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Needs Assessment for an Errors-Based Curriculum on Thoracoscopic Lobectomy

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Abstract

Background—Research suggests a benefit from a skills curriculum emphasizing error prevention, identification, and management. Our purpose was to identify common errors committed by trainees during simulated thoracoscopic lobectomy for use in developing an error-based curriculum.

Methods—Twenty-one residents (postgraduate years 1 to 8) performed a thoracoscopic left upper lobectomy on a previously validated simulator. Videos of the procedure were reviewed in a blinded fashion using a checklist listing 66 possible cognitive and technical errors.

Results—Of the 21 residents, 15 (71%) self-reported completing the anatomic lobectomy; however, only 7 (33%) had actually divided all of the necessary structures correctly. While dissecting the superior pulmonary vein, 16 residents (76%) made at least one error. The most common ($n = 13$, 62%) was dissecting individual branches rather than the entire vein. On the bronchus, 14 (67%) made at least one error. Again, the most common ($n = 9$, 43%) was dissecting branches. During these tasks, cognitive errors were more common than technical errors. While dissecting arterial branches, 18 residents (86%) made at least one error. Technical and cognitive errors occurred with equal frequency during arterial dissection. The most common arterial error was excess tension on the vessel ($n = 10$, 48%).

Conclusions—Curriculum developers should identify skill-specific technical and judgment errors to verify the scope of errors typically committed. For a thoracoscopic lobectomy curriculum, emphasis should be placed on correct identification of anatomic landmarks during dissection of the vein and airway and on proper tissue handling technique during arterial dissection.

There has been significant interest in how to anticipate, prevent, and manage cognitive and technical errors in surgical procedures, in both the professional literature and in the lay press. Policies created to reduce errors that only penalize the surgeon or institution have

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been largely ineffective; for example, fining hospitals for wrong-site operations has never been shown to decrease the incidence of those types of error. Instead, a focus on identifying the events leading to a wrong-site operation and instituting policies, such as surgical site marking, have been more effective [1].

In response to the need to decrease medical errors, a different approach to education is now being advocated [2]. Rather than only teaching how to do a skill correctly, using errors to teach higher-level cognitive skills may lead to decreased errors overall and faster and more effective recovery when errors do occur [3, 4]. This concept has been investigated in the field of cognitive neuroscience, which focuses on how the brain processes information and incorporates new data [5, 6]. That work has shown that the best way to reduce errors and their consequences may be to teach error recovery. This has been described as a multistep process, beginning with error identification [7]:

- first, trainees practice recognizing errors in others' work;
- then, they move on to recognizing their own errors;
- finally, they learn to recover from errors.

Error recovery requires a much deeper comprehension of the key elements and nuances of the procedure as well as the possible errors and their effects. The first step toward developing any type of error-based curriculum is understanding the possible errors that may occur as well as when, why, and how often they occur [8]. The purpose of this study was to identify common errors committed by trainees during simulated thoracoscopic lobectomy for use in planning an error based curriculum.

Material and Methods

This study was conducted under a protocol approved by the Institutional Review Board and the Animal Care and Use Committee.

Participants

Twenty-one residents, postgraduate years (PGYs) 1 to 8, performed a thoracoscopic left upper lobectomy on a porcine tissue block simulator. Volunteer residents were recruited from two different academic surgical training programs and all consented to participation in the study. Each resident performed the study task in a quiet room with only the camera operator present.

Simulator Task

The simulator consists of a previously described porcine heart–lung block (Animal Technologies Inc, Tyler, TX) with the left pulmonary artery and left pulmonary veins distended with a blood substitute fluid (Fig 1) [9]. The tissue block is placed within a 10-gallon plastic container with openings created on the side and end to act as surgical incisions. There is a camera port opening on the caudal end of the box that is equivalent to an incision in the eighth intercostal space, posterior axillary line. There are several incision options on the remainder of the box, including anterior incisions that represent a working incision in the anterior axillary line fourth or fifth inter-costal space and an opening on the

top of the box that provides an angle similar to a posterior retractor port commonly used in thoracoscopic operations.

