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Simulation-based training for thoracoscopic lobectomy: a randomized controlled trial

Virtual-reality versus black-box simulation

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Abstract
Background Video-assisted thoracic surgery is gradually replacing conventional open thoracotomy as the method of choice for the treatment of early-stage non-small cell lung cancers, and thoracic surgical trainees must learn and master this technique. Simulation-based training could help trainees overcome the first part of the learning curve, but no virtual-reality simulators for thoracoscopy are commercially available. This study aimed to investigate whether training on a laparoscopic simulator enables trainees to perform a thoracoscopic lobectomy.
Methods Twenty-eight surgical residents were randomized to either virtual-reality training on a nephrectomy module or traditional black-box simulator training. After a retention period they performed a thoracoscopic lobectomy on a porcine model and their performance was scored using a previously validated assessment tool.
Results The groups did not differ in age or gender. All participants were able to complete the lobectomy. The performance of the black-box group was significantly faster during the test scenario than the virtual-reality group: 26.6 min (SD 6.7 min) versus 32.7 min (SD 7.5 min). No difference existed between the two groups when comparing bleeding and anatomical and non-anatomical errors.
Conclusion Simulation-based training and targeted instructions enabled the trainees to perform a simulated thoracoscopic lobectomy. Traditional black-box training was more effective than virtual-reality laparoscopy training. Thus, a dedicated simulator for thoracoscopy should be available before establishing systematic virtual-reality training programs for trainees in thoracic surgery.

Keywords Simulation · Thoracoscopy · VATS lobectomy · Virtual-reality · Simulator training

During the past 20 years, different types of scopic surgery have become common practice in a variety of surgical disciplines [1, 2]. This trend is also true for thoracic surgery, in which video-assisted thoracic surgery (VATS) is gradually replacing conventional open thoracotomy as the method of choice for the treatment of early-stage non-small cell lung cancers. The new technique delivers more promising results [3] but learning and mastering it is challenging for thoracic surgical trainees.

Development and refinement of surgical skills are critical and time-consuming components of the training curriculum of novice surgeons. The necessity to move away from the 'learning on patients' paradigm and to reduce errors to increase patient safety has caused surgical simulation to emerge in the education and training of surgical residents [4–7]. Gallagher et al. [8] hypothesized that surgical simulation creates a 'pre-trained novice' who has mastered psychomotor skills, sensory acuity, and, to some extent, cognitive planning of surgical tasks through

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simulation, rather than spending valuable operating-room time on the refinement of skills.

A meta-analysis found that technology-enhanced simulation learning (in other words, training on virtual-reality simulators) had significant effects on knowledge, skills, and behavior compared with no intervention [9]. Unfortunately, no virtual-reality simulators are commercially available for thoracoscopy training, and the effects of virtual-reality VATS training have not been studied. Many university hospitals and simulation centers possess a laparoscopic virtual reality simulator, and practicing on one of these could facilitate thoracoscopic skills. Scenario-based practice in a specifically designed simulated environment is a valuable adjunct to traditional educational methods [10], and training in procedures such as a nephrectomy that involve dissection of three tubes (ureter, artery, and vein) may be a model for training VATS lobectomy (bronchus, artery, and vein). Studies exploring this concept should use reliable and valid outcome measures, and avoid the unfair comparison with no intervention by using traditional training as a control [11].

The primary aim of this study was to explore whether virtual-reality training on a nephrectomy model enables novice surgeons to perform a VATS lobectomy on a porcine heart and lung block, and, second, to compare the efficiency of virtual-reality training with standard black-box training.

Materials and methods

Sample size calculation

The outcome measure of performance was the scores from the test derived by Meyerson et al. [12]. For sample size calculations, we used the approximate values from that study and sought to detect a clinical meaningful difference of 10 %: to detect a difference of 3 min between the groups, the hypothesized mean value for sample one and two were set to 30 and 33 min, respectively, and the standard deviation for each sample was set to 3 with a two-sided 5 % significance level and a power of 80 %. This rendered a minimum of 12 samples in both arms. Sample size calculations were carried out using a sample size calculator (www.dssresearch.com).

