



REVIEW ARTICLE

# Defining the learning curve of robotic thoracic surgery: what does it take?

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## Abstract

**Background** Controversy exists as to what constitutes a learning curve to achieve competency, and how the initial learning period of robotic thoracic surgery should be approached.

**Methods** We conducted a systematic review of the literature published prior to December 2018 using PubMed/MEDLINE for studies of surgeons adopting the robotic approach for anatomic lung resection or thymectomy. Changes in operating room time and outcomes based on number of cases performed, type of procedure, and existing proficiency with video-assisted thoracoscopic surgery (VATS) were examined.

**Results** Twelve observational studies were analyzed, including nine studies on robotic lung resection and three studies on thymectomy. All studies showed a reduction in operative time with an increasing number of cases performed. A steep learning curve was described for thymectomy, with a decrease in operating room time in the first 15 cases and a plateau after 15–20 cases. For anatomic lung resection, the number of cases to achieve a plateau in operative time ranged between 15–20 cases and 40–60 cases. All but two studies had at least some VATS experience. Six studies reported on experience of over one hundred cases and showed continued gradual improvements in operating room time.

**Conclusion** The learning curve for robotic thoracic surgery appears to be rapid with most studies indicating the steepest improvement in operating time occurring in the initial 15–20 cases for thymectomy and 20–40 cases for anatomic lung resection. Existing data can guide a standardized robotic curriculum for rapid adaptation, and aid credentialing and quality monitoring for robotic thoracic surgery programs.

**Keywords** Robotic surgery · Learning curve · Lobectomy · Segmentectomy · Thymectomy

The benefits of minimally invasive surgery in comparison to open thoracotomy or sternotomy have been well established, which include the potential for shorter in-hospital recovery, improved pain control, decreased blood loss, and equivalent oncologic outcomes [1–3]. Although video-assisted thoracoscopic surgery (VATS) is a well-established and effective approach, the use of robotic-assisted thoracoscopic (robotic) approach has recently increased substantially and propelled the adoption of minimally invasive thoracic surgery for lung and mediastinal procedures [4, 5]. Although there are no clear differences between VATS and robotics, surgeons have recognized several benefits of the robotic platform [6]. These

benefits include the improved visualization with three-dimensional optics, and the improved fine motor movements and freedom of motion with wristed instruments, as well as the improved ergonomics for surgeons working in the console [4, 7]. Although multiple centers have demonstrated the safety and feasibility of adopting robotic thoracic surgery, the process is still daunting for many surgeons who are comfortable and safe performing VATS or open procedures.

The learning curve is often discussed when gauging the experience that is needed to efficiently and safely perform major thoracic procedures robotically. A generally accepted definition of a learning curve is the number of cases it takes a surgeon to become comfortable and proficient in performing a particular procedure [8]. Discussion regarding the feasibility and ability to learn robotics, especially in surgeons previously trained in open procedures, has remained an important topic of conversation [9]. Given the lack of a specific definition of a learning curve in robotic thoracic surgery, the

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strategies for best implementation and credentialing process can vary widely between departments and hospitals. Several studies have sought to determine the number of cases performed to define the learning curve to achieve proficiency in robotics within thoracic surgery. However, it is difficult to estimate a learning curve from one individual study.

The aim of this study was to review the existing literature on the adoption of thoracic surgery, to define the typical learning curve required to perform thymectomy and anatomic lung resections. We sought to analyze the average number of cases performed to achieve a significant decrease in operative time in addition to other outcomes such as conversion rates and blood loss.

## Methods

### Literature search strategy

We performed a systematic search of the literature using the PubMed/MEDLINE databases. The search terms were combined to create MeSH headings that included the following: “lobectomy” OR “segmentectomy” OR “thymectomy” AND “robotic” AND “learning”. Additional studies were retrieved through review of the references listed in the retrieved studies. Studies were found through December 2018. No involvement of human subjects was used in this study and therefore IRB approval was not required.

