Original Article

Objective improvement in dexterity for trainees undergoing a video-assisted thoracoscopic surgery simulation program, a prospective single center study

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Background: Video-assisted thoracoscopic surgery (VATS) is the recommended approach for the management of early-stage operable non-small cell lung carcinoma as well as for other pathologies of the thoracic cavity. Although VATS approaches have been largely adopted in Europe and North America, teaching the technique to novice thoracic surgery trainees remains challenging and non-standardized. Our objective was to assess the impact of a VATS simulation training program on the dexterity of thoracic surgery residents in a prospective single institution study.

Methods: We developed a 6-month VATS simulation training program on two different dry-lab simulators (Johnson & Johnson Ethicon Stupnik® lobectomy model; CK Surgical Simulation® Crabtree perfused lobectomy model) and assessed the skills of first year thoracic surgery residents (study group, n=7) before and after this program using three standardized exercises on the Surgical Science Simball® Box (peg placement on a board, rope insertion in loops, precision circle cutting). The results were compared to those of last-year medical students who performed the same Simball® Box exercises at a 6-month interval without undergoing a training program (control group, n=5). For each participant, the travel distances of instruments, operation time and absences of periods of extreme motion were assessed for each exercise by the use of the computer-based evaluation of the Simball® Box.

Results: After the 6-month VATS training program, all residents revealed a significant increase of their performance status with respect to instrument travel distances operation times and absence of periods of extreme motion in all three exercises performed. The performance of the control group was not different from the study group prior to the training program and remained unchanged 6 months later, for all exercises and parameters assessed.

Conclusions: Our results suggest that the implementation of a VATS simulation training program objectively increases the dexterity of thoracic surgery residents and could be an interesting training tool for their surgical education.

Keywords: Video-assisted thoracoscopic surgery (VATS); surgical training; dry laboratory; surgical simulators; dexterity

Submitted Aug 17, 2023. Accepted for publication Nov 03, 2023. Published online Dec 21, 2023.
doi: 10.21037/jtd-23-1288
View this article at: https://dx.doi.org/10.21037/jtd-23-1288

Introduction

Background

With the introduction of minimal invasive procedures, thoracic surgery has dramatically changed over the past years. Video-assisted thoracoscopic surgery (VATS) and robotic-assisted thoracoscopic surgery (RATS) are nowadays performed in more than 60% of operable lung cancer patients (1-3). Many studies have shown the benefits of minimal invasive surgery such as reduced postoperative pain, early mobilisation, and faster return to normal activities (2,4-7). The prospective VIOLET trial with more than 500 randomized patients undergoing either VATS or open surgery for early-stage lung cancer, revealed less complications, shorter hospitalization, better overall recovery within 5 weeks and less pain within one year following VATS compared to open surgery, with an equivalent oncological outcome for both groups (8). To date, VATS is the recommended approach for the management of early-stage operable non-small cell lung carcinoma as well as for many other thoracic procedures and for many other interventions as well (2,9,10).

The integration of VATS in daily practice requires adaptations in the surgical training program of residents. In 2013, an International VATS Lobectomy Consensus revealed a learning curve for these techniques and defined a minimum number of VATS lobectomies required to obtain the necessary skills (11). Although the quality of surgery is highly dependent on the surgeon's general level of experience, studies on the learning curve for VATS lobectomy have shown 25 to 50 procedures to be the minimum number necessary to be performed for a surgeon to be considered competent in this minimally invasive technique (12,13).

Highlight box

Key findings
- A 6-month video-assisted thoracoscopic surgery (VATS) simulation training program improves the performance of residents on standardized exercises by reducing travel distances of instruments, procedure time and periods of extreme motion.

What is known and what is new?
- Simulation training has shown to be an effective learning tool in different surgical disciplines so far such as general surgery and gynecology. Little has been done in the field of thoracic surgery with VATS being a challenging surgical approach for novice trainees.
- Simulation training can also be used in thoracic surgery allowing a quick acquisition of skills in a safe and controlled environment.

What is the implication, and what should change now?
- A structured VATS simulation training program objectively increases the performance of trainees and could be an interesting adjunct tool for thoracic surgery curriculums.

Rationale and knowledge gap

Surgical training in general has substantially changed in many countries in the recent years with early specialisation and an overall shortening of the training period. This bears the risk of reduced exposure of residents to basic surgery techniques which holds especially true for VATS procedures. Formerly, thoracic surgery trainees performed a vast number of open thoracic surgeries before embarking on VATS procedures. This is no longer the case nowadays, with traditional open approaches being generally reserved for more advanced and complex pathologies that are usually performed by more experienced surgeons. More importantly, VATS interventions can be hazardous procedures since the supervisor's possibilities of immediate damage control are reduced during minimally invasive thoracic surgery compared to open surgery. Simulation-based training has therefore emerged as an essential part of a modern thoracic surgery teaching practice and has already been proven efficient in the field of general surgery (14).

Currently, simulation-based VATS training can be distinguished into "dry-lab" (synthetic) and "wet-lab" (biologic) hands-on modules. Wet-lab modules are performed on living, anesthetized animals (*in vivo*) or on autologous or heterologous tissues (*ex vivo*) and are accompanied by ethical and logistical concerns which interfere with an easy and uncomplicated daily practice application (15). Dry-lab modules on the other hand do not rely on organic tissues and their inconveniences and thus are better suited for daily hands-on courses of busy residents. In addition, they have considerably evolved in recent years including box trainers, surgical simulators, virtual and augmented reality tools and organ replicas which have been specifically designed for VATS lobectomy and lymph node dissection (16,17). While several options exist for VATS simulation training, little data is available for evaluating the efficiency of such teaching methods and their application to modern thoracic surgery residency programs.

Objective

Here we developed a thoracic surgery training program addressed to the residents of our department using two currently available dry-lab VATS simulation platforms. We evaluated the gain of skills for the participants, overall satisfaction as well as the feasibility of integrating such programs in the department's weekly activities. The objective of our study was to assess the impact of this VATS simulation training program on the dexterity of thoracic surgery residents in a prospective single institution study.

