Robot-assisted *vs.* video-assisted thoracoscopic lobectomy: a systematic review of cost effectiveness

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Background: The aim of this study was to systematically review the hospital costs associated with robot-assisted thoracoscopic surgery (RATS) and video-assisted thoracoscopic surgery (VATS) lung lobectomy.

Methods: We performed a systematic review of articles comparing the costs of RATS and VATS lobectomy using online databases. Primary outcome was the difference in total hospital stay cost. Secondary outcomes were operating room (OR), OR supply and non-OR costs, as well as OR times, length of hospital stay, rate of conversion to open, complication and mortality rates.

Results: Seven articles met inclusion and exclusion criteria. All were retrospective reviews. Data quality and comparability were variable, but RATS lobectomy was consistently more expensive while exhibiting no significant improvement in outcomes compared to VATS. Pooled estimates indicated a reduced complication rate with VATS compared to RATS (odds ratio 0.83, 95% confidence interval: 0.77–0.90, P<0.0001) Mean total cost of RATS was 25.7% greater ($16,645 *vs.* $13,310). For the subset of studies which further delineated costs, the mean operative costs of RATS were 54.4% higher, while mean non-operative costs were 6.5% lower. Average cost of RATS supplies was 130.3% higher than VATS.

Conclusions: Robot-assisted lobectomy is currently not as cost effective when compared to video-assisted thoracoscopic lobectomy. Additionally, there is no evidence that robot-assisted lobectomy will eventually outperform video-assisted alternatives in terms of cost effectiveness. However, there was wide variation in the detail and quality of the data in the studies reviewed, and there is also a need for higher-quality evidence.

Keywords: Video-assisted thoracoscopic surgery (VATS); robot-assisted surgery; thoracic surgery; lobectomy; cost effectiveness

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Introduction

Robot-assisted surgery has been widely adopted in the United States since the da Vinci robotic platform was approved by the FDA in 2000. The ability to convert open operations to minimally invasive operations using the robotic platform has grown with the introduction of robotics. However, the cost effectiveness of robot-assisted surgery compared to laparoscopic and thoracoscopic operations remains controversial (1,2). A mixture of surgeon, patient and hospital administrator perceptions appear to be driving the adoption of robotic surgery (3,4). Given the increased utilization of robot-assisted surgeries, further understanding of the benefits *vs.* the costs of such procedures is necessary. When looking at cost effectiveness, current research has only shown cost advantages of robotic surgery in select instances (5). Nevertheless, the proliferation of robotic surgery has continued apace across specialties and procedures even as its cost effectiveness has remained controversial (6,7).

Existing studies on cost effectiveness following both robot-assisted and laparoscopic/thoracoscopic surgeries often do not contain a detailed breakdown of the costs necessary to determine whether gains in clinical outcomes are financially sensible. Additionally, cost effectiveness should not be assumed to be the primary driver behind adoption of a specific procedure type. Although the first video-assisted thoracoscopic surgery (VATS) lobectomy cases were published in 1993 and first robot-assisted thoracoscopic surgery (RATS) lobectomy cases in 2002 (8,9), which showed good evidence for superior outcomes and costs with VATS (10,11), open surgery (thoracotomy) was still the procedure of choice for most lobectomies through 2010. The superiority of RATS over VATS, in turn, is significantly less clear (12-14). Multiple studies and systematic reviews have compared the two procedures (15,16), but have generally focused more on clinical outcomes than cost comparisons (17-22). Additionally, if any cost-effectiveness data were incorporated, most studies have not incorporated equipment depreciation and a breakdown of the costs by category. Including such data would be important for departmental and hospital purchasing decisions, given the high up-front cost and the complexity of calculating total costs of robotic surgery suites. The aim of this systematic literature review was to conduct such an in-depth cost analysis and comparison for RATS *vs.* VATS lobectomy, in order to inform robotics planning and purchasing decisions for robotic surgery programs.

Methods

Electronic searches

We performed and report this review in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines (23).

We performed a systematic search of the Cochrane Library, EMBASE, Google Scholar, Ovid Medline, PubMed and Web of Science from 1 January 1995 to 1 September 2019. Key free-text search terms included "robot", "robotic", "robot-assisted", "da Vinci" AND "lobectomy" or "pneumonectomy". We did not restrict by language or study type. We also searched the clinicaltrials.gov website for any registered randomized controlled trials (RCTs) comparing RATS lobectomy to VATS lobectomy that were not yet published. References in relevant previous papers and trials were analyzed to identify further publications not captured by the initial search terms. This review occurred as part of a broader study approved by the University of Michigan Institutional Review Board (HUM00089766).