### Selection criteria

The literature search and study selection process can be visualized in Fig. 1 with the preferred reporting items for systematic reviews and meta-analysis (PRISMA) diagram [10]. The inclusion criteria for the review were as follows: 1. Studies in English; 2. Clinical trials and observational studies; 3. Studies evaluating robotic lobectomy, segmentectomy, and thymectomy; 4. Patients with benign or malignant disease; and 5. Studies with comparison of operative time with progression of increasing cases performed. The exclusion criteria for the review consisted of: 1. Abstracts; 2. Expert opinion; 3. Reviews and meta-analysis; and 4. studies with results reported in comparison to VATS or including VATS cases in the outcomes.

### Data extraction and critical appraisal

Two reviewers (PK and AP) performed the literature search and reviewed the results. Abstracts were screened for inclusion and exclusion criteria. Data elements extracted from selected articles that included operative times, docking times, estimated blood loss, postoperative complications, conversion to thoracotomy. The primary outcome that was

evaluated was comparison of operative time with increasing number of cases performed.

The quality of the articles was assessed using the Downs and Black quality assessment checklist. Articles were graded based on the answers to twenty-seven questions that represent internal validity, external validity, and bias [11]. The answers to each question correspond to a point value. After evaluating the article, the point value was tallied for an overall score. Low-quality articles were considered a score of 0–9. Moderate-quality articles were considered a score of 10–18. High-quality articles were considered a score of 19–27.

## Results

The initial literature search yielded search of a total of 54 results, of which 31 articles were assessed by full text review, and 12 articles were found to meet our inclusion criteria. All articles were observational studies (Fig. 1). Methodological assessment revealed that all studies were of moderate quality with Downs and Black scores ranging from 14 to 18 (Table 1). No study was excluded based on the quality assessment. Nine studies evaluated the initial robotic experience with anatomic lung resection (6 dealing with lobectomy; 1 dealing with segmentectomy; 1 dealing with lobectomy, segmentectomy, and pneumonectomy; 1 dealing with lobectomy, segmentectomy, and sublobar resection) and three with thymectomy (Tables 2, 3). All but one of the studies were performed at a single institution [12]. Six studies (50%) evaluated cases performed by a single surgeon. The baseline approach for thymectomy was sternotomy in all studies, and one study reported prior experience with the VATS technique (Table 2). Of the nine studies discussing lung resection, five reported previously performing their operations routinely with VATS (Table 3). Two studies reported their previous experience with lung resections to be mainly with thoracotomy (Table 3). The remaining two studies reported experience thoracotomy and some experience with VATS (Table 3).

### Operative time in robotic thymectomy

Studies evaluating robotic thymectomy were relatively small groups of patients ranging from 9 to 70 patients. The learning curve for robotic thymectomy appeared to be steep in the first 10–20 cases with significant reductions in operative time (Table 2). Huang et al. evaluated a group of 23 patients that showed a mean operative time of 105.3 min in the first 10 cases and a mean operative time of 80.4 min in the last 10 cases ( $p < 0.05$ ) [13]. A smaller observational study performed by Ro et al. also illustrated a drastic learning curve in the initial robotic cases [14]. The first 5 cases performed