Inclusion

A convenience sampling of 30 surgical residents from different surgical specialities (urology, abdominal surgery, cardiothoracic surgery, and orthopedic surgery) were included in the study between 1 October 2012 and 1 March 2013. A dropout rate up to 20 % was allowed. Residents from different hospitals in Denmark were invited to participate through bulletins at the hospitals. The residents were included on a first-come, first-served basis. Inclusion criteria were having performed less than three supervised laparoscopic, arthroscopic, or thoracoscopic procedures, and no simulation-based training in scopic procedures. Background data were collected by invitation and inclusion was determined by the criteria. The training and testing took place at the Centre for Clinical Education in Copenhagen, Denmark. Collected data from the surgical residents and the video-recorded test scenarios were assigned a number for further use, and remained anonymous for everyone except for the main investigator.

Randomization

The surgical residents were consecutively paired, and the pairs were randomized into two groups: black-box training and virtual-reality training (Fig. 1). Randomization was carried out by one of the co-authors (LK) via www.random.org by generating a list comprised of the numbers 1 and 2 written randomly in a column. This list was given to a medical student who was not involved in the study at any time, and the numbers were transferred from the top to the list of training pairs using uneven numbers for the virtual-reality simulator and even numbers for the black-box simulator.

Training

When participants arrived for the training, one of the authors (KJ) gave a 15-min PowerPoint (Microsoft Corporation, Redmond, WA, USA) presentation to explain the background and aim of the study. The training was in pairs (dyad training) and participants were allowed to give verbal and hands-on instructions to help one another, and took turns after each attempt with a scenario. All participants trained to a predefined level without any time constraints. KJ was present during the training to assist participants who had trouble understanding the simulator or the scenario.

Group 1: Virtual-reality simulator training

Group 1 practiced on a computer-based virtual-reality simulator from SimSurgery called SEP (SEP v. 3.0.1) (Fig. 2), and the training scenario was a laparoscopic nephrectomy. This scenario was chosen because it mimics the principles of a lobectomy with dissection of connective and fatty tissue and division of vessels. The simulator has an in-build instruction module for the nephrectomy scenario, and participants were shown this module before they