Methods

We prospectively included seven residents from our division (training group) and five medical students (control group) with no experience with VATS to our simulation training program. The training group had to undergo objective performance assessment on the Simball® Box (Surgical Science, Göteborg, Sweden) before the beginning and after the end of our 6-month training program. The control group underwent the same evaluation on the Simball® Box (Surgical Science) at 0 and 6 months but did not participate to the training program. This study was part of the residents and medical student training. It did not involve patients and thus did not require Local Ethical Committee approval nor informed consent given as all results were anonymized. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

Participants

The study group consisted of seven first-year thoracic surgery residents of our institution. The control group consisted of five final year (sixth-year) medical students spending a one-month clinical internship in thoracic surgery during their last study year. Both groups had no experience with VATS, laparoscopy, or surgery-simulation courses.

Study design

Both groups were initially evaluated by use of the Simball® Box (Surgical Science) (*Figure 1*) while performing three standardized exercises. The Simball® Box (Surgical Science) is a video box trainer equipped with two trocars for minimal invasive surgery instruments, allowing for a computer-assisted, four-dimension motion analysis to objectively quantify the surgeon's performance during the exercises practiced. The Peg Picker exercise consists of alternative cross-hands picking of blue and yellow pegs and placing them in their platform's pins (*Figure 1A*); in the Rope Racer exercise, a thin rope is passed consecutively through differently oriented loops in a clockwise manner (*Figure 1B*); and during Precision Cutting, a fine membrane is cut precisely between two black circles using a grasper and laparoscopic scissors (*Figure 1C,1D*). For each exercise and each participant, the travel distances of instruments (cm), time required to perform the exercise (s) and absences of periods of extreme motion were assessed by the use of a computer-based evaluation performed by the Simball® Box (Surgical Science) device and scores were provided. Travel distance of instruments measured in centimeters is a great objective measurement of precision since a smaller distance represents a more efficient and structured execution of the task. Likewise, the total time measured in seconds also represents economy of movement and thus precision. Finally, absences of periods of extreme motion are calculated directly by the four-dimensional motion analysis of the Simball® Box (Surgical Science) and represent gestural control and respect of tissue. All procedures were supervised by a board-certified thoracic surgeon. For each exercise, a demonstration video was initially shown followed by a practice round and then by formal evaluation with scoring.

After the initial Simball® Box (Surgical Science) evaluation, the study group underwent a weekly VATS simulation training program for 6 months, followed by an identical Simball® Box (Surgical Science) reevaluation. The control group underwent an identical Simball® Box (Surgical Science) reevaluation as the study group at a 6-month interval but without having followed the VATS training. For each participant in both groups, the initial and final scores for all parameters and exercises were recorded and analyzed.

VATS stimulation training program

During 6 months, the study group underwent a weekly, simulation-based, dyad VATS training program using the Johnson & Johnson Ethicon Stupnik® Simulator (Johnson & Johnson, New Brunswick, USA) with 2D and 3D lung models (*Figure 2*) and the CK Surgical Simulation® Crabtree Simulator (CK Surgical Simulation, Springfield, USA) (*Figure 3*). Each session lasted 3 hours and trainees worked in dyads while using standard thoracoscopic instruments and stapling devices (*Figure 4*). One 3-hour training session was carried out per week and trainees had an average of 10-hour hands on training over a period of 6 months. The exercises aimed to train specific tasks and included camera use and familiarization with the 30-degree optic, lung