Participants were shown a 10-minute video of a correctly performed left upper lobectomy on the simulator done by one of the investigators (S.L.M.) and provided with written step-by-step instructions, including diagrams and instrument choice suggestions for each step. A variety of common thoracoscopic instruments were available (Scanlan, St. Paul, MN; Covidien, Mansfield, MA), and visualization was provided by an experienced camera operator with a 30-degree, 10-mm thoracoscope (Karl Storz Endoscopy, Tuttlingen, Germany). The camera operator was not allowed to provide any assistance or verbal commentary.

Each resident was given 30 minutes of practice with the simulator before beginning the scored task to limit the simulator-specific learning curve. The resident was asked to divide the necessary veins, arteries, and bronchi for a left upper lobectomy. Division of the fissure was not performed to limit the number of staple loads needed. A time limit of 60 minutes was set to limit frustration, although several of the most junior residents did quit before the time limit. All lobectomies were videotaped for later review and assessment.

Data Collection Tool

An assessment tool was created by consensus of the surgeons involved in the study as a comprehensive checklist of errors a resident could create while performing the procedure. An error was defined, using the discussions of the Bellagio Conference on Human Error [10], as any action or lack of action that (1) fails to meet an implicit or explicit external standard or (2) fails to achieve its desired outcome other than through chance occurrence. Errors were subdivided by the major steps of the procedure: vein division, arterial division, airway division, and retraction and exposure. Table 1 shows a representative portion of the full procedure checklist (apical artery division), which contained 66 possible errors.

Errors were additionally divided into cognitive and technical. Cognitive errors included those showing poor knowledge of the anatomy and steps of the procedure, such as dissecting the incorrect structure or the incorrect location of the correct structure. Technical errors occurred when the correct action was attempted but executed incorrectly, such as vascular injury, torn lung parenchyma, or excessive tension on a structure. All videotapes were reviewed by a single experienced surgeon (S.L.M.) in a blinded fashion, and the checklist was used to identify each potential error as present or absent.

Once the initial review of all videotapes was completed, a random subset of 6 videotapes was chosen for validation. These were reviewed by the same single surgeon, again in a blinded fashion, to establish intrarater reliability. Interrater reliability was investigated similarly with a second experienced surgeon (B.C.T.) reviewing the same 6 blinded videotapes.

Statistical Analysis

Error results are shown as mean $\pm$ standard deviation per resident. Error frequencies are shown as percentage of residents in the group making the specified error. Statistical analysis

was performed using the Mann-Whitney U test for groups with unequal variances to investigate differences between types of error (cognitive vs technical) in the entire procedure and within each step of the procedure. The Mann-Whitney U test was also used to analyze differences in error types between senior and junior residents. A value of p of 0.05 or less was considered to be statistically significant.

Results

Participant Demographics

The study group comprised 11 residents in the first 3 years of clinical training (junior, PGYs 1 to 3) and 10 senior residents (PGYs 4 to 8). Junior residents had limited thoracoscopic surgical experience. Although many had rotated on a thoracic surgery service, only 3 had seen a thoracoscopic lobectomy in a patient and only 1 had attempted any portion of the operation in a patient. The senior residents had all rotated on a thoracic surgery service at a senior level and had all seen and attempted at least a portion of a thoracoscopic lobectomy in a patient.

Validation of Assessment Tool

Intrarater reliability of the assessment checklist using the 2 blinded reviews of the randomly selected subset of 6 videotapes showed good correlation, with a Cohen's κ coefficient of 0.81. After review of the same subset of 6 videotapes by the second experienced investigator, Cohen's κ coefficient for interrater reliability was 0.79.

