Review Article on Robotic Thoracic Surgery

Training residents in robotic thoracic surgery

Evan T. Alicuben, Sean C. Wightman, Kimberly A. Shemanski, Elizabeth A. David, Scott M. Atay, Anthony W. Kim

Division of Thoracic Surgery, Department of Surgery, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA

Contributions: (I) Conception and design: ET Alicuben, SC Wightman, AW Kim; (II) Administrative support: None; (III) Provision of study materials or patients: None; (IV) Collection and assembly of data: ET Alicuben, SC Wightman, AW Kim; (V) Data analysis and interpretation: ET Alicuben, SC Wightman, KA Shemanski, EA David, SM Atay, AW Kim; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Anthony W. Kim, MD. Professor of Clinical Surgery, Chief, Division of Thoracic Surgery, Keck School of Medicine, University of Southern California, 1510 San Pablo St., Suite 514, Los Angeles, CA 90033, USA. Email: Anthony.kim@med.usc.edu.

Abstract: With growing integration of robotic technology in thoracic surgery, the need for structured training has never been greater with trainees expressing desire for additional experience. Determining the ideal education program is challenging as the collective experience is still relatively early and growing with many experienced surgeons still becoming facile with the platform. Understanding differences between robotic and thoracoscopic approaches including lung retraction and dissection, use of carbon dioxide insufflation, and lack of tactile feedback serves as the foundation for building a skillset. Currently, there is no standard accepted curriculum for residents. Inclusion of these trainees in structured programs has been shown to be safe with equivalent patient outcomes. There are multiple curricula under development, all of which incorporate use of simulation technology, dual console, and clear, graduated responsibilities within operations. These include introduction to the robotic system prior to progressing to bedside assistance and finally to time as console surgeon. The importance of clear definition of training milestones with deliberate graduation to more complex tasks once competency has been demonstrated cannot be overstated. It is crucial for surgeons practicing robotic surgery to make efforts to further the training of residents, but there has not been any perfect and suitable program identified yet.

Keywords: Robotic surgery; residency training

Submitted Mar 12, 2020. Accepted for publication Nov 12, 2020.
doi: 10.21037/jtd-2019-rts-06
View this article at: http://dx.doi.org/10.21037/jtd-2019-rts-06

Introduction

The application of robotic technology to thoracic surgical procedures has been shown to be safe and possibly with equivalent oncologic outcomes (1-5). Paralleling the increasing adoption in various disciplines across the world, use of the robotic platform in thoracic surgery suggests that it is becoming a more permanent fixture (6-8). As comfort levels have grown, cases typically approached via thoracotomy have been successfully performed robotically, thereby giving patients the benefits of minimally invasive surgery (5). Education in robotics is a challenging topic to wrap the proverbial surgeon's arms around as the collective experience is relatively early and growing. Furthermore, at the individual level, many surgeons have yet to become facile with this platform. Thoracic surgeons must first learn the robot themselves prior to teaching it, thereby complicating the ease of educating trainees. Nevertheless, it is necessary to elucidate a training curriculum which adequately prepares residents for independent practice. This task must be achieved while also acknowledging a known robotic learning curve. Including robotic training in an already busy resident curriculum is an additional challenge for surgical program directors nationwide.

Fundamental differences of the robotic versus the thoracoscopic approach

The use of robotic technology in thoracic surgery is fundamentally different from robotic utilization in other surgical specialties. The differences in robotic surgery from standard thoracic surgery include lung retraction, dissection, carbon dioxide insufflation, camera adjustment, lack of tactile feedback, and limited maneuverability within the chest. These differences translate into additional challenges to overcome when teaching the robot to an early user. Traditionally, training in thoracic surgery has been a pursuit that has required a fundamental skillset in general surgery. Classical pathways as well as the relatively newer integrated thoracic training paradigms still warrant establishing fundamental skills prior to pursuit of thoracic training. Consequently, this required training hints at a different level of necessary teaching especially as it pertains to training in robotic thoracic surgery.

In robotic thoracic surgery anatomic resections, lung retraction is fundamentally different from video-assisted thoracoscopic surgery (VATS). Owing to the lack of haptic feedback, the concept of "visual haptic" feedback requires a degree of attention to be paid toward the visualization of avoiding traumatic retraction injuries rather than feeling the force feedback in thoracoscopic surgery that can allow for more intuitive movements. This understanding may translate into subtler movements that include pushing the lung laterally aside to expose the hilum rather than retracting the lung away from the hilum as in a thoracoscopic case. In this regard, traction injuries from a "drift" phenomenon give way to increased pushing of tissue which ostensibly do not result in significant injury. This exposure strategy may change the angle of visualization appreciated with the thoracoscopic approach and thus, introduce, visualization challenges. Fortunately, some of this difficulty is ameliorated by a unique and arguably improved visualization and also attenuates with greater experience as it becomes the new standard.