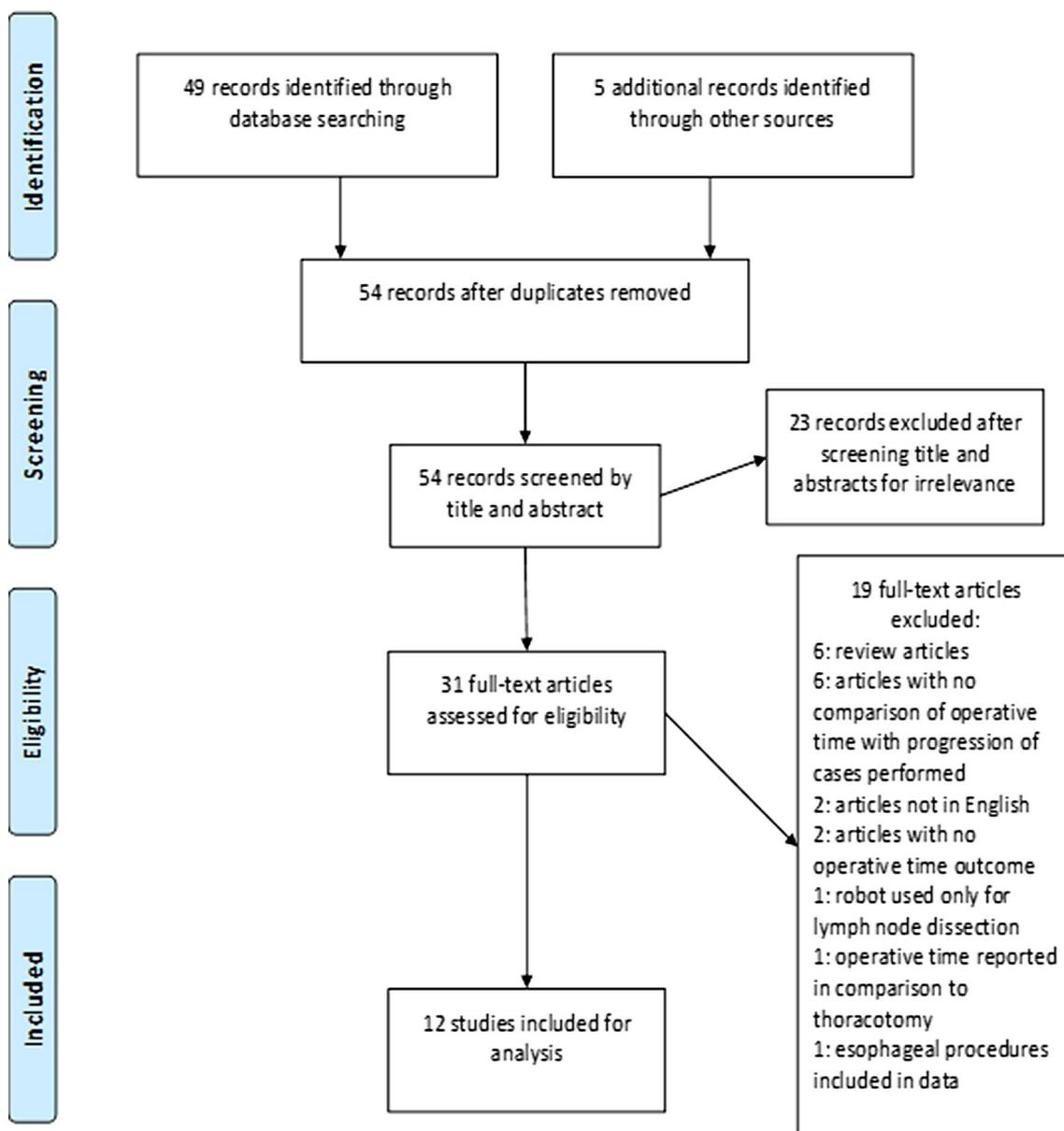


Fig. 1 PRISMA diagram outlining the selection of included studies

had a mean operative time of 282 min with the next 4 cases having a mean operative time of 118 min ( $p=0.014$ ) [14]. Kamel et al. reported the largest series of 70 initial patients undergoing thymectomy for myasthenia gravis [15]. The operative time was longest in the first 15 cases, as compared to the last 15 cases (mean 107 vs. 94 min,  $p=0.018$ ), and reached a plateau after the first 15–20 cases [15]. There were no significant differences in blood loss, conversions to open, or length of stay reported in any of the three studies (Table 2). All three studies confirm a rapid learning curve in regard to operative time over the first 10–20 cases.