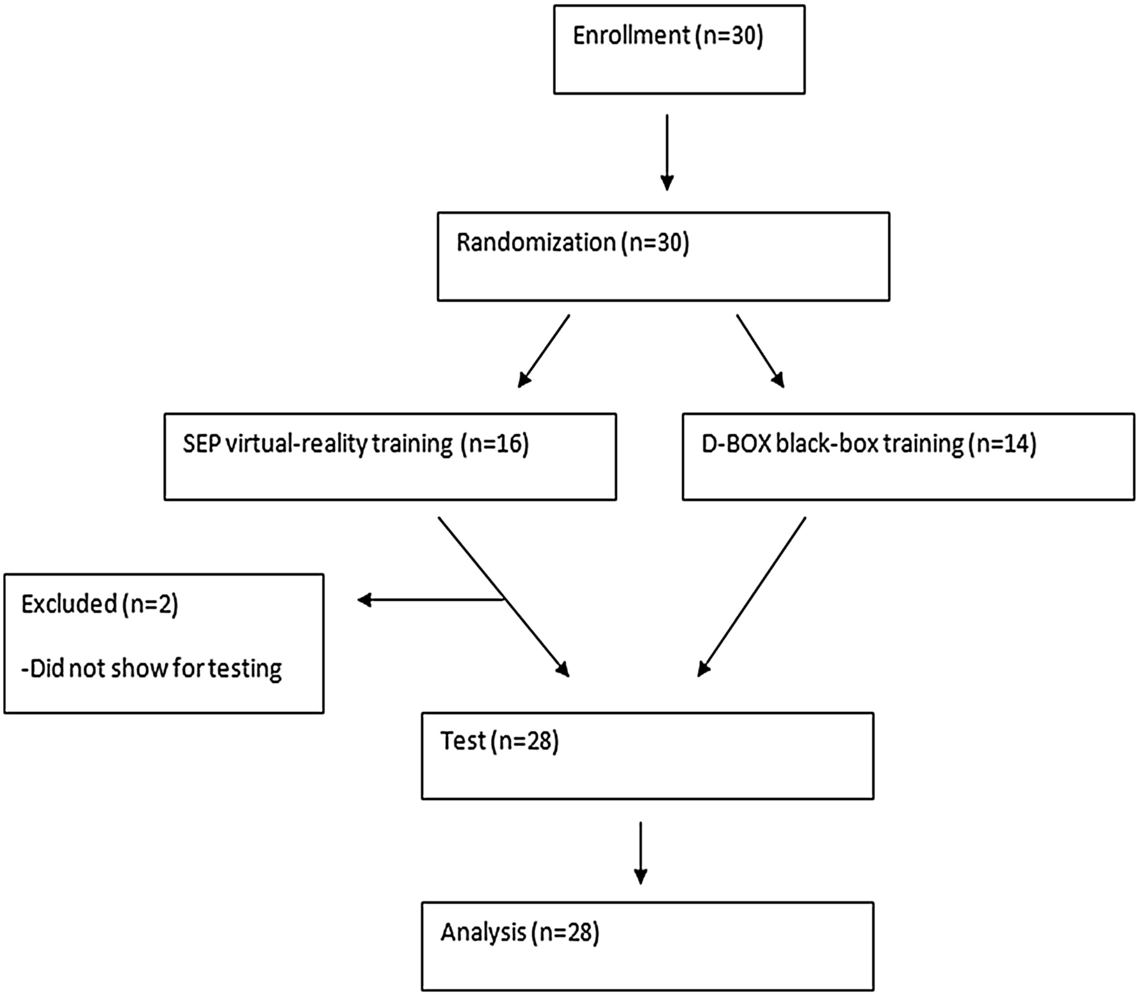

Fig. 1 Flowchart of the study

performed, in addition to the instructions from the main investigator. The scenario consisted of two parts: bowel mobilization and hilar dissection with securing and dividing of vessels. The first part, in which participants had to dissect the Line of Toldt and the splenocolic ligament, resembled dissection of pleural adherences and freeing of the lower pulmonary ligament in a thoracoscopic lobectomy (Fig. 3). The second scenario mimicked hilar dissection and the division of veins, arteries, and bronchus in a lobectomy. The score required for passing each part of the scenario was set by pilot testing the scenario with two Danish VATS experts who have performed more than 1,000 VATS procedures each, including several hundred thoracoscopic lobectomies. The computer-based simulator was programmed with the experts' scores in each part of the scenario, and the residents had to score 95 % of the experts' scores on each part to pass. Each pair of residents practiced until they both passed all parts of the scenario twice.

Group 2: Black-box simulator training

Group 2 practiced on a black-box simulator from SimSurgery called the D-BOX Basic simulator (Fig. 4), and their training-scenarios are described in detail by Bjurström et al. [13]. Participants also received instructions for the simulator and scenarios before they started their practice, and were shown videos beforehand on how to master the scenarios constructed by a co-author (LK), who also helped design the scenarios in the study by Bjurström et al. Three scenarios were used. The first scenario consisted of threading a peg through ten loops fixed at different depths and angles that had to be performed in less than 2.5 min (Fig. 5). The second scenario consisted of collecting ten matches from small, non-fixed plastic cups and placing them into the thumb of a size 8 surgical glove. The matches had different colors, and one color had to be picked up using the right hand and the other using the left hand in less than 3 min in total (Fig. 6). If the trainee accidentally spilled a cup, he or she had to start over.