Selection of studies

Study eligibility was independently determined by two of the study authors (TP Keeney-Bonthrone and RM Reddy). Any RCTs, observational studies and case series examining lobectomy with VATS and RATS comparison groups were included. We excluded publications that did not include procedural cost data.

Data extraction and quality assessment

Outcome measures were extracted into a standardized extraction form (Microsoft Excel) by TP Keeney-Bonthrone and verified by AM Hawes. Any discrepancies were resolved via and consensus by TP Keeney-Bonthrone, LM Frydrych and RM Reddy. We analyzed the quality and generalizability of any RCTs that met inclusion criteria based on the appraisal methodology set forth in Schulz *et al.* (24). Retrospective reviews were evaluated with the Newcastle-Ottawa Quality Assessment Scale (25). Median costs were converted into mean costs wherever possible for easier cross-study comparison.

Outcome measures

The primary outcome measure was difference in total hospital stay cost, including procedure costs, between RATS and VATS. Secondary outcomes were difference in total cost (measured in percent, to account for significant institutional and regional cost differences), operating room (OR) time, hospital stay length, conversion rate, complication rate and mortality rate.

Results

Literature search

The database search identified 1,447 unique citations. An

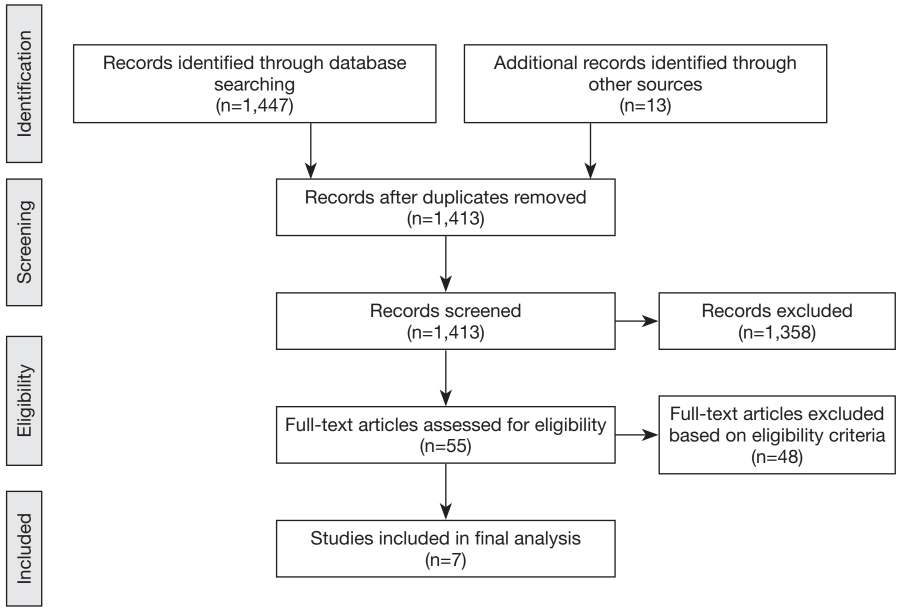

Figure 1 PRISMA 2009 flow diagram.

additional 13 studies were identified from citation review. After removal of duplicates, 1,413 abstracts were screened for eligibility and 1,358 were excluded as part of that process. The remaining 55 articles underwent full-text review (*Figure 1*).

Study characteristics

Seven articles met inclusion and exclusion criteria (*Table 1*). We found no eligible RCTs comparing VATS to RATS lobectomy. Study periods ranged between 2001 and 2016, and sample size ranged between 52 and 40,093. All seven included articles were retrospective cohort studies. Five analyzed data from single institutions; one used the Premier Hospital Database and one the United States Nationwide Inpatient Sample. Three investigations used data from single sites outside the United States (Austria, China and Italy). The remainder used data from the U.S. The included articles were evaluated on the Newcastle-Ottawa Quality Assessment Scale (*Table 2*).

Individual study cost outcomes

To begin to understanding cost differences, a single-surgeon study that eliminates inter-surgeon variability is helpful. This type of single-surgeon study was completed in Austria. A comparison of 26 consecutive RATS lobectomies conducted between 2001 and 2008 *vs.* 26 VATS lobectomies conducted in 2009 (26), showed that the median procedure cost of RATS was 44% (EUR 771) higher than VATS. RATS procedures used a 3-arm approach and 96% of operations were for lung cancer. The only demographic difference between groups was clinical stage > IB was 23.1% of RATS patients *vs.* 0% in VATS. There was no significant difference in postoperative complications or length of stay between groups. Median operating time was 32 minutes (17.4%) longer in the RATS group. Rate of conversion to open was not statistically significant (P=0.42). Unfortunately, total cost was not broken down into individual components and the study did not measure non-operative costs, so further costs conclusions could not be drawn.