Additionally, the absence of tactile feedback further translates into a requirement for a different dissection strategy from that of a thoracoscopic approach. The ability to sense the resistance of tissue during a thoracoscopic dissection lends itself to blunt probing and entry into planes around delicate structures, such as veins or arteries. During a thoracoscopic case a surgeon can receive tactile feedback, while not always via direct palpation, through the instruments inserted into the chest. During a robotic case, the surgeon is removed from the patient and stationed at the console. The console surgeon does not experience any direct tactile feedback, but only appreciates the limitations in an instrument's movement; therefore, the surgeon must rely on visual cues for feedback. Furthermore, while an understanding of the anatomy is a *sine qua non* of being a qualified surgeon, the lack of a reliance on tactile feedback mandates a greater understanding of where the dissecting instrument, and more importantly, important structures, are located.

While carbon dioxide insufflation can be used during thoracoscopy, it typically is not utilized in the majority of cases. In part, the use of an access or utility incision during the VATS approach does not lend itself to the creation of a route that will allow for the needed degrees of freedom while maintaining a sealed system to retain carbon dioxide. A fully robotic approach using only ports allows for a closed system that will retain insufflated carbon dioxide. This added component, routinely utilized for robotic cases results in a "push" of the diaphragm inferiorly and "compression" of the mediastinum to the contralateral side. This latter effect has the ability to minimize the mediastinal shifting during ventilation of the contralateral lung. While the CO_2 insufflation increases the working space within the chest, it also causes potential tension pneumothorax physiology. Ultimately, for the purposes of teaching, the use of CO_2 diminishes the need for retraction to a certain extent but comes at the expense of further limiting direct access to the pleural cavity due to the need for the aforementioned sealed state (*Figure 1*). Although rare, this access issue can be problematic with bedside assisting or, less commonly, during the need to address an urgent or emergent situation, such as retracting at specific angles so that utilization of the robotic arms for a specific movement can be performed or even to apply pressure for bleeding.

Three-dimensional (3D) visualization can fortunately offset some of the challenges associated with the robotic platform. A fundamental difference between the dual lens 3D camera and the two dimensional (2D) single lens thoracoscopic camera is that most thoracoscopic cases are done in a broad view for all participants to see. The robotic approach requires that there is frequent toggling between a broad and a close-up view. For a bedside assistant, a close-up view can create a situation in which identifying locations of instruments in the chest placed through an assistant port may be difficult. Many times this requires a surgically competent assistant who can maneuver independently as the console surgeon is unable to direct all movements at

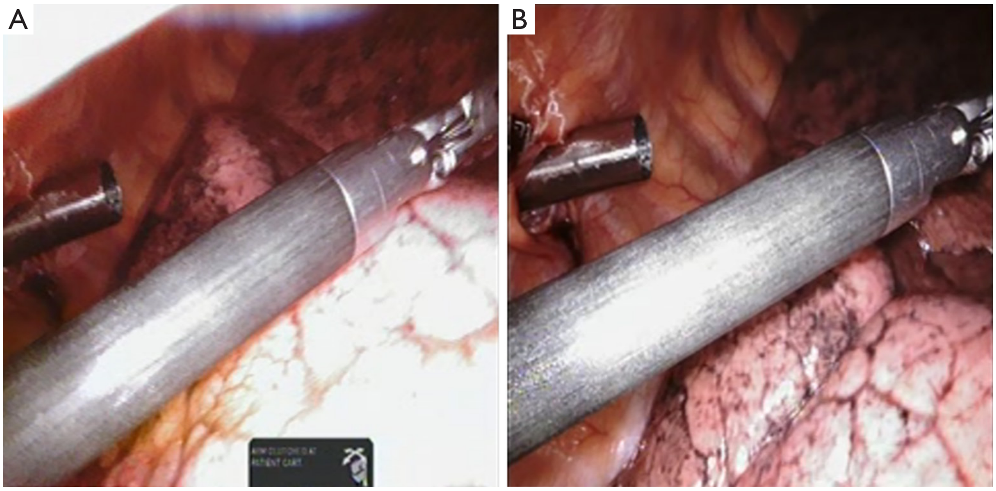


Figure 1 Difference in visualization afforded (A) without and (B) with carbon dioxide insufflation.