Fig. 2 Picture of the virtual-reality simulator

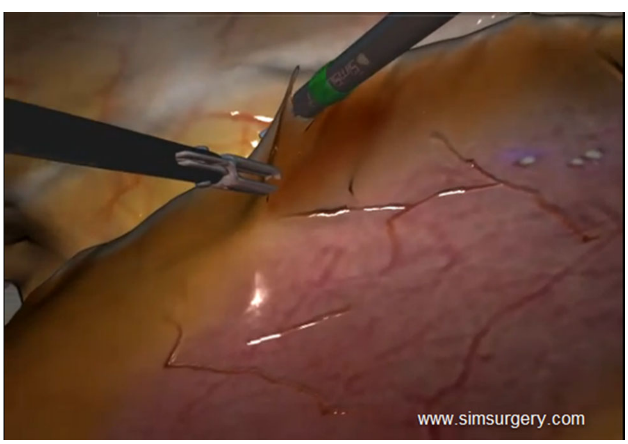

Fig. 3 Picture from the nephrectomy scenario freeing the Line of Toldt

The third scenario consisted of locating an artificial small tumor hidden in layers of sponge washcloths using haptic perception. The third scenario was passed by stapling out the 'tumor' with an endostapler and placing it in a retraction bag to the satisfaction of the main investigator (Fig. 7). The first two scenarios were designed to practice fine motor skills, bimanual dexterity and scopic distance assessment, leading to increased speed. The last scenario practiced caution, quality of movement, and correct use of instruments; therefore, time consumption was not of interest.

Test and outcome measures

To test whether the training had an effect, participants had to remove a left upper lobe on a porcine heart and lung block. The test was carried out on a simple VATS lobectomy simulator described by Meyerson et al. [12]; however, instead of the casing they used, the heart and lung block was placed inside the D-BOX. The porcine lungs were collected from freshly slaughtered pigs on the same day of testing, and KJ prepared the lungs as described in Meyerson et al. Before the testing, participants were instructed in the D-BOX simulator and the scenario, shown pictures of a lobectomy on a real patient and a pig, and received instructions by KJ on the anatomy needed to perform the procedure; this instruction took 30 min. Both the instruction and the testing were done