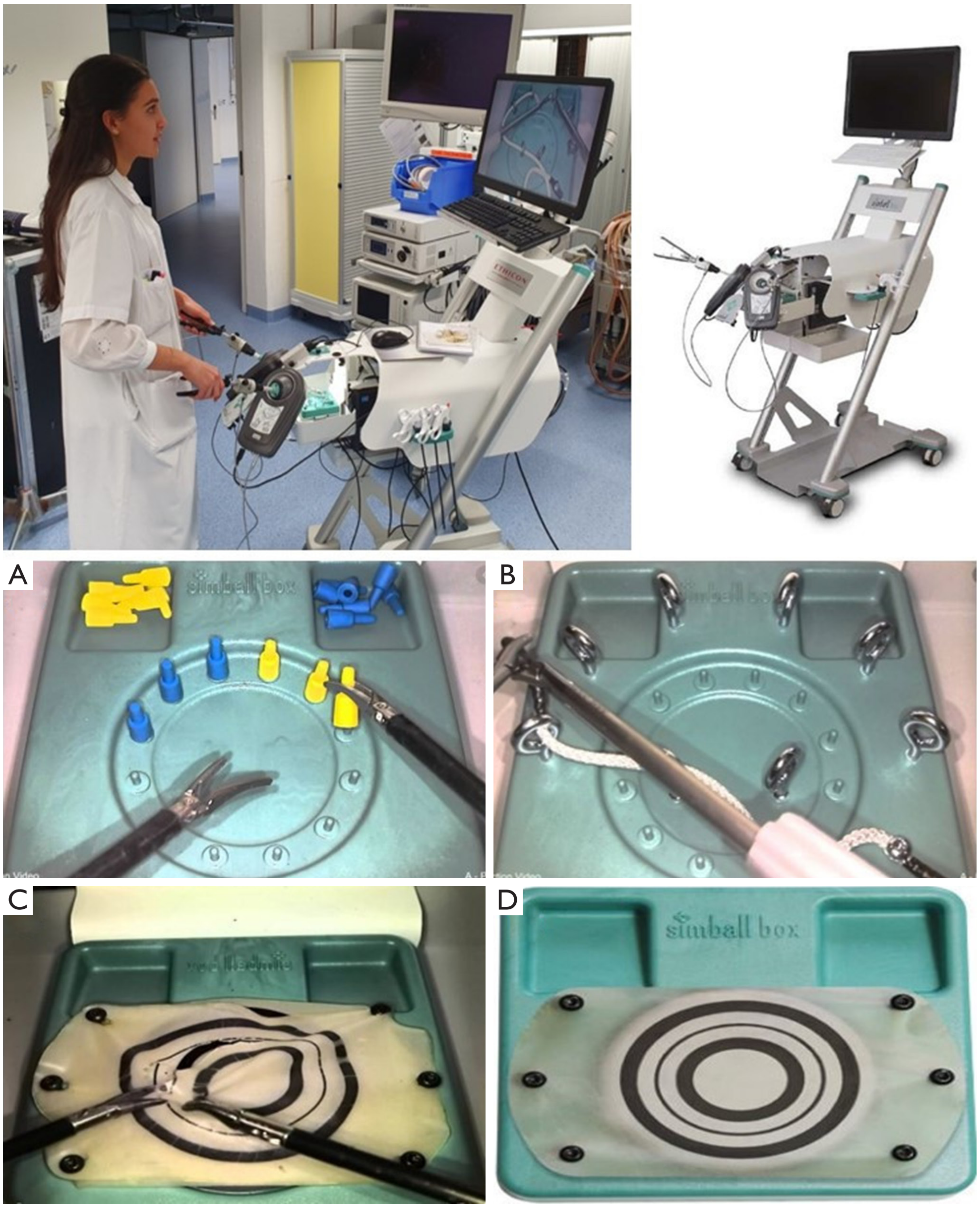

Figure 1 Illustration of the Surgical Science Simball® Box, a video box trainer with computer-assisted analysis of the candidate's dexterity during standardized exercises such as (A) peg picker; (B) rope race; and (C,D) precision cutting.

manipulation for anterior/posterior hilum exposure, non-anatomical lung resections, vessel dissection and stapling procedures and lobectomies (*Figure 5*). All sessions were supervised by a board-certified thoracic surgeon.

General impressions and compliance

Throughout the course of the training sessions, we gathered feedback from trainees and supervisors regarding the quality of the two dry-lab simulators. We focused in particular on the subjective impression of the training experience provided, quality of the training program and on organizational aspects.

Our aim was to assess the strengths and limitations of each training platform and training program satisfaction.

The feasibility of integrating such programs in the

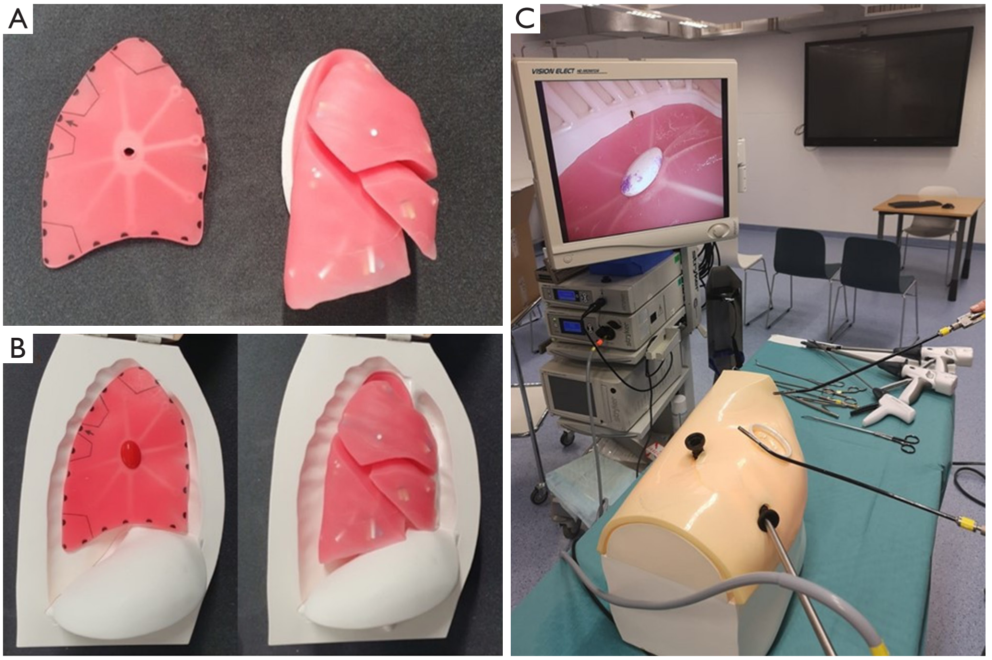

Figure 2 The Johnson & Johnson Ethicon Stupnik® VATS simulator. (A) 2D and 3D lung model inserts. (B) Inserts placed into the mannequin. (C) Final setup with thoracoscopy tower including monitor, light source, optic and thoracoscopic instruments. VATS, video-assisted thoracoscopic surgery; 2D, two dimensional; 3D, three dimensional.

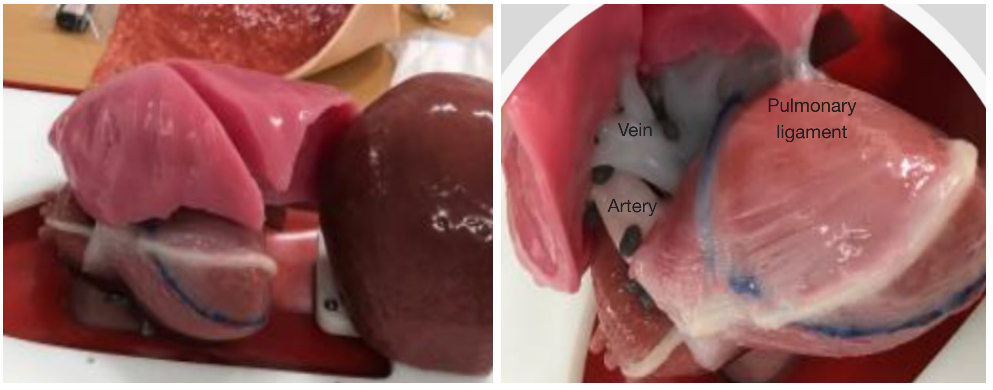

Figure 3 The CK Surgical Simulation® Crabtree simulator with 3D lung model inserts. 3D, three dimensional.

department's weekly activities was evaluated by collecting participants' attendance to the sessions.