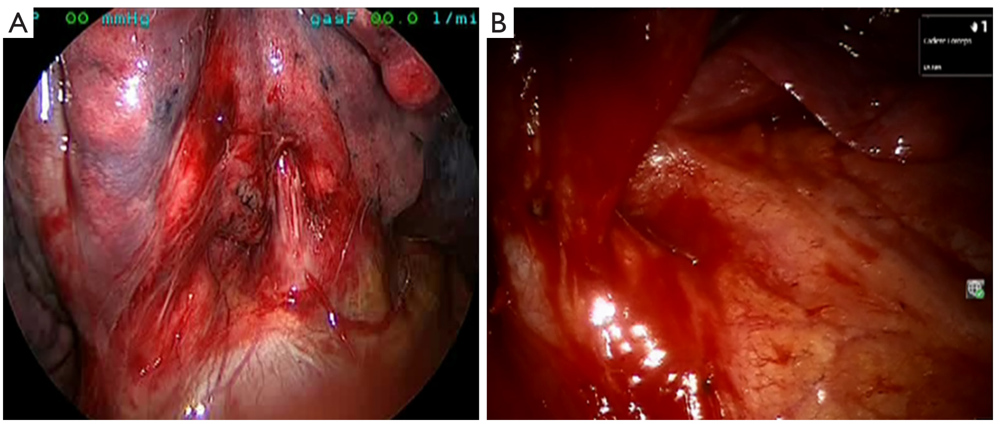
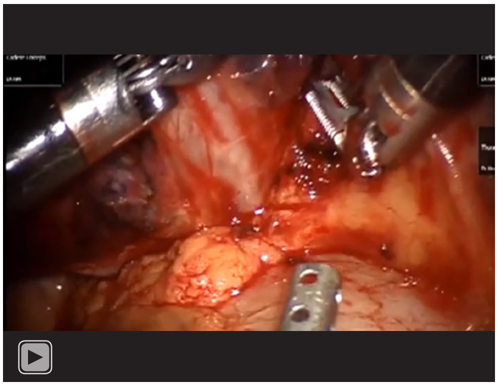


Figure 2 Differences in visualization of the inferior pulmonary vein during right lower lobectomy viewed (A) anterolaterally afforded by thoracoscopic approach and (B) caudally afforded by robotic approach.

the bedside. For the console surgeon, a broad view leads to the inability to dissect delicate structures with the much-needed visual feedback. Furthermore, the close-up view can lead to a situation where there is a loss of understanding of the role or activity of the arms that are outside of the visual field. Without the aforementioned tactile feedback and the potential for drift, injury to intrathoracic structures may occur. Finally, in this regard, a subtle but exacerbating feature of the robotic approach is the fact that for robotic operations, owing to the need to have optimal visualization, the trocar incision site selection is critical and very specific to the target anatomy. As an example, if performing a lobectomy, the ports are placed lower in the chest than where traditional thoracoscopic incisions are placed. This is contrary to a thoracoscopic incision strategy where much of the chest can be explored and operated within through the same incisions. The robotic incision strategy requires an understanding that the camera and instruments are arriving from a more caudal approach, and thus, the visualization is different than what would be seen with a thoracoscopic approach (*Figure 2*). Additional challenges can be found in the fact that the thoracic cavity represents a fixed space limiting the mobility of the robotic arms especially compared to the abdomen. This fact underscores the importance of proper incision locations for trocar placement at the beginning of an operation as there is little



Video 1 Video demonstrating different phases of developing the fissure for left upper lobectomy. The beating of the heart, motion of the pulmonary artery, and the respiratory motion of the mediastinum from the ventilation of the contralateral lung illustrate the constant motion that is encountered during pulmonary lobectomy.

forgiveness due to the rigidity of the rib cage.

When compared to intra-abdominal surgery, the proximity of intrathoracic surgery to the lungs and heart cause the operative field to be in constant motion (*Video 1*). This moving target adds complexity to thoracic operations. This proximity to the heart and major vasculature also distinguishes itself from intra-abdominal operations in that any injury has a greater degree of lethality and often has a zero margin of error during an operation. Given the lack of ability of the vasculature to constrict once injured such as with a peripheral artery, emergent conversions to address pulmonary vascular injuries can become a necessity. Some degree of vascular injury can be controlled while remaining with the robotic approach (9,10). Again, this requires a bedside assistant with surgical competence who can help gain control of or at least temporize the situation. Additionally, augmenting experience suggesting increased exposure and utilization of the robotic platform may decrease the need for conversions (11).

Cumulatively, it is due to many of these challenges that the adoption, implementation, and mastery of the robot in thoracic surgery is associated with an increased level of complexity. In general, the use of the robotic platform in thoracic surgery is fundamentally different than its use in many other surgical disciplines. These challenges not only must be considered by anyone utilizing the robot for thoracic surgery but also specifically adds a layer of complexity when educating trainees on the robot.

Learning robotic thoracic surgery

The acceptance of the robotic platform in thoracic surgery parallels that of VATS historically. As the thoracoscopic approach to various thoracic surgical diseases grew in popularity, its limitations were also identified. These limitations primarily included the specific need for well-trained, facile surgeons who could maneuver safely and deal with potential complications within the closed chest. Logically, this resulted in initial training targeting experienced surgeons (12,13). Eventually, the development of standardized training programs demonstrated that surgeons of varied experience levels could be trained in procedures such as VATS lobectomy without compromising patient care (14). Presently, the routine utilization of the thoracoscopic approach by many institutions has translated into many trainees becoming facile with this approach following their standard training (15). There still remains a number of other formal advanced training opportunities in which skills with thoracoscopic surgery can be further honed. This similar approach was taken with those learning robotic surgery with development of structured training programs also resulting in safe performance of similar operations (12,13,16,17). Similarly, there are opportunities that exist to receive additional training in robotic thoracic surgery beyond standard board certification requirements. Presently, the current scientific data support the success of learning and training robotic thoracic surgery. Most of the earliest reports highlighting patient safety emerged from large academic programs, with experienced thoracoscopic surgeons (12,18). Eventually this expanded to smaller centers demonstrating similar outcomes (13). European and Asian centers with limited experience have relied on these large programs to successfully expand into the area (17,19). Currently, surgeons in training are also being trained in robotic procedures.