Fig. 4 Picture of the black-box simulator

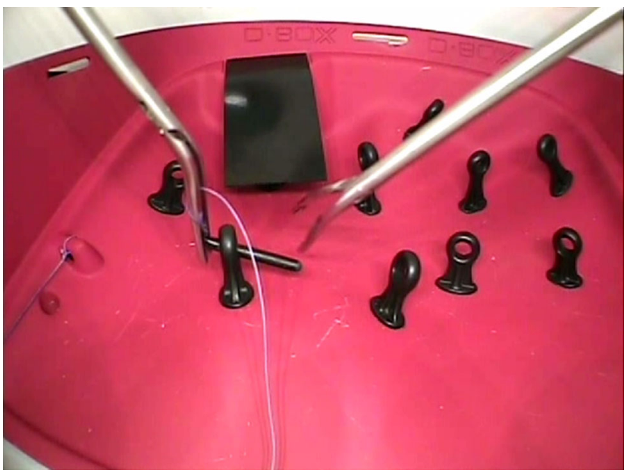

Fig. 5 Scenario 1 on the black-box simulator

Fig. 6 Scenario 2 on the black-box simulator

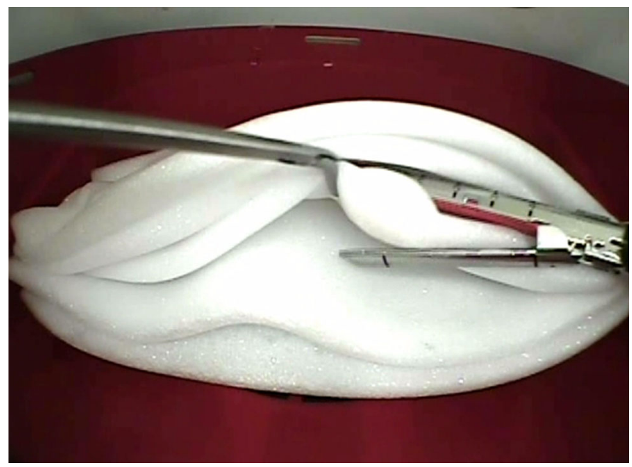

Fig. 7 Scenario 3 on the black-box simulator

individually. The original protocol calls for testing to occur approximately 4 weeks after the training, but this schedule proved to be impossible for participants to follow, as explained in the "Discussion" section. Consequently, testing was carried out within 4 months after the simulation training, but before the study's deadline. Scoring the performance was carried out using a validated scoring system described by Tong et al. [14], specifically developed for this lobectomy scenario. Mistakes made during the lobectomy resulted in penalty time being added to the final time, and participants who were unable to complete the lobectomy within 60 min were given a time of 60 min plus the penalty time obtained during this hour. Penalty times were given for bleeding and anatomical and non-anatomical errors. Participants' performance was video recorded with a USB recorder plugged into the black-box, and KJ scored their performances during testing and by reviewing the video afterwards to be sure no errors were missed. Thus, outcome measures were performance scores based on time and errors.

Data analysis

Continuous data are presented as means with standard deviations. Age, performance score, and retention of skills time were approximately normally distributed, and were compared between groups using an independent-sample *t* test. The number of errors and subsequent penalty minutes were not normally distributed and these data were compared between groups using the Mann–Whitney *U* test. Categorical data such as gender and errors or no errors were presented as numbers and percentages, and compared using Fisher's exact test. A p value <0.05 was considered significant. IBM SPSS statistics version 19 (IBM Corporation, Armonk, NY, USA) was used for the data analysis.

Results

Two participants from the virtual-reality group dropped out because they did not turn up for testing before 1 March 2013, which left 28 surgical residents in the study (Fig. 1). The groups did not differ in age and gender, and all participants were able to complete the lobectomy (Table 1). The black-box group waited significantly longer than the virtual-reality group before they took the test (56.7 vs. 33.4 days; $p = 0.027$). Figure 8 shows no correlation between the test scores with penalty time and days between training and the test for the two groups ($R^2 = 0.043$ and 0.17, respectively).

Table 1 Test results summarized for the two groups

	D-BOX (n = 14)	SEP (n = 14)	p Value
Age	28.7 ± 3.2	29.6 ± 2.5	0.40
Gender ratio (M:F)	6:8	4:10	0.70
Days between training and test	56.7 ± 6.6	33.4 ± 7.5	0.027
Time used in the test scenario without penalty	26.6 ± 6.1	32.7 ± 7.9	0.032
Time used in the test scenario with penalty	29.6 ± 6.6	35.0 ± 6.9	0.043
Total number of errors on			
Vein	9	4	0.13
Artery	8	8	1
Airway	2	2	1
Number of participants with bleeding	8	4	0.25
Number of participants with anatomical error:			
With correction	3	1	0.60
Without correction	0	2	0.5
Number of participants with non-anatomical errors	8	7	1
Mean number of errors per participant	1.1 ± 1.2	1 ± 0.8	0.35

M male, *F* female

The black-box group performed significantly faster during the test scenario than the virtual-reality group: 26.6 (SD 6.7) mins versus 32.7 (SD 7.5) mins without penalty time ($p = 0.032$), and 29.6 (SD 6.6) versus 35.5 (SD 6.9) mins ($p = 0.043$) with penalty time. These results equal a difference of 6.1 min without penalty time and 5.6 min with penalty time added between the groups. No difference existed between the groups when the mean number of errors per participant and the errors divided onto the structures were compared. When looking at the different types of errors in the group, no difference existed when comparing bleeding and anatomical and non-anatomical errors. In conclusion, the groups made the same type and amount of errors during the test scenario.

Discussion

All participants were able to complete the lobectomy on the porcine heart and lung block. In the study by Tong et al. [14], only 38 % of the novice participants and 67 % of the intermediate participants completed the lobectomy, but the participants in that study were not pre-trained and were not given any instructions during the procedure. Our participants made fewer errors and took less time than the participants in the study by Tong et al. [14]. Possible explanations could be that the author's instructions to the participants in this study for the test scenario were very detailed, and the participants in this study knew they wanted to become surgeons and were interested in getting good scores on the test. Furthermore, our porcine lungs were out of the pig for a maximum of 6 h and were kept between 0 and 5 °C until preparation, whereas the porcine lungs in the study by Tong et al. [14] were frozen for preservation. Therefore, our tissue was more easily dissected because of the missing stiffness it gets from being frozen, enabling participants to complete the lobectomy in a shorter time.

