steps 5–7 of the proposed framework emphasize nontechnical skills and team training as critical success factors. Evidence shows that team-based VATS training in a center of excellence results in a higher rate of adoption than individual training (7). Effective mentorship, appropriate case selection, and a prepared team are essential to maximize the chances of success. Allowing dedicated time for briefings before and after the procedure is also essential to develop a culture that allows every team member to share views, raise concerns, and learn from experience. Attending holistic leadership and management courses also improves understanding in neglected areas, such as the patient–provider journey, and is crucial to deliver the best possible outcomes and ensure continuous improvement.

Finally, a high-quality program necessitates constant reevaluation of outcomes to identify deficiencies and areas for improvement. These outcome measures should include clinical outcomes, patient pathway metrics, patient-reported outcomes, and the multidisciplinary impact on the overall patient journey. As an example, the Enhanced Recovery After Surgery Thoracic Guidelines (15) emphasized how multidisciplinary collaboration can shorten the postoperative length of stay from weeks to days. The combination of the VATS procedure, better anesthetic delivery, chest drain management, pain management, and intense physiotherapy leads to less time spent in the hospital and cost reductions, which benefits the patient, the healthcare provider, and the funding body (1, 2, 16). A holistic understanding of the patient–provider journey and a focus on continuous improvement will improve the experience for all.

LIMITATIONS

Although validated through a Delphi process, the effectiveness of the proposed training model will need to be evaluated in a comparative study. The model also relies on simulation for skill acquisition before operating on patients, which is not widely available, particularly in small-volume centers. Finally, the Delphi process did not result in specific guidance regarding e-learning and other educational strategies; specific training is based on the requirements of the trainees and can be applied locally in alignment with the model.

CONCLUSIONS

We developed a learning model for VATS and reframed the training problem as one of education and change management, drawing from expertise in different fields of training. The model provides a flexible framework with a focus on both individual and team proficiency to optimize outcomes for patients.

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REFERENCES

1. Demmy TL, Yendamuri S, D'Amico TA, Burfeind WR. Oncologic equivalence of minimally invasive lobectomy: the scientific and practical arguments. *Ann Thorac Surg* 2018;106:609–617.

2. Bendixen M, Jørgensen OD, Kronborg C, Andersen C, Licht PB. Postoperative pain and quality of life after lobectomy via video-assisted thoracoscopic surgery or anterolateral thoracotomy for early stage lung cancer: a randomised controlled trial. *Lancet Oncol* 2016;17:836–844.

3. Dziedzic D, Orlowski T. The role of VATS in lung cancer surgery: current status and prospects for development. *Minim Invasive Surg* 2015;2015:938430.

4. Divisi D, Bertolaccini L, Barone M, Amore D, Argnani D, Zaccagna G, *et al.*; Italian VATS Group. National adoption of video-assisted thoracoscopic surgery (VATS) lobectomy: the Italian VATS register evaluation. *J Thorac Dis* 2018;10:330–338.

5. Gonzalez-Rivas D, Bonome C, Fieira E, Aymerich H, Fernandez R, Delgado M, *et al.* Non-intubated video-assisted thoracoscopic lung resections: the future of thoracic surgery? *Eur J Cardiothorac Surg* 2016;49:721–731.

6. Rohrich RJ. "See one, do one, teach one": an old adage with a new twist. *Plast Reconstr Surg* 2006;118:257–258.

7. Hurreiz H. The evolution of surgical training in the UK. *Adv Med Educ Pract* 2019;10:163–168.

8. Štupnik T, Stork T. Training of video-assisted thoracoscopic surgery lobectomy: the role of simulators. *Shanghai Chest* 2018;2:52.

9. Solomon B, Bizekis C, Dellis SL, Donington JS, Oliker A, Balsam LB, *et al.* Simulating video-assisted thoracoscopic lobectomy: a virtual reality cognitive task simulation. *J Thorac Cardiovasc Surg* 2011;141:249–255.

10. Spruit EN, Band GP, Hamming JF, Ridderinkhof KR. Optimal training design for procedural motor skills: a review and application to laparoscopic surgery. *Psychol Res* 2014;78:878–891.

11. Jørgensen M, Konge L, Subhi Y. Contrasting groups' standard setting for consequences analysis in validity studies: reporting considerations. *Adv Simul (Lond)* 2018;3:5.

12. Gallagher AG, O'Sullivan GC. Fundamentals of surgical simulation: principles and practice. Berlin, Germany: Springer Science & Business Media; 2011.

13. Cannon-Bowers JA, Salas E, Converse S. Shared mental models in expert team decision making. In: Castellan NJ, editor. Individual and group decision making: current issues. New York, NY: Psychology Press; 2013. pp. 221–242.

14. Kim FJ, da Silva RD, Gustafson D, Nogueira L, Harlin T, Paul DL. Current issues in patient safety in surgery: a review. *Patient Saf Surg* 2015;9:26.

15. Batchelor TJP, Rasburn NJ, Abdelnour-Berchtold E, Brunelli A, Cerfolio RJ, Gonzalez M, *et al.* Guidelines for enhanced recovery after lung surgery: recommendations of the Enhanced Recovery After Surgery (ERAS®) Society and the European Society of Thoracic Surgeons (ESTS). *Eur J Cardiothorac Surg* 2019;55:91–115.

16. Yang CJ, Kumar A, Klapper JA, Hartwig MG, Tong BC, Harpole DH Jr, *et al.* A national analysis of long-term survival following thoracoscopic versus open lobectomy for stage I non-small-cell lung cancer. *Ann Surg* 2019;269:163–171.