### Operative time in robotic lung resection

The learning curve for robotic lung resections appeared to be more variable in comparison to thymectomy. For most studies the learning curve appeared to be reported around 20–40 cases but varied from 14–20 cases to 40–60 cases. Most studies were conducted by surgeons with experience mostly in VATS with two studies citing thoracotomy as their baseline experience (Table 3). There did not appear to be any difference in the reported learning curve for studies experienced with thoracotomy when compared to the studies performing primarily VATS (Table 3). Two studies

**Table 1** Downs and black critical appraisal of study quality

Citation	Report/study quality (n of 11)	External validity (n of 3)	Study bias (n of 7)	Confounding selection bias (n of 6)	Total score (n of 27)
Baldonado et al. [4]	10	0	4	1	15
Cheufou et al. [16]	9	0	3	2	14
Fahim et al. [12]	11	0	4	1	16
Gallagher et al. [9]	10	0	5	2	17
Hernandez et al. [8]	6	0	4	2	12
Meyer et al. [18]	7	0	3	2	12
Toker et al. [19]	11	0	4	3	18
Veronesi et al. [17]	9	0	5	3	17
Zhang et al. [20]	9	0	5	3	17
Huang, 2014	9	0	5	3	17
Kamel et al. [15]	11	0	4	3	18
Ro et al. [14]	11	0	5	0	16

**Table 2** Studies evaluating the learning curve of robotic thymectomy

Citation	No. of patients	No. of ports	Baseline approach	Operative times	Intraoperative outcomes	Postoperative outcomes
Huang et al. [13]	23	3 robotic ports	Sternotomy	Mean operative time First 10 cases: 105 min Last 10 cases 80 min, ( $p=0.05$ ) Docking time: First 10 cases: 15 min Last 10 cases 12 min, ( $p<0.05$ )	No conversions No Intraoperative complications	–
Kamel et al. [15]	70	3 robotic ports	Sternotomy and VATS	Mean operative time First 10 cases: 107 min Last 10 cases 94 min, ( $p=0.018$ ) *Reporting learning curve as 15–20 cases	No significant differences in conversions, or blood loss	No significant differences in length of stay
Ro et al. [14]	9	3 robotic ports	Sternotomy	Mean operative time Cases 1–5: 282 min Cases 6–9: 118 min, ( $p=0.014$ )		No significant differences in length of stay

used a pre-defined case number of 20 and 18 cases curve to evaluate their learning curves [16, 17]. Both studies found a significant reduction in operative time after these first cases but did not demonstrate a plateau.

Five studies reported a reduction in operative time with the learning curve being 20 cases or less [12, 16–19]. Three of these studies analyzed data consisting of at least one hundred patients [12, 18, 19]. Fahim et al. illustrated a significant regression in median operative time with a steady reduction in operative time until case 20 with a plateau between cases 20–40 [12]. Meyer reported a similar phenomenon with a steady decrease in operative time over the

first 15 cases with a plateau after the first 15 cases [18]. Toker et al. reported their learning curve as a decrease in operative time over the first 14 cases with a plateau starting after the 14th case [19]. Hernandez did not specifically state a case number that signaled a significant reduction in operating time, but an overall decrease in operative time with all operative times being under 220 min after case 15 and what appears to be a plateau in the range of 15–20 [8].