Additional data has emerged identifying the time required for proficiency in robotic thoracic procedures. Collectively, these studies have identified the performance of approximately 20 lobectomies (range: 15–60) as a marker for technical facility with the robotic platform (20-27). In one of the more statistically rigorous determinations of this learning curve, Arnold *et al.* utilized a cumulative sum (CUSUM) analysis of operating time to identify a 22-case learning curve with mastery achieved after 63 cases (28). However, this study acknowledged that the operating surgeon had significant thoracoscopic experience prior to transitioning into robotic technology. In aggregate, these studies have

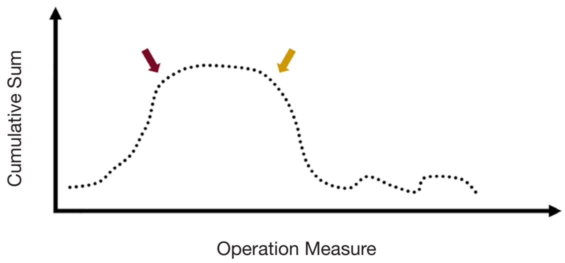


Figure 3 Cardinal arrow depicts the end of the first phase of the Cumulative Sum (CUSUM) analysis where the operator is deemed to have come off the initial learning curve and is plateauing into the expert competence portion of the learning curve. The gold arrow indicates the end of the second phase where the operator is deemed to have entered the mastery phase of the learning curve.

focused on surgeons in practice, with suggestion that those with more thoracoscopic experience will have a shorter learning curve (20-22,27,28). None have examined the differing requirements for those in training with little to no experience and even more so those actively learning general surgical principles concurrently. Defining this learning curve will be an important aspect of a standardized curriculum (*Figure 3*).

Teaching robotic thoracic surgery

There is a demand among trainees to learn the robot during residency (29,30). This was a similar finding to other specialties (31). Gynecology and urology were the early-adopting specialties with robotic implementation. Presently, robotic techniques are widely recognized as a minimally invasive modality for their respective curricula and board certification requirements (32,33). For thoracic surgery, while robotic education is not incorporated into every residency, there has been a notable increase in its integration.

Residents are already mandated to learn open and video-assisted techniques by the American Board of Thoracic Surgery. The addition of robotic education has added a layer of complexity to an already crowded curriculum for resident training. Resident education in robotic surgery is of paramount importance to trainees themselves (29). Recent graduates of thoracic surgery training programs completed a voluntary survey with the goal of identifying areas where they felt more instruction was needed (34). A significant percentage of respondents reported discomfort with robotic procedures including cardiac (55.8%), pulmonary (55.8%) and esophageal (61.5%) operations. The fact that the majority of graduates indicated a lack of confidence in these robotic procedures highlights the importance of quickly modifying current training programs (34).

In a meticulously designed system, Cerfolio and colleagues were able to demonstrate the effectiveness of their system in resident training (35). They divided robotic lobectomy into 19 distinct steps each encompassing a different technical maneuver with assigned time goals. If a resident was able to perform a step, scores of 100% were recorded. The system also accounted for performance across multiple sequential operations allowing for scores between 0 and 100%. Following the operation, formal review was held between resident and attending surgeon with focus on areas unable to be performed by the trainee. Over 5 years, 520 operations were performed with a significant increase in the percentages of the operation accomplished. Some steps increased to over 90–100% completion by the resident. Importantly, patient outcomes including mortality and major morbidity were unchanged. In fact, need for conversion to thoracotomy (15% to 2.5%, P=0.042) and major vascular injury (3% to 0%, P=0.018) significantly decreased (35). This success was demonstrated elsewhere in over 100 robotic cases again resulting in no difference in operative outcomes with the trainee as the primary surgeon (36).

In total, these studies demonstrate a significant need for increased robotic training and a system that is not currently meeting the need. Concerns of patient safety are not well founded and should not preclude trainee participation in operations. A well described step by step approach has been developed and validated. Similar protocols should be made for other thoracic operations.

The study performed by Cerfolio *et al*. demonstrated safety in robotic education. This differs from other surgical teaching where both attending and trainee are operating simultaneously. With robotic teaching, even if a dual console is utilized, only one surgeon is interacting with the patient at a time; often requiring the attending surgeon to give up more control during robotic cases to the trainee.

Robotic education in thoracic surgery is distinctly different from that in other more integrated robotic fields like urology and gynecology. Specific and intentional focus is required in thoracic surgery to provide appropriate training to learners. In urology and gynecology, since the tool of the robot is more widely accepted, those trainees are more adept and likely to graduate their training program comfortable using the robot independently.