Exercise description (see Appendix 1) and statistical analysis

Each participant performed all three exercises on the Simball® Box (Surgical Science) simulator once before recording their performance, before the beginning and after the end of the training program. For each exercise, the distance in centimeters the time in seconds and the absence of extreme motion in % were recorded for each participant. A mean ± standard deviation was calculated using Excel (Microsoft). The statistics were performed using the double-sided Student T test for each group between the pre-training and post-training performance using Excel (Microsoft). A P value below 0.05 was considered as significant.

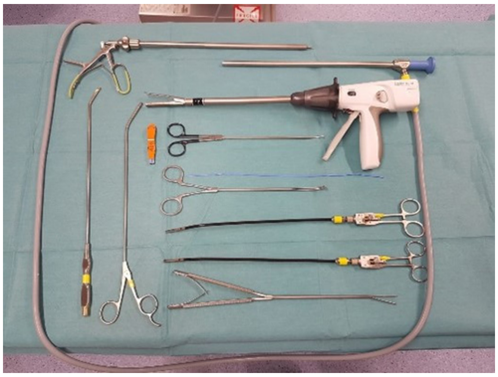

Figure 4 Equipment and instruments used during the training sessions: Laparoscopic clipping reusable device, 30-degree camera with fiber optic light cable, Ethicon Echelon Flex 45 mm stapler, Ethicon Echelon Endopath 45 mm endoscopic linear cutter reload blue (3.6 mm), thoracoscopic dissection scissors, vessel loop, Scanlan node grasping clamp, fenestrated Johann forceps, Scanlan DeBakey Forceps, thoracoscopic dissector, thoracoscopic biopsy forceps.

Results

Compliance

The weekly participation was excellent in the study group and 95% of the planned sessions could be maintained as scheduled. Cancellation was mainly related to duty and emergency surgeries requiring the presence of residents in the operating room.

General impressions

We gathered comments of the study group and supervisors on the different models. The Johnson & Johnson Ethicon Stupnik® (Johnson & Johnson) 3D insert provides realistic bronchial, arterial and venous anatomy up to the segmental level. However, the lung manipulation and the circling of vessels or bronchi was perceived to be difficult due to the rigidity of the silicon lung models and there was no possibility to train hook wire dissection. On the other

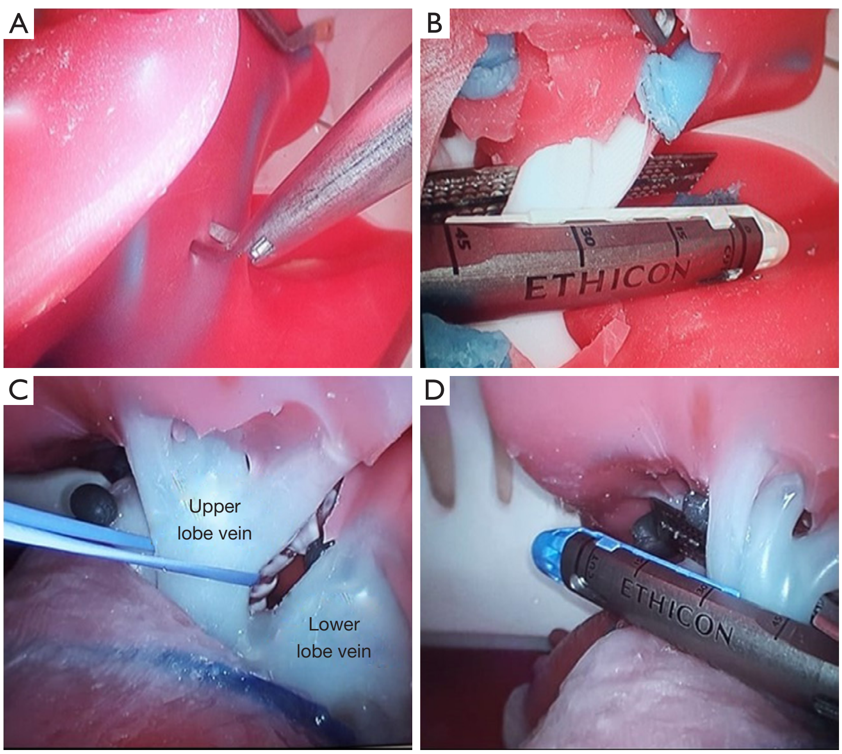

Figure 5 Lobectomy on the two dry-lab simulators. (A,B) Right upper lobectomy performed on the Johnson & Johnson Ethicon Stupnik® VATS simulator. (A) Dissection of the hilum. (B) Stapling of the truncus anterior. (C,D) Left upper lobectomy performed on the CK Surgical Simulation® Crabtree simulator. (C) Vessel loop placement on the left upper lobe vein. (D) Stapling of the upper lobe vein. VATS, video-assisted thoracoscopic surgery.