Finding a 6-min difference between the groups was surprising, particularly because the black-box group only trained in basic scenarios and, hence, in the acquisition of motor skills. In contrast, the virtual-reality group trained in both motor skills, controlling of bleeding and in planning of a surgical procedure that mimicked a thoracoscopic lobectomy. Despite the black-box group only having trained in basic scenarios and having waiting longer before

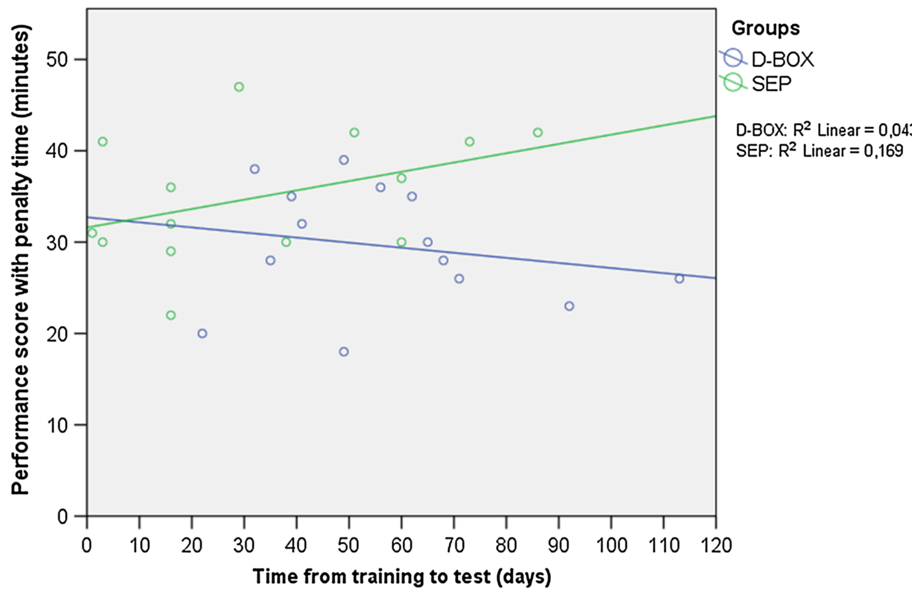

Fig. 8 Graph shows no correlation between time from training to test and performance score with penalty time

taking the test, they were still significantly faster. This result could be attributable to the fact that participants in the black-box group had a better feeling for the instruments and the force they could apply to the structures because they trained with real instruments, making this group perform faster than the virtual-reality group. The virtual-reality group did not have force feedback in their training, which could be of importance in learning a new technique [15]. The main investigator observed that the virtual-reality group was more careful around the vessels, which may be explained by the notion that they were afraid of bleeding, because they almost all encountered fatal bleeding in the scenario on the virtual-reality simulator, making them perform the test more carefully and thereby making them perform slower. The black-box group did not train in scenarios that involved bleeding. However, no statistically significant difference existed in the number of participants who experienced bleeding in the test scenario. These explanations could account for the significant difference between the times used in the test scenario.

The skill transfer from the virtual-reality simulator to the test scenario was not well accomplished. The black-box group had an advantage in the test scenario since they trained and took the test on the same simulator and the virtual-reality group did not. Training on a laparoscopic virtual-reality simulator in a nephrectomy did not have an advantage over the more simple black-box training in any of the measured points, We believe this was due to the missing haptic feedback in the virtual-reality training, hereby only relying on the vision when training.

Participants had difficulty finding a day for the test and, coincidentally, the number of days from training to test varied significantly between groups. The number of errors are expected to increase as the time between training and test increased, but this was not the case and no correlation existed between the test results and the time from training to test (Fig. 8). In prior studies, the retention of skills learnt on a simulator was retained for at least 6 weeks and as long as 1 year [16–19]. Our study found that the effects of training lasted for up to 3 months.