Robotic thoracic surgery training curriculum

Currently there is no standardized or widely accepted curriculum for the training of thoracic surgery residents sponsored by the American Association of Thoracic Surgery (AATS) or the Society of Thoracic Surgeons (STS), nor is any robotic experience required to sit for the American Board of Thoracic Surgery exam. Additionally, no case minimums exist from the Accreditation Council for Graduate Medical Education to determine proficiency during training. These curricula are currently under independent development by training programs (17). While some curricula already exist for surgeons in practice, most have identified residents as having different requirements for training in robotic technology (37). The AATS does sponsor a surgical robotics fellowship providing opportunities for senior trainees and their attending surgeons to participate in a two-day intensive course at a designated Intuitive Surgical Inc. (Sunnyvale, CA, USA) training facility followed by an advanced course. Didactic lectures are integrated with hands-on porcine and cadaveric labs exposing participants to robotic technology and its surgical applications. This training parallels that of a practicing attending surgeon who desires to be trained appropriately and credentialed using the robotic system.

Raad and colleagues recently have proposed a program based on survey responses from 17 cardiothoracic integrated program directors and a review of urological, gynecological, and general surgical robotic surgery training curricula published in the literature (38). Their program was divided into two stages: pre-clinical (PGY 2 and 3) and clinical (PGY 4-6). In the pre-clinical years, residents complete online modules via the Fundamentals of Robotic Surgery or Intuitive Surgical Inc. da Vinci Surgery Online Community (Sunnyvale, CA, USA) to learn elements of utilizing the robot and its safety features. Additionally, completion of carefully selected simulation modules is required with demonstration of mastery of each. Lastly, hands-on workshops are held to emphasize and review key principles. In the clinical years, residents serve as both beside assistants and console surgeons in a graduated fashion. Importantly the role of the bedside assistant is clearly defined with the trainee demonstrating proficiency in trocar insertion, instrument insertion, and assistance with retraction and suctioning. Each surgical procedure is broken down into steps of varying difficulty with a formalized assessment of the resident's performance of these steps. Only when residents demonstrate proficiency of these steps can they progress to more complex components (38). This curriculum would include all of the recommended components for a robotics training program outlined by the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) consensus document (39). There have been efforts made to codify an international structured training program, but presently these have yet to be published and recognized by professional organizations.

The role of simulation technology has become an essential component in preparing to perform robotic procedures (40,41). With the currently available programs, learners complete specially designed tasks on a robotic console identical to that which an actual operation is performed. These tasks progress in difficulty and translate directly to required operative skills. In fact, use of the simulator has been shown to result in more significant skill improvement compared to training using the surgical system on inanimate objects (42). Creation of user accounts allows for the tracking of performance over time with specific improvement targeted feedback on aspects such as economy of motion, tissue handling, and time. These metrics can help educators gauge when a learner may be ready to take control of an operation. The use of the simulator also was found to translate into performance improvement (42-45). While the simulator is demonstrated to be an effective tool, there still lies an inherent leap of faith when moving from the simulator to a human patient. This clearly demonstrates a need for more cadaveric or animal tissue laboratory sessions in training to provide the proverbial "tissue touches".

Emphasis on the dual console has further evolved education with the robotic platform. Prior to its implementation, there was a high threshold to switch the operator between the attending surgeon and the bedside trainee as this involves scrubbing and rescrubbing into the sterile field. With the dual console, a third person, who is presumably a facile assistant, is required to function as bedside assistant. This, in turn, allows the teaching surgeon to switch from being the observer to operator easier at the console by making the toggling of the operation back to the trainee relatively seamless. Additionally, the attending surgeon can use the robotic controls to maneuver a pointer across the screen, providing precise visual and verbal direction to trainees. The importance of the dual console was further emphasized in a recent survey of general surgery

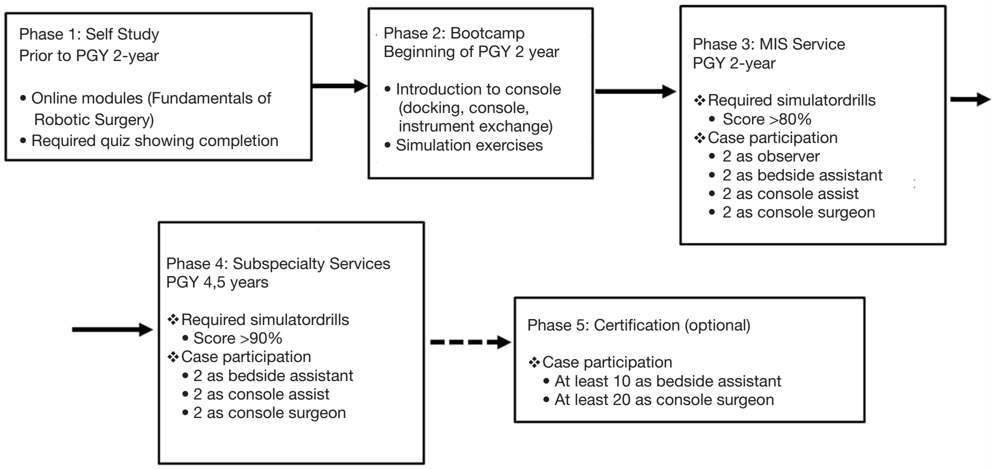


Figure 4 University of Southern California Robotics Curriculum: trainees complete each phase with graduated responsibilities. Most phases are completed by the end of PGY 2 years and simultaneously fulfills requirements to achieve certification by the end of residency training.