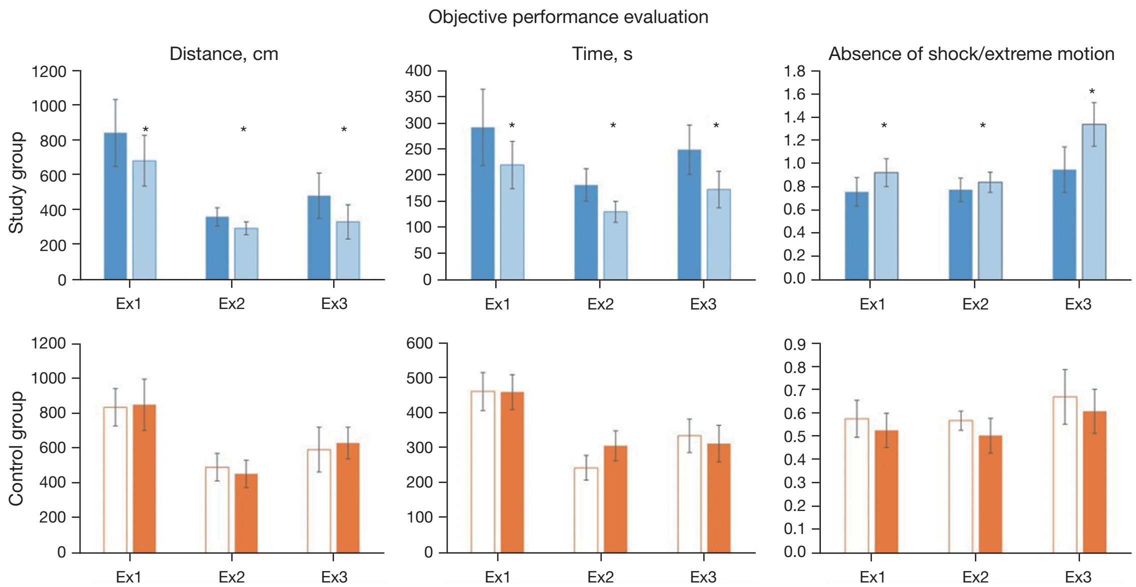

Figure 6 Dexterity evaluation (travel distances of instruments, time required to perform the exercise and absences of periods of extreme motion) on (Ex1, Ex2, and Ex3) 3 standardized exercises (1 peg placement, 2 rope insertion, 3 precision cutting) using the Surgical Science Simball® Box of the study group before (dark blue bars) and after a 6-month training program (light blue bars), and of the control group at 0 months (white bars) and 6 months (orange bars) without simulation training. After the 6 months VATS training program, the study group revealed a significant increase of the performance status with respect of instrument travel distances (P<0.001), operation times (P<0.045) and absences of extreme motion (P<0.002) in all three exercises performed. The performance of the control group was comparable to that of the study group prior to the training program (P>0.05) and remained unchanged 6 months later (P>0.05) for all exercises and parameters assessed. *, statistically important P value, below 0.05. VATS, video-assisted thoracoscopic surgery.

hand, the accurate anatomy of this model and the stepwise teaching on the model was felt to be useful for surgical training and understanding. With respect to the CK Surgical Simulation® Crabtree (CK Surgical Simulation) lung simulator, the silicone lung inserts, and their vessels and bronchi were felt to be even more realistic with lymph nodes situated at appropriate locations. Moreover, this model provides the possibility of perfusion of the lung inserts with possible "bleeding scenarios" in case of handling errors during stapling and vessel manipulation. However, we only had, in the training sessions, a left upper lobectomy model (a right upper lobectomy model has since been developed). Thus, the CK Surgical Simulation® Crabtree Simulator (CK Surgical Simulation) did not allow lower/middle lobectomy training nor segmentectomy.

Performance

A 6-month VATS simulation training period led to a significant increase of the dexterity and surgical skills in the study group, objectified by the Simball® Box (Surgical Science). After a 6-month VATS simulation training, the study group revealed a significant decrease of instrument travel distances (P<0.001), operation times (P<0.045) and periods of extreme motion (P<0.002) in all three exercises performed (*Figure 6*). The performance of the control group which was initially not significantly different from that of the study group, did not improve 6 months later for any of the parameters assessed (*Figure 6*).

Discussion

Key findings

In this prospective study, we evaluated the objective impact of a dry-lab VATS simulation training program on the dexterity of thoracic surgery residents.

For our study, we used two different types of VATS training simulators (Johnson & Johnson Ethicon Stupnik®, CK Surgical Simulation® Crabtree; Johnson & Johnson, CK Surgical Simulation) and created a 6-month VATS simulation training program which was integrated in the department's weekly schedule. We then assessed the impact of our program on surgical skills and overall dexterity of our trainees. For this purpose, the participants underwent an initial (before training) and final (post training) evaluation of their performance on three standardized exercises using a specifically designed box trainer, the Simball® Box (Surgical Science). The latter allowed for a computer-based, objective performance analysis by measuring three different parameters on each of the exercises tested. The parameters that were evaluated were the following: instrument travel distances, operation times and absence of periods of extreme motion. Two groups of participants were created: the study group, which consisted of first-year thoracic surgery residents of our department and the control group, which consisted of medical students who spent an internship in our thoracic surgery unit during their last year of medical school. Both groups were initially evaluated on the Simball® Box (Surgical Science) as described earlier. The study group was then enrolled to our 6-month VATS simulation training program while the control group did not undergo any training during this period. At 6 months, both groups were reevaluated on the initial exercises on the Simball® Box (Surgical Science). The performance of the two groups was compared.

Through our experiment and during a relatively short period of time, we observed 3D orientation enhancement as well as right- and left-hand coordination in thoracoscopy tasks from the study group's participants who had previously no experience in the field of thoracic minimally invasive surgery. By the end of the program, the instructors of the training program reported a global technical improvement amongst trainees.

Thoracic surgery training in Switzerland has recently become specific with no board certification in general surgery. The duration of training until board certification of thoracic surgery can vary between 6 and 10 years. Each trainee is responsible to complete the curriculum requirements before being able to undergo board examination and certification. Besides the minimum duration of training that each candidate has to complete (2 years of general surgery, 0.5 years of intensive medicine 3.5 years of thoracic surgery) there are also other requirements necessary in order to be eligible for board examination. Several courses (general surgery examination, radio-protection) and mandatory training courses such as the advanced trauma life support and others have to be successfully completed. The participation to a minimum of three annual thoracic surgery society meetings as well as a peer-reviewed publication as a first author are also mandatory. Finally, a logbook of more than 500 thoracic surgery interventions has to be completed.

Depending on years of experience, a resident can be promoted to a registrar/fellow position before their board examination. Generally speaking, this promotion occurs after 4 years of experience and often results in a privileged access as operator for anatomical lung resections. Similarly to other surgical disciplines, in a thoracic surgery department, the registrar/fellow has a more prioritized access to the operating room and tends to perform the majority of the cases depending on their skills and experience. During a lobectomy, residents will typically perform the incisions and closure of wounds, part of the pleural and vein dissection and assist the rest of the case. The pulmonary resection will be performed, if possible, by the registrar/fellow, under the supervision of the attending surgeon. Less complex VATS interventions such as bullae resection, pleurodesis and non-anatomical pulmonary resections will be typically performed by residents under the supervision of the registrar/fellow or/and the attending surgeon. Due to this organization, the transition from resident to registrar/fellow operator requires assistance such as with a simulation training program. Such a program can help residents overcome certain technical difficulties in a relaxed and safe environment.