Two studies reported slightly higher learning curves of at least 40 cases in relation to operative time [9, 20]. Both studies also consisted of at least 100 patients. Zhang reported competence at the 40th performed case [20]. In this study,

**Table 3** Studies evaluating the learning curve of robotic anatomic lung resection

Citation	No. of patients	No. of ports; procedure type	Baseline approach	Operative times	Intraoperative outcomes	Postoperative outcomes
Baldonado [4]	272	4 robotic ports; lobectomy	VATS	Mean first 120 cases: 181.9 min Mean last 120 cases: 147.4 min ( $p < 0.0001$ )	Conversion to open: first 120 cases: 2.5% Last 120 cases: 1.7% ( $p = 1$ )  Intraoperative complications: first 120 cases: 5% last 120 cases: 0% ( $p = 0.029$ ) Mean EBL: first 120 cases: 234.6 ml Last 120 cases: 78.69 ml ( $p < 0.001$ )	Mean chest tube duration: first 120 cases: 3.49 days last 120 cases: 3.11 days, ( $p = 0.007$ )  Mean Length of stay first 120 cases: 4.08 days last 120 cases: 3.48 days ( $p < 0.001$ )
Cheufou et al. [16]	64	4 arm robotic for first 15 cases then switched to 3 arm; lobectomy	Thoracotomy	Mean first 20 cases: 286 min Mean last 44 cases 211 min, ( $p = 0.0003$ )	Conversion to open: first 20 cases: 20% Last 44 cases: 4.5%, ( $p = 0.07$ )	Mean chest tube duration: first 20 cases: 4.3 days Last 44 cases: 3.8 days, (not significant)
Fahim et al. [12]	157	4 arm and 3 arm robotic ports; lobectomy, segmentectomy,	VATS	Median cases 1–60 = 309 min Median cases 61–107 = 258.5 min Median cases 108–157 = 236 min, ( $p < 0.001$ ) *steady decline in operative time until case 20, with plateau between case 20 and 40	Conversion to open: Cases 1–60: 3% Cases 61–107: 4% Cases 108–157: 14%, ( $p = 0.07$ )  Intraoperative complications: Cases 1–60: 11.67% Cases 61–107: 4.25% Cases 108–157: 10%, ( $p = 0.28$ )	Mean length of stay first 20 cases: 8.3 days last 44 cases: 7.9 days, (not significant)  *No significant difference in median LOS, chest tube duration
Gallagher et al. [9]	100	4 robotic ports; lobectomy	Thoracotomy and VATS	Mean cases 1–20: 252.2 min Mean cases 21–40: 200.5 min Mean cases 41–60: 244.5 min Mean cases 61–80: 190.5 min Mean cases 81–100: 177.8 min ( $p = 0.002$ for negative regression) *reporting learning curve between 40 and 60 cases	Conversion to open: first 40 cases: 22.5% Last 60 cases: 6.7%, ( $p = 0.02$ ) Median estimated blood loss; Cases 1–20 65 ml Cases 21–40 75 ml Cases 41–60 50 ml Cases 61–80 100 ml Cases 81–100 75 ml (no significant regression $p = 0.89$ )	Median length of stay: Cases 1–20 6 days Cases 21–40 7 days Cases 41–60 5 days Cases 61–80 5 days Cases 81–100 6.5 days (no significant regression $p = 0.52$ )