residents where all participants indicated that having this technology was necessary for maximal learning (30). Most importantly, use of the dual console formalizes the educational aspect of the operation and has been shown to be safe with equivalent outcomes (46). A possible limitation of the dual console is the increased emphasis on verbal instruction required given the inability to share control of an instrument as would be possible with open or laparoscopic surgery (47).

A formalized, detailed, thoracic surgery specific curriculum needs to be accepted and made available for training programs to adopt easily. This should include clearly defined graduated responsibilities within operations that will allow for efficient advancement once competency has been reached. Integration of simulation and dual console technology is essential, and every effort should be made on making these available to trainees if not easily accessible currently. Our institution has developed a robotics training curriculum utilizing these principles for general surgery residents (*Figure 4*).

Other challenges associated with teaching robotic thoracic surgery

The integration of new technology into patient care is fraught with challenges. Early on in a surgeon's robotic utilization, appropriate patient selection for successful robotic cases can be challenging. Scheduling cases can be difficult due to limited availability and multiple surgeons' desire to take advantage of this limited resource. The added concern that robot use may cost more than performing the case VATS may deter its use (48,49). However, it should be noted that other studies have demonstrated equivalent cost between the two approaches when a propensity adjusted comparison was performed (50). Lastly in this regard, there currently is one large robotic provider of surgical technology. This lack of competition may, to some degree, stifle the advancement of innovative robotic technology.

The final challenge of robotic training is the same for all aspects of surgical training. The skill sets of surgical trainees are not always equal and some may be more facile in their use of the robot and therefore catch on more quickly. Constant assessment of skills acquisition is crucial and predicting performance level with robotic technology is difficult (51). One study has demonstrated that laparoscopic skill level may correlate with robotic ability (52). However, with the increasing integration of robotics into surgical curriculum, there are likely trainees who will learn the robotic approach as their first minimally invasive modality. This may not be an issue as some have suggested that robotic surgery more closely mimics open approaches given the similar hand and wrist movements (47). Taken in total, this requires the instructor to individualize teaching style to the learner (53).

In the current economic climate, a hospital's position emphasizing rapid throughput or a medical practice's desires to generate more relative value units in the operating room may not be aligned with the time and effort necessary to teach a technically demanding operation. These concerns warrant a rethinking among all invested parties to revalue the importance of teaching trainees on this platform.

Conclusions

Trainee interest in robotic thoracic surgery has never been stronger, with most graduates indicating the need for additional training. Integrating the robot into surgical training is challenging but must be intentional. This intent also requires that the trainee understands the obvious and nuanced challenges associated with thoracic surgery that is unique to this discipline. It also demands a structured curriculum incorporating simulation technology and expectations for trainees as they progress through thoracic robotic cases and increase their involvement. While the professional organizations have begun to prioritize robotic training integration, this has yet to permeate to every thoracic training program. And while additional studies are still needed to determine the ideal program, it is incumbent upon practicing robotic surgeons to put forth the required effort now to train residents in this technology.

Acknowledgments

Funding: None.

Footnote

Provenance and Peer Review: This article was commissioned by the Guest Editor (Ghulam Abbas) for the series "Robotic Thoracic Surgery" published in *Journal of Thoracic Disease*. The article has undergone external peer review.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/jtd-2019-rts-06). The series "Robotic Thoracic Surgery" was commissioned by the editorial office without any funding or sponsorship. AWK serves as an unpaid editorial board member of *Journal of Thoracic Disease* from Jan 2020 to Dec 2021. The authors have no other 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.