Assessment of Resident Performance

The standard for the task was set by one of the investigators (S.L.M.), who performed the procedure in 18 minutes with no errors. Of the 21 residents, 6 (29%) ran out of time (took longer than 1 hour) or voluntarily quit before completion of the lobectomy due to lack of progress. The remaining 15 residents (71%) reported they had completed the lobectomy before the 1-hour time limit. A review of the videotapes, however, showed only 7 of the 21 residents (33%) had divided all of the necessary structures correctly. Although senior residents were more likely to claim they had completed the procedure (100% senior vs 45% junior, $p = 0.006$), they did not have a higher rate of successful anatomic lobectomy (40% senior vs 27% junior, $p = 0.56$). Only one resident (PGY 8) of the entire group completed the entire anatomic lobectomy without errors. The residents committed an average of 9.1 ± 4.6 errors during the procedure. This estimate of errors is conservative count because those who did not finish the procedure were unable to show they would or would not have committed errors during those latter steps.

Overall, a significantly higher number of cognitive errors were made per resident (5.5 ± 3.9) compared with technical errors (2.9 ± 1.7 , $p = 0.017$) even though there were similar numbers of potential cognitive errors (36) and potential technical errors (30) on the assessment tool. The most common overall error ($n = 13$, 62%), a cognitive-type error, was dissecting too distally on the vein branches rather than around the entire vein (Table 2). The most common technical errors were excessive tension on the lingular artery during

dissection ($n = 8$, 38%) and tearing of lung parenchyma due to excessive force during retraction ($n = 6$, 29%).

Analysis of Cognitive and Technical Errors by Error Location

The procedure was divided into four tasks: division of the superior pulmonary vein, division of the upper lobe bronchus, division of all pulmonary arterial branches to the upper lobe, and retraction and exposure. While dividing the superior pulmonary vein, 16 of 21 residents (76%) made at least one error, with an average of 2.8 ± 2.4 errors per resident (Table 3). The two most common errors were dissecting too distally on the vein branches, as mentioned, and separate division of the lingular vein branch ($n = 9$, 43%). These were both classified as cognitive errors, and overall the number of cognitive errors was six times higher than the number of technical errors during vein division (2.4 ± 2.2 cognitive errors per resident vs. 0.4 ± 0.7 technical errors per resident, $p = 0.002$).

Division of the airway was similar, with 14 residents (67%) making at least one error. The two most common errors were, again, cognitive. Nine residents (43%) dissected too distally on the bronchial branches rather than around the upper lobe bronchus as a whole, and 7 residents (33%) not only began their dissection too distally but also went on to encircle only the upper division bronchus rather than the lobar bronchus.

While dissecting the arterial branches, 18 of 21 residents (86%) made at least one error. During arterial dissection, the number of technical errors was equal to the number of cognitive errors. The most common error during arterial branch division was technical, comprising excess tension on an arterial branch: 6 (29%) created excessive tension on only the lingular branch, 2 (10%) caused excessive tension on only the apical branch, and 2 additional residents (10%) created excessive tension on both arterial branches. Cognitive errors remained common, however, with 5 residents (24%) dissecting too proximally, encircling the main left pulmonary artery with the potential consequences of unintentional pneumonectomy.

Errors of retraction and exposure were also very common. Eleven residents (52%) made at least one cognitive retraction error, such as trying to dissect or pass a stapler without retraction or pushing the retractor posteriorly, which flattens the hilum making vascular injury more likely. Six residents (29%) retracted with enough force to tear the lung parenchyma where the retractor grasped the tissue. Although there are no long-term consequences to this error because the tissue affected is going to be removed anyway, this error in a patient will lead to bleeding that often obscures the operative field and can make dissection difficult.