We created a VATS simulation curriculum which allowed practice of a number of possible exercises in VATS, starting from camera use and hilum exposure to more complex procedures such as wedge resections and lobectomies.

Overall, there was a high level of satisfaction for all residents of the study group and an excellent adherence to the scheduled VATS training program. Training cancelations were rare and only occurred in case of emergency cases during resident duty. Overall, 95% of the weekly sessions were maintained as scheduled. The high compliance of the study group participants correlated with a significant increase of their dexterity and surgical skills as assessed by the Simball® Box (Surgical Science) testing. Instrument travel distances, procedure duration and extreme motion were all improved with the VATS training program. In contrast, the performance of the control group which was initially comparable to that of the study group, was unchanged 6 months later for all exercises and parameters assessed.

Strengths and limitations

We believe that different factors explain the high acceptance and positive results of this training program.

First, the Johnson & Johnson Ethicon Stupnik® (Johnson & Johnson) and CK Surgical Simulation® Crabtree (CK Surgical Simulation) simulators combined, provide a very accurate anatomic replication of the thoracic cage, pleura and the lung with presence of lymph nodes, bronchi and perfused vessels for teaching purposes. These dry laboratory models accurately provide a realistic simulation of the operating room set-up, installation and environment. This holds especially true since standard VATS instruments can be used. Also, these simulators have an acceptable cost compared to other dry lab simulators such as virtual or augmented reality simulators (18-20). The latest virtual reality simulator LapSim® developed by Surgical Science© (Gothenburg, Sweden) in cooperation with VATS experts at the Department of Cardiothoracic Surgery at Rigshospitalet and Copenhagen Academy for Medical Education and Simulation (CAMES), which is capable of simulation training on VATS lobectomy of all five lobes, has a total cost of €79,000 (21).

There are wet lab models available (animal or cadaveric training) but their handling is impaired by logistical, ethical, financial and hygienic concerns. On the contrary, our dry lab modules can be easily handled, stocked and installed. All participants indicated Johnson & Johnson Ethicon Stupnik® (Johnson & Johnson) and CK Surgical Simulation Crabtree® (CK Surgical Simulation) simulators to be excellent learning tools, offering a large range of possible exercises that could be performed. Moreover, several procedures can be performed on the same insert thus minimizing the exploitation costs.

Second, the integration of the Simball® Box (Surgical Science) in the beginning and the end of the training program, allowed for an objective assessment of the trainees' technical skill progress. This device allows for a computer-assisted analysis of the candidate's dexterity during standardized exercises and offers a bias-free evaluation (22). The objective quantification of the training progress also strongly influenced the participant's motivation which is not achieved by conventional box trainers (19). Other types of assessments could be considered such as the Objective Structured Assessment of Technical Skills (OSATS) and The Global Operative Assessment of Laparoscopic Skills (GOALS) (23,24). We did not apply those but would certainly consider them for further studies as a more subjective way of evaluating the training program.

Third, the presence of a dedicated instructor who recognizes the participant's strengths and weaknesses while addressing individual learning objectives was also felt to strongly influence the trainee's motivation and performance (25).

Finally, the organization of training sessions in dyads proved not only to be motivating but also cost and time efficient. We feel that this organization also helped to better enhance the trainee's motor skills learning. This is also supported by other studies who suggest that a combination of observational learning and physical practice can contribute to an overall more effective and satisfying didactic experience (25,26).

Our study is limited by its small size of trainees following this educational program. Although we have established this kind of VATS simulation training in our department, larger studies with more participants need to be carried out in order to validate our findings and this novel teaching tool.

Comparison with similar researches

Several publications exist in the field of simulation training. The benefits of simulation training for minimal-invasive surgery, especially for trainees at the beginning of their curriculum have clearly been demonstrated (14,19). In the field of thoracic surgery and most specifically in VATS simulation surgery, a series of studies have been conducted by the Copenhagen Group which has been developing simulation modules for training and performance evaluation tools for over a decade. Jensen *et al.* first described a virtual reality simulator developed by Surgical Science© in cooperation with VATS experts at the Department of Cardiothoracic Surgery at Rigshospitalet, the LapSim®. The simulator was tested during the 22nd meeting of European Society of Thoracic Surgeons (ESTS) in Copenhagen, where 103 thoracic surgeons of different experience completed a lobectomy of the right upper lobe on the simulator. Although built-in metrics could not distinguish between the different levels of experience of the surgeons, this was the first commercially available virtual reality simulator for VATS lobectomy which was perceived as realistic from the participants at the time (27). On 2016 the same group achieved to correlate the level of experience of the 53 participating thoracic surgeons in VATS lobectomy, with their scores on the simulator, identifying seven discriminating built-in metrics. This allowed them to establish a pass/fail level and thus, validate their virtual reality simulation model as an assessment tool for evaluating competence in right upper lobe VATS lobectomy (28). Having formerly developed an assessment tool for evaluating competence in VATS lobectomy (29), they created a modified version of this assessment tool, which was used in order to evaluate performance during video-recorded lobectomies on the LapSim® Simulator (Surgical Science) (30). They demonstrated a valid procedure-specific assessment tool for VATS lobectomy performance in order to further evaluate competency of trainees in this procedure. The most recent work of the group published by Haidari *et al.* using the same simulator which has now been upgraded in order to offer simulation training for VATS lobectomies of all five lobes, identified three measured parameters to be the most relevant in order to differentiate between the trainees' experience: procedure time, total instrument path length and blood loss (21). While blood loss is an imaginary metric provided by this specific virtual reality simulator, procedure time and total instrument path length are metrics that are objective and easily measurable while they have been shown to be shorter for experienced surgeons in previous studies (21,31). Similarly, in our study we also evaluated instrument travel distance and time while the absences of periods of extreme motion is a metric measured by the Simball® Box (Surgical Science) simulator which gives information about the control of movement and respect of tissue. The biggest downside of virtual reality simulators is off course the high cost. The LapSim® (Surgical Science) comes with a hefty price tag of €79,000 which is probably a considerable investment for many institutions (21).