References

1. Park BJ, Melfi F, Mussi A, et al. Robotic lobectomy for non-small cell lung cancer (NSCLC): long-term oncologic results. J Thorac Cardiovasc Surg 2012;143:383-9.
2. Giulianotti PC, Buchs NC, Caravaglios G, et al. Robot-assisted lung resection: outcomes and technical details. Interact Cardiovasc Thorac Surg 2010;11:388-92.
3. Cerfolio RJ, Ghanim AF, Dylewski M, et al. The long-term survival of robotic lobectomy for non-small cell lung cancer: A multi-institutional study. J Thorac Cardiovasc Surg 2018;155:778-86.
4. Reddy RM, Gorrepati ML, Oh DS, et al. Robotic-Assisted Versus Thoracoscopic Lobectomy Outcomes From High-Volume Thoracic Surgeons. Ann Thorac Surg 2018;106:902-8.
5. Nelson DB, Mehran RJ, Mitchell KG, et al. Robotic-Assisted Lobectomy for Non-Small Cell Lung Cancer: A Comprehensive Institutional Experience. Ann Thorac Surg 2019;108:370-6.
6. Kent M, Wang T, Whyte R, et al. Open, video-assisted thoracic surgery, and robotic lobectomy: review of a national database. Ann Thorac Surg 2014;97:236-42; discussion 42-4.
7. Rajaram R, Mohanty S, Bentrem DJ, et al. Nationwide Assessment of Robotic Lobectomy for Non-Small Cell Lung Cancer. Ann Thorac Surg 2017;103:1092-100.
8. Oh DS, Reddy RM, Gorrepati ML, et al. Robotic-Assisted, Video-Assisted Thoracoscopic and Open Lobectomy: Propensity-Matched Analysis of Recent Premier Data. Ann Thorac Surg 2017;104:1733-40.
9. Louie BE. Catastrophes and complicated intraoperative events during robotic lung resection. J Vis Surg 2017;3:52.
10. Cao C, Cerfolio RJ, Louie BE, et al. Incidence, Management, and Outcomes of Intraoperative Catastrophes During Robotic Pulmonary Resection. Ann Thorac Surg 2019;108:1498-504.
11. Arnold BN, Thomas DC, Narayan R, et al. Robotic-Assisted Lobectomies in the National Cancer Database. J Am Coll Surg 2018;226:1052-62.e15.

12. Cerfolio RJ, Bryant AS, Minnich DJ. Starting a robotic program in general thoracic surgery: why, how, and lessons learned. Ann Thorac Surg 2011;91:1729-36; discussion 36-7.
13. Lee BE, Korst RJ, Kletsman E, et al. Transitioning from video-assisted thoracic surgical lobectomy to robotics for lung cancer: are there outcomes advantages? J Thorac Cardiovasc Surg 2014;147:724-9.
14. Hu YY, Peyre SE, Arriaga AF, et al. Postgame analysis: using video-based coaching for continuous professional development. J Am Coll Surg 2012;214:115-24.
15. Reed MF, Lucia MW, Starnes SL, et al. Thoracoscopic lobectomy: introduction of a new technique into a thoracic surgery training program. J Thorac Cardiovasc Surg 2008;136:376-81.
16. Cerfolio RJ, Bryant AS. How to teach robotic pulmonary resection. Semin Thorac Cardiovasc Surg 2013;25:76-82.
17. Shahin GMM, Brandon Bravo Bruinsma GJ, Stamenkovic S, et al. Training in robotic thoracic surgery-the European way. Ann Cardiothorac Surg 2019;8:202-9.
18. Jang HJ, Lee HS, Park SY, et al. Comparison of the early robot-assisted lobectomy experience to video-assisted thoracic surgery lobectomy for lung cancer: a single-institution case series matching study. Innovations (Phila) 2011;6:305-10.
19. Ahn S, Jeong JY, Kim HW, et al. Robotic lobectomy for lung cancer: initial experience of a single institution in Korea. Ann Cardiothorac Surg 2019;8:226-32.
20. Veronesi G, Agoglia BG, Melfi F, et al. Experience with robotic lobectomy for lung cancer. Innovations (Phila) 2011;6:355-60.
21. Meyer M, Gharagozloo F, Tempesta B, et al. The learning curve of robotic lobectomy. Int J Med Robot 2012;8:448-52.
22. Power AD, D'Souza DM, Moffatt-Bruce SD, et al. Defining the learning curve of robotic thoracic surgery: what does it take? Surg Endosc 2019;33:3880-8.
23. Fahim C, Hanna W, Waddell T, et al. Robotic-assisted thoracoscopic surgery for lung resection: the first Canadian series. Can J Surg 2017;60:260-5.
24. Hernandez JM, Humphries LA, Keeling WB, et al. Robotic lobectomy: flattening the learning curve. J Robot Surg 2012;6:41-5.
25. Gallagher SP, Abolhoda A, Kirkpatrick VE, et al. Learning Curve of Robotic Lobectomy for Early-Stage Non-Small Cell Lung Cancer by a Thoracic Surgeon Adept in Open Lobectomy. Innovations (Phila) 2018;13:321-7.
26. Toker A, Ozyurtkan MO, Kaba E, et al. Robotic anatomic lung resections: the initial experience and description of learning in 102 cases. Surg Endosc 2016;30:676-83.
27. Merritt RE, Kneuertz PJ, D'Souza DM. Successful Transition to Robotic-Assisted Lobectomy With Previous Proficiency in Thoracoscopic Lobectomy. Innovations (Phila) 2019;14:263-71.
28. Arnold BN, Thomas DC, Bhatnagar V, et al. Defining the learning curve in robot-assisted thoracoscopic lobectomy. Surgery 2019;165:450-4.
29. Farivar BS, Flannagan M, Leitman IM. General surgery residents' perception of robot-assisted procedures during surgical training. J Surg Educ 2015;72:235-42.
30. Zhao B, Lam J, Hollandsworth HM, et al. General surgery training in the era of robotic surgery: a qualitative analysis of perceptions from resident and attending surgeons. Surg Endosc 2020;34:1712-21.
31. Foote JR, Valea FA. Robotic surgical training: Where are we? Gynecol Oncol 2016;143:179-83.
32. Case Log Information: Urology. 2018. Available online: http://acgme.org/Portals/0/PFAssets/ProgramResources/480-Urology-Case-Log-Info.pdf. Accessed 9/21/2019.
33. Minimum Numbers: Obstetrics and Gynecology. 2018. Available online: https://www.acgme.org/Portals/0/PFAssets/ProgramResources/220_Ob_Gyn_Minimum_Numbers_Announcement.pdf?ver=2018-06-25-104354-993. Accessed 9/21/2019.
34. Chu D, Vaporciyan AA, Iannettoni MD, et al. Are There Gaps in Current Thoracic Surgery Residency Training Programs? Ann Thorac Surg 2016;101:2350-5.
35. Cerfolio RJ, Cichos KH, Wei B, et al. Robotic lobectomy can be taught while maintaining quality patient outcomes. J Thorac Cardiovasc Surg 2016;152:991-7.
36. White YN, Dedhia P, Bergeron EJ, et al. Resident training in a new robotic thoracic surgery program. J Surg Res 2016;201:219-25.
37. Linsky PL, Wei B. Training in robotic thoracic surgery. J Vis Surg 2018;4:1.
38. Raad WN, Ayub A, Huang CY, et al. Robotic Thoracic Surgery Training for Residency Programs: A Position Paper for an Educational Curriculum. Innovations (Phila) 2018;13:417-22.
39. Herron DM, Marohn M, Group S-MRSC. A consensus document on robotic surgery. Surg Endosc 2008;22:313-25; discussion 311-2.
40. Lallas CD, Davis JW; Members Of The Society Of Urologic Robotic S. Robotic surgery training with commercially available simulation systems in 2011: a