Analysis of Cognitive and Technical Errors by Resident Level

There was no difference in the total number of errors between junior residents (10.0 ± 3.5) and senior residents (8.0 ± 5.6 , $p = 0.31$). Looking more closely at the types of errors showed that cognitive errors, which made up most of the errors committed, were also not different between resident groups (6.3 ± 3.5 junior vs. 6.1 ± 5.3 senior, $p = \text{NS}$). The most common cognitive error by junior residents, committed by 8 (73%), was dissecting too

distally on the vein branches, followed by dissecting too distally on the bronchial branches and separately encircling the lingular vein, each committed by 5 residents (45%). Six (54%) of the junior residents failed to look for the lingular artery, but none of the senior residents omitted this task. Senior residents made some of the same cognitive errors as the junior residents, with the most common being dissecting too distally on the vein ($n = 5$, 50%) and dissecting too distally on the bronchus ($n = 4$, 40%). Technical errors, however, were significantly more common among junior residents (3.8 ± 1.5) than senior residents (1.9 ± 1.2 ; $p = 0.008$). The most common technical errors among junior residents were excessive tension on the lingular arterial branch and tearing of lung parenchyma due to excessive force during retraction ($n = 5$, 45%). Senior residents also commonly created excessive tension on the lingular arterial branch ($n = 3$, 30%), but only 1 senior resident caused tearing of the lung parenchyma due to excessive force during retraction.

Comment

There has been significant interest in cardiothoracic surgery in improving preparation of our trainees for their first practice, especially in the setting of reduced educational contact hours and decreased years of training. Some of this interest has focused on the use of errors in training. Teaching error detection and, ultimately, error recovery through an active learning process has been suggested as a technique to help trainees develop robust mental constructs, allowing them to be more prepared for situations such as aberrant anatomy, unfamiliar pathology, and unexpected events and complications [7]. The ability to detect surgical errors has also been shown to correlate with surgical skill [11]. Curricula that include the correct version of a procedure and examples of possible errors have been shown to improve the quality of task performance [12–14].

Simulation curricula have the unique ability to provide controlled variation in the situations presented to enhance learning in contrast to the traditional learning method of exposure in the operating room, which is limited to the random variability of patients and situations encountered. Although residents may derive significant learning from an adverse event in the operating room, the surgeon's primary goal in the operating room is the safe and expedient completion of the planned procedure with a minimum of detours.

To design this type of error-based curriculum, it is important not only to understand what types of errors are possible for a given procedure but also which errors are most common and which carry the most risk to the patient. Before the initiation of this study, an extensive list of possible errors was developed by the consensus of the authors. Its 54 elements included a wide variety of technical and cognitive errors for each major component of a thoroscopic left upper lobectomy. During review of the videotaped procedures, an additional 12 error types were identified that had not occurred to the authors.

The videotape review was an essential part of identifying all potential errors given that expert surgeons perform tasks largely without conscious knowledge as a result of experience [15]. Previous studies have shown that when experts describe how to perform a difficult task, they unintentionally omit up to 70% of the critical information due to their

“unconscious competence.” This is an important process point for others wanting to develop any type of procedural checklist [16].

This also highlights the differences in thought processes between experienced surgeons and trainees. One example of this was a trainee who encircled and divided the lingular artery at the same time as the upper lobe bronchus, a possibility not even considered on the original list. Another error seen on several videos was trying to pass the stapler with the larger (cartridge) side through the small opening behind a vessel, causing excessive tension and bleeding. Although facing the stapler in the correct direction seems obvious to an experienced surgeon, it clearly is not to a beginner and as such should be noted in a curriculum.

By observing the types and locations of errors, a pattern emerges that will help focus a curriculum. In the first step of the procedure, division of the superior pulmonary vein, the most common errors were cognitive, mainly relating to the anatomy of the branches. Many residents who initially only divided one branch of the vein did recognize their error and went on to take the other branch separately. Several who divided only the upper division branch went on to do a lingular-sparing upper lobectomy without realizing their mistake, demonstrating that an early anatomic misidentification can have significant downstream effects if the error is not recognized. Errors can be classified based on their consequences, with dividing only one branch being a high consequence error if not recognized. Recognition and subsequent division of the other branch changes the situation to a low-consequence error that requires extra staple loads and time but does not change the outcome of the operation.

On the basis of this pattern, it will be important when designing a curriculum to focus on identification of the branches of the superior pulmonary vein to ensure that all branches are included in the dissection. The concept of careful anatomic identification can then be translated into bronchial dissection, which has a similar pattern of branching. In the case of the bronchus, dissecting too distally on the airway can cause the dissecting clamp to catch on an early posterior branch. If not recognized, this can lead to airway injury or make encircling the airway impossible.