**Table 3** (continued)

Citation	No. of patients	No. of ports; procedure type	Baseline approach	Operative times	Intraoperative outcomes	Postoperative outcomes
Hernandez et al. [8]	20	3 robotic ports with 1 assistant port; lobectomy	VATS and thoracotomy	Mean: 203 min Range 136–293 min *Overall trend with a decrease in operative time and after case 15 all cases were under 220 min *7 of final 10 cases were under 180 min	Conversion to open in all 20 cases: 10%  Mean estimated blood loss: 142 ml with range of 25 to 400 ml	Median postoperative hospital stay: 3 days with range of 2–22 days  Complication rate in all 20 cases: 20%
Meyer et al. [18]	185	3 robotic ports; lobectomy	VATS	Mean: 211 min Range 102–454 min Decrease in operative time in the first 15 cases, before reaching plateau	Surgeon comfort has dramatic increase after case 20	Length of stay range from 2 to 21 days with a median of 4 days. Regression line shows trend toward a decrease in hospital stay with consecutive cases  3 mortalities in first 20 cases with no further after case 20
Toker et al. [19]	102	3 robotic ports; lobectomy, segmentectomy, pneumonectomy	VATS	Mean: 104 min Range 50–230 min Decrease in operative time over consecutive cases with plateau starting at 14 cases, linear regression $R^2 = 0.57$	Decrease in docking time with consecutive cases with plateau at 14 cases  Decrease in console time with consecutive cases with plateau at 13 cases	
Veronesi et al. [7]	91	4 robotic ports; lobectomy	Thoracotomy	Median operative time first 18 cases: 260 min Last 73 cases: 221 min ( $p = 0.01$ )	*No significant reduction in conversion rate	Median length of stay first 18 cases: 6 days last 73 cases: 5 days ( $p = 0.02$ )  major complications First 18 cases: 11% last 73 cases: 4%
Zhang et al. [20]	104	4 robotic ports; segmentectomy	VATS	Mean operative time: Phase I: Cases 1–21 180 min Phase II: Cases 22–46 140 min Phase III: Cases 47–104 135 min ( $p = 0.062$ overall regression) ( $p = 0.001$ from phase I to II) *Report competence as the 40th case	Estimated blood loss: Phase I: Cases 1–21 50 ml Phase II: Cases 22–46 50 ml Phase III: Cases 47–104 100 ml ( $p = 0.048$ from phase I to phase II)	*No significant differences in length of stay or postoperative morbidity

the cases were compared the second phase (cases 22–46) did show a significant reduction in mean operative time in comparison to the first 21 cases [20]. The third phase (cases 47–104) showed a non-significant reduction in operative time in comparison to the second phase which may indicate a plateau begins to occur shortly after case 40 [20]. Gallagher reported a significant regression of operative time across their one hundred cases with a reported plateau in operating room time between 40 and 60 cases [9].

The study by Baldonado et al. was the largest study on the learning curve. This study illustrated a continuous improvement in operative time in 272 cases, with a mean operative time of 181.9 min and 147.4 min in the first and last 120 cases, respectively ( $p < 0.001$ ) [4]. The overall trend of the plotted data showed an overall regression of operative time even well beyond 100 cases [4]. A gradual trend toward decreased operative times after the initial learning curve and beyond 40 cases was shown in multiple studies [9, 12, 19, 20].

### Additional outcomes

Several studies analyzed the occurrence of conversions to thoracotomy in their early robotic experience [4, 8, 9, 12, 16, 17]. One study showed a higher conversion rate in the first 20 cases of 20%, which thereafter reduces to 4.5% ( $p = 0.07$ ) [16]. Another study showed a significant reduction in the conversion rate to thoracotomy after the first 40 cases from 22.5 to 6.7% ( $p = 0.02$ ) [9]. In contrast, Fahim showed an increase in conversion rate to thoracotomy with increasing case numbers [12]. This may be explained further by the selection of more advanced cases, as evidenced by higher number of T2 and T3 tumors in their later cases [12]. An increase selection of more difficult cases, with higher tumor stage and difficult anatomy, beyond after the initial 40 cases was reported by two studies, indicating an increased comfort level [9, 12]. Interestingly, this trend was associated with longer operative times in cases 41–60 as compared cases 20–40 in the study by Gallagher et al. [9]. A study conducted by Meyer et al. also reported a significant increase in surgeon perceived comfort level after 20 robotic lung resections [18].

Blood loss, length of stay, and intraoperative complications were frequently analyzed and yielded mixed results. Two studies found a significant reduction in blood loss after the learning curve, while one study found no significant difference [4, 9, 20]. Two studies also found a significant reduction in the length of hospital stay while four studies specifically stated there was no significant difference in length of stay [4, 17]. Finally, one large study of 272 patients found a significant reduction in intraoperative complications with increasing case number [4].