current review and practice pattern survey from the society of urologic robotic surgeons. J Endourol 2012;26:283-93.
41. Bric JD, Lumbard DC, Frelich MJ, et al. Current state of virtual reality simulation in robotic surgery training: a review. Surg Endosc 2016;30:2169-78.
42. Lerner MA, Ayalew M, Peine WJ, et al. Does training on a virtual reality robotic simulator improve performance on the da Vinci surgical system? J Endourol 2010;24:467-72.
43. Hung AJ, Patil MB, Zehnder P, et al. Concurrent and predictive validation of a novel robotic surgery simulator: a prospective, randomized study. J Urol 2012;187:630-7.
44. Kang SG, Ryu BJ, Yang KS, et al. An effective repetitive training schedule to achieve skill proficiency using a novel robotic virtual reality simulator. J Surg Educ 2015;72:369-76.
45. Chang L, Satava RM, Pellegrini CA, et al. Robotic surgery: identifying the learning curve through objective measurement of skill. Surg Endosc 2003;17:1744-8.
46. Smith AL, Krivak TC, Scott EM, et al. Dual-console robotic surgery compared to laparoscopic surgery with respect to surgical outcomes in a gynecologic oncology fellowship program. Gynecol Oncol 2012;126:432-6.
47. Green CA, Mahuron KM, Harris HW, et al. Integrating Robotic Technology Into Resident Training: Challenges and Recommendations From the Front Lines. Acad Med 2019;94:1532-8.
48. Worrell SG, Dedhia P, Gilbert C, et al. The cost and quality of life outcomes in developing a robotic lobectomy program. J Robot Surg 2019;13:239-43.
49. Novellis P, Bottoni E, Voulaz E, et al. Robotic surgery, video-assisted thoracic surgery, and open surgery for early stage lung cancer: comparison of costs and outcomes at a single institute. J Thorac Dis 2018;10:790-8.
50. Kneuertz PJ, Singer E, D'Souza DM, et al. Hospital cost and clinical effectiveness of robotic-assisted versus video-assisted thoracoscopic and open lobectomy: A propensity score-weighted comparison. J Thorac Cardiovasc Surg 2019;157:2018-26.e2.
51. Batirel HF. Completeness of training in thoracic surgery: the perfect operative log book. J Thorac Dis 2019;11:S1014-7.
52. McVey R, Goldenberg MG, Bernardini MQ, et al. Baseline Laparoscopic Skill May Predict Baseline Robotic Skill and Early Robotic Surgery Learning Curve. J Endourol 2016;30:588-92.
53. Cerfolio RJ, Ferrari-Light D. How to get the most out of your trainees in robotic thoracic surgery-"the coachability languages". Ann Cardiothorac Surg 2019;8:269-73.

Cite this article as: Alicuben ET, Wightman SC, Shemanski KA, David EA, Atay SM, Kim AW. Training residents in robotic thoracic surgery. J Thorac Dis 2021;13(10):6169-6178. doi: 10.21037/jtd-2019-rts-06