The main strengths of this study are the randomization of the participants and the use of validated setups. The black-box simulator and the training scenarios were tested and validated in a previous study [13], and the virtual-reality simulator was pilot-tested by expert surgeons (HJH and RHP). A previously developed lobectomy simulator [12] and a validated assessment tool [14] were used to test performance. Another strength of the study is the predefined specific criteria the participants trained to complete [20]. This study used training in pairs (dyad training) because it has been shown to be superior to practicing alone on a simulator, primarily because the training partners can observe the performance of the other [21–23]. Statistical power calculations provided 99.99 % statistical power when based on the difference between the test scores. Consequently, the included number of participants was large enough to find a statistical difference, even if 28 participants arguably represents a small study sample.

The question of transfer of skills and predictive validity from a lobectomy simulator remains to be further researched because it represents the definitive endpoint in simulator research [14, 24, 25]. Unfortunately, assessing this question in the operating room without creating risk to patients is difficult. A senior surgeon is always present in the operating room and prevents the trainee from making errors that harm the patient, and the surgeon will do the operation properly and not risk the patient for the sake of being a few minutes faster. Therefore, assessment tools that rely on the identification of errors and time, such as the one used in this study, are not useful for research in this area, and other tools that allow a more detailed assessment of technical skills should be used to assess real operations [26].

Finally, the authors would like to point out some considerations for the further implementation and development of future simulators. A computer-based simulator is far more expensive than a black-box simulator, and software development takes time. A black-box simulator is rather inexpensive and only requires some instruments, a monitor, and a scenario of some kind, such as a lung or a liver from a pig that can be placed in it to learn the suture technique [12, 27]. The black-box simulator can easily be modified to the skill requiring practice; a new instrument can be tested just by putting it inside the box and using it as intended instead of using it on the patient for the first time. A computer-based simulator requires programming new software for an instrument, which again takes time and money. A black-box simulator enables the resources to be used optimally and at low cost [28]. The advantages of a computer-based simulator are the direct feedback and the instruction modules, minimizing the need for an instructor and enabling realistic simulation of bleeding and anatomical variations. The black-box simulator requires the scenario to be constructed and set up in the box, and simulating bleeding is difficult. Furthermore, the feedback is best given by an instructor who observes the performance [19, 29]. A computer-based simulator is ready to use when it is turned on. In a few years we believe the computer-based simulator will be able to simulate pathology and manage a patient based on that information; hence, this simulator will be able to provide comprehensive and versatile education, and not just practice of participants' motor skills. Accordingly, when selecting a simulator, one must consider the need; if the need is to train a small group in a specific skill or to test a new procedure or instrument, the black-box simulator is an excellent option. However, if the aim is streamlined training and education of residents, the virtual-reality simulator is a better choice. Timing of practicing surgical skills is shown not to affect the quality of skill acquisition [30]; therefore, simulator training is a perfect training tool for practicing outside normal working hours.

This study allows us to reach the conclusion that basic training on both a black-box and a virtual-reality simulator in a scenario that mimics the principles of a thoracoscopic lobectomy, facilitates surgical skills to an extent where the participants, in combination with targeted instructions, are able to perform a lobectomy on a porcine heart and lung block. The skills learnt on the laparoscopy virtual-reality simulator did not transfer as well to the heart and lung block as those skills learnt on the black-box simulator. The future will show whether training on a dedicated thoracoscopic virtual-reality simulator will offer better skills transfer.

Ethics

All data were kept strictly confidential. At any time, participants could withdraw their consent for participation and their data would be deleted. The assessment of each participant was not discussed with senior colleges or other individuals. Participants were not told how they performed compared with the others. No samples from humans were used in the study and no drugs were administered; hence, this study needed no approval and no protocol number from The Danish National Committee on Biomedical Research Ethics (www.cvk.sum.dk/English/guidelinesaboutnotification.aspx#Afsnit 1.0).

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