To our knowledge, this is the first study to prospectively evaluate the efficacy of a VATS simulation training protocol for novice residents using two different VATS-specific dry lab modules and authentic instruments. The progress in motion parameters is clearly noticeable from objective data provided by the four-dimension computer analysis of the Simball® Box (Surgical Science).

Sato *et al.* described a polyvinyl alcohol hydrogen lung model with more anatomic details concerning lymph nodes and pleura, and a spongy parenchymal texture which can be used for more advanced surgical procedures such as segmentectomies (32). This model could be therefore proposed to more experienced surgeons who wish to train in more complex procedures such as sub-lobar resections.

The anatomical details provided by our simulation platforms were sufficient for the training of thoracic surgery residents at the beginning of their career. In addition, the CK Surgical Simulation® Crabtree (CK Surgical Simulation) model offers the possibly of lymph node and vessel dissection as well as handling intra-operative vascular complications.

Bjurström *et al.* showed in a comparative study of self-guided versus educator-guided simulation training programs that a 3-hour simulation training with a dedicated educator led medical students to perform a wedge resection with a similar dexterity as certified surgeons (33). Even for more advanced trainees, the presence of an experienced supervisor can lead to a more subtle use of surgical instruments in a setting of a controlled stress-free environment. Other studies endorse this observation and suggest that a combination of observational learning and physical practice can contribute to a more effective didactic experience (25,26,33).

The encouraging results of our study, complement evidence from previous research concerning the benefits of minimal-invasive simulation training in surgery, especially for trainees at the beginning of their curriculum (19-21,27-31,33).

In 2010, Petersen *et al.* reported their experience on introducing VATS lobectomy to a training consultant. They found that introducing the procedure to a trainee in a high volume center under supervision by an experienced surgeon and upon careful selection of patients, results in similar surgical outcomes and complication rates with those of an experienced VATS surgeon. Only operation time was found to be significantly longer for the training surgeon (34). However, the training surgeon in this study was an experienced surgeon in open procedures, had performed more than 200 minor VATS procedures and had assisted more than 50 VATS lobectomies. This is rarely the case with trainees nowadays who are exposed very quickly to minimally invasive surgery without former experience in open or minimal invasive surgery. The authors concluded that simulation training in VATS lobectomy would play an important role in the future in lowering the initial steep learning curve of this high-risk procedure.

Explanations of findings

We believe that our training program has been successful to initiate novice thoracic surgery trainees to VATS and help them quickly overcome technical difficulties in a safe environment before reaching the operating room. Aside from the objective improvement of dexterity of our trainees demonstrated at the end of the program, a high overall satisfaction was reported from all participants.

It can be argued that the residents participating to this training program were also exposed to surgery as part of their everyday activities. This, of course, could explain some of the progress observed in this study. However, first year residents rarely perform complex procedures in their first months and thus the everyday practice has likely contributed but cannot explain alone the movement parameter improvements. Also, compared to the irregular/highly variable exposure to surgical cases in the first months of residency, the weekly simulation training sessions were consistent and standardized. This allowed for a smooth progression of the trainees' skill in a regular basis. Eventually, our objective was to create a realistic and reproducible training program which would act as an adjunct to the everyday activity and training curriculum of thoracic surgery trainees.

Finally, the supervision of the training sessions by an experienced educator who guided participants through the program, allowed for a personalized training experience with focus on individual strengths and weaknesses while exercises and training objectives could be tailored to each trainee according to their skills and capabilities.

Implications and actions needed

The encouraging results of our study endorse the results of prior research showing the benefit of minimal-invasive simulation training in surgery for trainees at the beginning of their curriculum (19-21,27-31,33). Our results suggest that a structured VATS simulation training program as proposed in this study is effective and could be integrated in a modern thoracic surgery residency teaching program. The steep increase in high-technology expertise and skill which are necessary for a modern practice of thoracic surgery mandate a quick adaptation to evolving technologies and new techniques. In the last decade, thoracic surgery practice has drastically changed with a major swift over minimally invasive techniques by VATS or RATS but also with technological advances in other domains of the discipline such as extracorporeal respiratory support for lung transplant and three-dimensional modelling for segmental anatomy just to name a few. Today more than ever, the need for a standardization of the thoracic surgery curriculum is evident. In their effort to create a harmonized and standardized training curriculum for European thoracic surgeons, Massard *et al.* highlight the role of simulation training in acquiring the necessary skills for numerus procedures in which a thoracic surgeon needs to be proficient (35). However, it is not defined which procedures must be trained through simulation.

In this direction Haidari *et al.* published a consensus of key thoracic surgeons worldwide in an effort to identify and prioritize technical procedures for simulation-based training to be integrated into the thoracic surgery curriculum based on international needs assessment. Seventeen technical procedures were included for simulation training with the top-three procedures being VATS lobectomy, segmentectomy and mediastinal lymph node dissection, indicating the frequency of performing these procedures and the potentially fatal consequences of operative complications (20).

As discussed earlier, different simulation modules exist and all come with advantages and inconveniences. It is yet to be determined which module is best suited for simulation training of a specific procedure. We have described a simulation training program for learning VATS procedures using commercially available simulators, suitable for thoracic surgery residents which allows for familiarization with minimally invasive thoracic surgery in a realistic environment. Larger scale studies are necessary in order to validate such programs which could then be included in thoracic surgery training curricula. Since the field of thoracic surgery is rapidly evolving, surgical education has to adopt modern technologies early in the training program. Our study suggests that VATS simulation training exposes young surgeons to minimally invasive thoracic surgery procedures in a realistic environment and plays a significant role in modern surgical education and practice (18-21,27-31,33).

Conclusions

Simulation training has gained an important role in modern surgical education over the past years. In the field of thoracic surgery, a discipline which has exponentially evolved during the last decade with a radical shift over minimal-invasive techniques, such application of simulation training programs has not yet been globally adopted. This study suggests, that the implementation of a protocol-based simulation training-curriculum is a valuable and effective tool in order to instill the principles of thoracoscopy at the early stages of education of young thoracic surgeons. Further research with larger groups of participants is suggested to validate the results of this study.

Acknowledgments

We thank Johnson & Johnson for providing the following

material for this training program (lung inserts, staplers and recharges).
Funding: None.