Technical errors during arterial dissection became as common as cognitive. The pulmonary artery is much more sensitive to technical errors such as excess tension on branch points. This will initially result in a subadventitial hematoma, which is often rapidly followed by significant bleeding. During dissection of the arterial branches, it would be helpful to focus on atraumatic technique, often described as working around the artery rather than working on it. Because bleeding from the pulmonary artery can be difficult to recover from, especially in a thoracoscopic procedure, focusing on technique at this point could limit the errors with the most severe consequences. Technical errors were more common with the junior residents, and some of the basic concepts of vascular dissection may have been previously taught during other surgical rotations such as vascular surgery or transplant surgery to the more senior residents.

In conclusion, the pattern of common errors among trainees in this study suggests that correct identification of anatomic landmarks is lacking for all segments of the procedure and in all levels of residents. However, technical errors are more common during arterial dissection and especially with more junior residents. These findings will help to define specifics regarding resident learning needs critical to designing an error-based curriculum for thoracoscopic lobectomy.

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Fig 1.
(A) Prepared tissue block shows distention of the superior pulmonary vein. (B) Tissue block during dissection. The superior pulmonary vein has been divided and the apical arterial branch is being dissected.

Table 1

Representative Portion of the Assessment Checklist

Mistake (Yes/No)	Apical Artery Errors	Error Type
	Bleeding	Technical
	Excess tension during dissection	Technical
	Unable to identify	Cognitive
	Unable to encircle	Technical
	Unable to pass stapler	Technical
	Dissect too distally (out on branches)	Cognitive
	Partial division (left some branches)	Cognitive
	Dissect too proximally (around main PA)	Cognitive
	Divide main PA	Cognitive
	Staple too proximal on branch, constrict PA	Technical
	Stapler passed backwards	Technical

PA = pulmonary artery.

Table 2**Most Common Errors At Each Step of the Procedure**

Surgical Task	Error Description	Error Type	Committed the Error
Vein			No. (%)
	Dissection too distal on the branches	Cognitive	13 (62)
	Separate division of the lingular vein	Cognitive	9 (43)
Artery	Separate division of the upper division vein	Cognitive	8 (38)
	Excessive tension on an arterial branch	Technical	10 (48)
	Dissection proximal around main PA	Cognitive	5 (24)
	Unable to identify the lingular artery	Cognitive	4 (19)
Bronchus	Unable to encircle the apical arterial branch	Technical	3 (14)
	Dissection too distal on the branches	Cognitive	9 (43)
	Encircle only upper division airway	Cognitive	7 (33)
	Divide upper division airway separately	Cognitive	6 (29)
Retraction	Staple load not all the way across airway	Technical	4 (19)
	Push retractor posteriorly, flattening hilum	Cognitive	7 (33)
	Tear lung parenchyma due to forceful retraction	Technical	6 (28)
	Attempt to pass stapler without retraction	Technical	2 (10)

PA = pulmonary artery.

Table 3

Analysis of Errors Committed by Portion of the Procedure

Surgical Task	Errors per Resident (Mean $\pm$ SD)			M-W <i>U</i> Test	<i>p</i> Value
	Total	Technical	Cognitive		
Vein	2.8 $\pm$ 2.4	0.4 $\pm$ 0.7	2.4 $\pm$ 2.2	107	0.002 ^a
Artery	3.2 $\pm$ 1.9	1.5 $\pm$ 1.1	1.7 $\pm$ 1.5	216	0.91
Bronchus	2.2 $\pm$ 2.1	0.7 $\pm$ 0.8	1.5 $\pm$ 1.8	188	0.38
Retraction	0.9 $\pm$ 0.6	0.3 $\pm$ 0.5	0.6 $\pm$ 0.6	165	0.10

M-W = Mann-Whitney; SD = standard deviation.

^a All *p* values are for technical errors compared with cognitive errors.