## Discussion

Several recent studies have reported their initial experience and path to gain proficiency in performing major thoracic operations using the robot. However, it remains unclear as to what defines a learning curve from the individual reports. As the adoption of robotic surgery increases in popularity, it is important for practicing general thoracic surgeons and the health system looking to adopt this technology to understand the extent of adequate training to ensure patient safety and proper utilization of resources. This study aimed to define the typical learning curve when performing robotic thoracic surgery. Common metrics used in the studies assessing the proficiency of robotic thoracic surgery was the operative time and conversions. These metrics mirror the intraoperative outcomes quality indicators used by health centers tracking the quality of robotic surgery across disciplines [21]. Current literature suggests that the learning curve needed to efficiently perform anatomic lung resection falls between 20 and 40 cases, ranging as low as 14 and as high as 60 for anatomic lung resection (Table 3). Few studies report higher conversion rates and intraoperative complications in the initial experience for lung resections, but overall the transition to robotics has been described as safe [4, 9]. The learning for thymectomy appears to be shorter, ranging between 15 and 20 cases (Table 2). For thymectomy, studies consistently found a plateau after the initial learning curve, as opposed to trend toward a continuous improvement in operative time beyond the initial learning curve. In addition, a few studies found a significant reduction in blood loss and length of stay with increasing number of cases performed [4, 9, 17, 20]. With the rapid learning curve that appears to be exhibited in robotic thoracic surgery, adoption of more standardized training curriculum that is based on the learning curve may allow for more surgeons to adopt and become efficient in robotic thoracic surgery.

Perhaps the most important question for the thoracic surgical community is what it takes for surgeons previously trained open procedures to adopt a minimally invasive approach. The thoracoscopic approach has been recommended for resection of early stage lung cancer; however, a substantial number of cases are still being performed open [1, 3]. Anecdotally, surgeons have argued that the robotic approach may be more easily learned than VATS [16]. From a learning perspective, the perceived advantages of robotics over VATS include a free range of instrument motion, magnified high definition camera, improved spatial awareness by three-dimensional visualization, and the ergonomic working position for surgeons at the robotic console [4, 16]. The question bears asking, which minimally invasive approach could be adopted more

efficiently? Although a direct comparison of the learning curve for robotic and VATS is not available, data exists for both techniques. A study published in 2014 by X Li et al. examined at the first 200 VATS lobectomies performed by two different surgeons and reported a learning curve between 100 and 200 cases [22]. A separate study published by Zhao described the initial learning curve with VATS between 30 and 60 cases [23]. A third separate study performed by Mazzella et al. reported a bimodal learning curve after the initial 30 cases and then efficiency achieved after 90 cases [24]. Comparing these numbers to the learning curve of 20–40 procedures found in current review of studies on the adoption of the robotic approach, would suggest a more rapid learning curve for the robotics. However, in most of the studies we have analyzed, surgeons had at least some proficiency with thoracoscopy by VATS, which may explain the rapid learning process. Notably, the two studies included in this review which listed thoracotomy as the baseline approach for lung resection also demonstrated a fast adoption with significant reduction in OR time after eighteen and twenty cases [16, 17]. This may signal that the robotic approach may be learned and performed efficiently even in a surgeon who is not previously trained in minimally invasive techniques.

A common observation we have made when reviewing the studies on learning curves, is that there appeared to be steady trend to shorter operative times for anatomic lung resection beyond the initial learning curve [4, 12, 19, 20]. At the same time, multiple studies indicated that more challenging cases were approach robotically, more frequently approaching lesions with more advanced T-stage [9, 12]. In one study, the conversion rate for robotic lung resections increased in the later experience, from 3 to 4% in the first 107 cases, to 14% in cases 108–157 [12]. This higher conversion rate probably reflects the increasing comfort level of the surgeon with the robot, and willingness to perform more difficult resections of larger and more central tumors, which is not accounted for in the present studies examining trends in OR time. The threshold to achieve true mastery of robotics for lung resection therefore likely extends far beyond the initial learning curve and likely exceeds over 100 cases [4, 16].