Footnote

Data Sharing Statement: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1288/dss

Peer Review File: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1288/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1288/coif). M.G. serves as an unpaid editorial board member of *Journal of Thoracic Disease* from February 2023 to January 2025. M.G. reports educational events (EMEA courses) sponsored by Johnson & Johnson. J.Y.P. reports educational events (EMEA courses) sponsored by Johnson & Johnson. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was part of the residents and medical student training. It did not involve patients and thus did not require Local Ethical Committee approval nor informed consent given as all results were anonymized. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

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Cite this article as: Koliakos E, Abdelnour E, Hasenauer A, Forster C, Ojanguren A, Ris HB, Gonzalez M, Krueger T, Perentes JY. Objective improvement in dexterity for trainees undergoing a video-assisted thoracoscopic surgery simulation program, a prospective single center study. J Thorac Dis 2023;15(12):6674-6686. doi: 10.21037/jtd-23-1288

Supplementary

Appendix 1

Methods

The supervisor provided assistance with tips and tricks as well as feedback at the end of each session. Each training session was devoted to two trainees and the 3 hours of the sessions were equally divided between the two with roles changing between operator and assistant. Each trainee would progressively perform the exercises as described further on this section. An exercise had to be successfully completed twice according to the supervisor's judgment before a new exercise could be initiated. When a new session began, each trainee would resume their training repeating the last exercise that they ended the previous session with. Once all the exercises of the training program had been completed by a trainee, they were left free to choose which exercises they wanted to practice for the remaining time of their training sessions. Generally speaking, upon completion of the all the exercises of the training program, trainees chose to practice on the most complex exercises such as non-anatomical lung resections, vessel dissection and stapling and lobectomies.
The exercises are detailed here below:

Camera use
In this exercise, trainees are introduced to the 30-degree optic and its proper utilization with focus given on the importance of maintaining the operating field at the center of the image as well as keeping the horizon line stable while changing the optic's angle.

Lung manipulation and hilum exposure
In this exercise, trainees learn ways to manipulate the lung in a gentle way respecting tissue and avoiding lesions. Both simulators (Johnson & Johnson Ethicon Stupnik® Simulator and CK Surgical Simulation Crabtree® Simulator) were used for this task. A non-grasping as well as a grasping technique for lung manipulation was demonstrated. The exercise combines the use of forceps and dissectors for lung handling, allowing an adequate exploration of the entire parenchyma as well as anterior and posterior hilum exposure.

Non-anatomical lung resections
For this exercise, we used the 2D model of the Johnson & Johnson Ethicon Stupnik® VATS Simulator. Trainees learned how to perform diverse non-anatomical lung resections. This is a type of lung resection that does not take into consideration the specific location of distant veins, arteries and bronchus. Different areas of the lung insert are marked. Using the lung manipulation techniques previously acquired, trainees perform different wedge resections of the lung apex as well as the anterior and posterior portion of the inferior lobe using automatic staplers. This exercise familiarizes our trainees with the overall use of staplers including insertion, angulation and secure firing.

Vessel dissection and stapling
In this exercise, trainees learned a systematic approach when dissecting vessels including careful grasping, dissection and vessel control with loop placement and finally stapling. Instruments used for this exercise include graspers, De Bakey endoscopic forceps, endoscopic scissors and Harmonic Ultracision as well as staplers. On the 2D model, the appropriate plane is firstly identified and then held with the De Bakey forceps. Scissors and/or Harmonic Ultracision were used to dissect the vessel away from the underlying plane. Once the vessel is sufficiently prepared, a Crawford is used in order to further liberate the vessel and a vascular loop is placed around it. After being properly angulated, the stapler is introduced through the posterior incision. Once appropriately placed, it is securely fired, stapling and transecting the vessel.

Right and left upper-lobe anatomical resections
For this exercise, the 3D model of the Johnson & Johnson Ethicon Stupnik® VATS Simulator was used for a right upper lobectomy and the CK Surgical Simulation Crabtree® 3D-printed Simulator was used for a left upper lobectomy (*Figure 5*). Here we described the steps of a typical right upper lobectomy that was practiced by trainees under the guidance of the educator. First, using previously acquired skills, the lung is mobilized in order to achieve an adequate exposure of the anterior

 https://dx.doi.org/10.21037/jtd-23-1288

hilum. Dissection is initiated at this level and the venous system is identified, allowing upper lobar vein dissection. The anatomical identification and dissection of the upper venous system constitutes a crucial step in the procedure. The upper lobar vein is completely liberated with delicate gestures in order to avoid injury to the underlying mediastinal branch of the pulmonary artery. Using a Crawford, a vascular loop is placed encircling the vessel. The stapler is then introduced through the posterior incision and placed securely on the vessel. Once in place, the loop is removed and the stapler is fired, stapling and sectioning the vein. The next step consists in dissecting the right pulmonary artery and identifying the mediastinal branch, which supplies blood to the apical and anterior segment of the upper lobe. The mediastinal artery is dissected using scissors or Harmonic Ultracision. Once the vessel is sufficiently liberated from the surrounding tissue, a loop is placed around it and using a stapler the vessel is divided. Attention is drawn to the presence of a posterior branch existing in our model, requiring delicate dissection as well as anatomical knowledge. This smaller vessel is generally clipped and then sectioned with scissors or using the Harmonic Ultracision. Afterwards, the upper lobar bronchus is identified and dissected. It is finally stapled using the parenchymal stapler entering once again from the posterior incision. The parenchymal resection is the final step of the procedure. At this point, the upper lobe is completely detached from the hilum, solely adherent to the parenchyma of the middle and lower lobe through the small and large fissure respectively. The lobe is mobilized inferiorly using Johann forceps or a Duval endoscopic grasper. The stapler is then introduced this time through the utility incision in the 4th intercostal space. It is carefully placed on the fissure with attention paid in order to preserve the middle-lobe vessels. Several firings are usually necessary in order to divide the upper and middle lobe. Finally, the large fissure is divided, allowing extraction of the right upper lobe, completing the exercise.

https://dx.doi.org/10.21037/jtd-23-1288