Another point of discussion that can be raised from this literature review is how the knowledge of the learning curve in robotic thoracic surgery can be implemented to standardize credentialing and carry out robotic training programs in residency, while maintaining highest quality standards. Due to lack of guidelines or consensus, credentialing process for performing robotic surgery can vary widely from institution to institution. Cerfolio et al. reported their experience with the initial 150 robotic thoracic cases after a short robotic curriculum, and showed a rapid and safe transition from open thoracotomy and sternotomy to robotics using a

systematic approach [16]. This approach consisted of 1 day of online training, followed by 1 day of on-site training with the console, 1 day of cadaver training, and an observational period with several proctored cases [16]. In addition to the surgeons training, the team approach of a dedicated robotic surgical team was emphasized, along with proper patient selection. It is possible that robotic training curriculums could be structured around the described learning curve of 20–40 cases. To guide the learning process, Cerfolio and Bryant have categorized robotic cases based on the level of difficulty. Accordingly, level one cases include resection of mediastinal cysts or small tumors, level II cases include thymectomy for myasthenia gravis, and anatomic lung resections are considered difficulty level III cases [25]. A good strategy for surgeons aiming to successfully start a robotic program may be to achieve proficiency with handling the robot, getting comfortable with docking, maneuvering the camera and dissection using robotic instruments in level I and II cases, before advancing to level III cases. In addition, a thoughtful patient selection, training of a dedicated robotic team, and preparing strategies for intraoperative emergencies cannot be over-emphasized.

The parameters that define the learning curve of thoracic surgery may also be helpful for institutions conducting health systems wide quality performance reviews. Operative times and conversion rates were the two metrics most consistently associated with surgical proficiency for thoracic procedures and are among some of the established outcomes used for quality monitoring of robotic programs across robotic surgical disciplines [21, 26]. Specifically, operative time may be an important outcome for quality assessment, demonstrating a significant reduction during the initial learning curve, and then remaining relatively constant with a trend of continuous improvements with growing experience [4, 12]. Higher conversion rates can be expected during the initial learning phase and should probably not be considered negatively, as this may reflect proper judgment of the surgeon focused on safely adopting the robot in practice. Even beyond the initial building phase, learning curve parameters may also aid ongoing quality assessments directed to maintain a successful robotic thoracic surgery program.

## Limitations

There are several limitations that are exhibited through this research. One limitation is that many of the studies describe different port placements for the robotic approach (Tables 1, 2). It is unclear whether certain port placements may allow the operation to be performed in a more efficient manner. Another limitation of the study is how operative time is defined. Some studies defined it as the time from incision to the time of closure while others did not describe this at all. Another limitation is that surgeons observed in the studies

may have varying skill levels and experience which could affect differences in operative time and learning curve. Lastly, two of the studies used a pre-set number of cases as the learning curve to compare operative time which may not accurately reflect the learning curve in those studies even though there is a significant reduction in operative time [16, 17].

## Conclusions

This systematic review demonstrates that the learning curve for robotic thoracic surgery appears to be rapid and feasible with or without prior experience with VATS. Operative time appears to be the most common tool used to define the learning curve in robotic thoracic surgery. The initial learning curve for robotic thymectomy appears to be between 15 and 20 cases, while the learning curve for robotic anatomic lung resection appears to be between 20 and 40 cases. Knowledge of the learning curve may guide curriculum building for surgeons and institutions planning to adopt the robotic technology, and help future efforts to standardize the credentialing process and quality monitoring of robotic thoracic surgery programs.

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## Compliance with ethical standards

**Disclosures** Dr. Merritt is a speaker for intuitive Surgical. Dr. D'Souza is a Proctor for Intuitive Surgical. Drs. Power, Moffatt-Bruce, and Kneuertz have no conflicts of interest or financial ties to disclose.

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