A single center study performed in a U.S. hospital between 2008 and 2012 analyzed open (n=69), VATS (n=58) and RATS (n=57) lobectomies and segmentectomies (27). The authors did not separate lobectomy and segmentectomy procedure costs. Twelve-point-three percent of RATS and 22.4% of VATS procedures were segmentectomies, which could skew cost in favor of VATS. The mean overall cost including depreciation for RATS was $3,182 (23.0%) higher than VATS. RATS was also $1,975 (13.1%) more expensive than open procedures, but only the RATS *vs.* VATS cost difference was statistically significant. This was the only study reviewed in which total costs included

Table 1 Baseline characteristics of included studies

Study	Publication year	Study period	Country	Study type	Source	Total # patients	# Open patients	# VATS patients	# RATS patients	Conflicts of interest
Augustin *et al.*	2013	2001–2009	Austria	Cohort (retrospective)	Single site	52	None	26	26	None
Swanson *et al.*	2014	2009–2011	USA	Cohort (database)	Premier Hospital Database	15,502	None	3,818	335	Consulting (4 authors incl. senior). Industry employment (2 authors)
Deen *et al.*	2014	2008–2012	USA	Cohort (retrospective)	Single site	184	69	58	57	Financial relationships with Intuitive Surgical (3 authors incl. primary)
Paul *et al.*	2014	2008–2011	USA	Cohort (database)	Nationwide Inpatient Sample	40,093	None	37,595	2,498	None
Bao *et al.*	2016	2014–2015	China	Cohort (retrospective)	Single site	138	None	69	69	None
Novellis *et al.*	2018	2015–2016	Italy	Cohort (retrospective)	Single site	103	38	42	23	Consulting (senior author)
Worrell *et al.*	2019	2010–2012	USA	Cohort (retrospective)	Single site	98	None	73	25	Consulting (2 authors including senior)

VATS, video-assisted thoracoscopic surgery; RATS, robot-assisted thoracoscopic surgery.

depreciation and in which costs were also broken by cost category, but with segmentectomies serving as a cost confounder for lobectomies. Without depreciation, RATS was $2,148 (15.7%) more expensive than VATS and $775 (5.2%) more expensive than thoracotomy. Depreciation therefore accounted for about a third of the cost difference between RATS and VATS. In terms of individual cost categories, only OR cost differences for RATS *vs.* VATS were statistically significant, with mean RATS costs being $723 (16%) higher and OR times being 21 minutes (10.4%) longer. There were no significant differences in hospital stay length or complication rates.

When looking at a larger scale, the same findings of increased costs with RATS hold true. Swanson *et al.* used the U.S. Premier multi-site hospital database from 40 sites to analyze 15,502 thoracic procedures conducted between 2009 and 2011 (28). This included 335 RATS lobectomies and 3,818 VATS lobectomies, 295 which were propensity-matched. Among these, RATS lobectomies were on average 22.3% ($4,564) more expensive. The study also included median RATS lobectomy costs, which were 20.8% ($3,753) higher than VATS. However, depreciation was not included in calculations, and costs were not broken down into individual components. Outcomes did not differ statistically in terms of OR time or hospital length of stay. Only 30% of participating hospitals performed RATS, compared to 100% performing VATS lobectomies. Eighty-seven-point-two percent of RATS lobectomies and 44% of VATS lobectomies were performed at teaching institutions.

Paul *et al.* (29) investigated data from the U.S. Nationwide Inpatient Sample from 2008 to 2011 to compare 2,478 RATS and 37,595 VATS lobectomy costs and outcomes. Given the large sample size of this study, we treated median costs as mean for comparison purposes. Median RATS cost was $4,708 (26.3%) higher compared to VATS. Once again, these figures did not include depreciation and there was no cost breakdown. The RATS complication rate was 4.9% higher (50.1% *vs.* 45.2%), with a noteworthy increase in iatrogenic bleeding (5.0% *vs.* 2.0%). Differences in length of stay were statistically insignificant. OR time was not measured.

The most recent U.S.-based study involved single-center data gathered between 2010 and 2012, with a sample size of 73 VATS and 25 RATS cases (18). The difference in mean total cost was $2,042 (18.4%), and the study also broke those figures by fixed, variable, OR and supply costs. The only significant outcome difference was in operative time, with RATS cases taking an average of 48 minutes (26.2%)

Table 2 Newcastle-Ottawa Scale (NOS) score of included studies

Score category	Augustin *et al.*	Swanson *et al.*	Deen *et al.*	Paul *et al.*	Bao *et al.*	Novellis *et al.*	Worrell *et al.*
Selection							
Cohort is representative	x	x	x		x	x	x
Non-exposed cohort selection	x	x	x	x	x	x	x
Exposure ascertainment	x	x	x	x	x	x	x
Outcome demonstration	x	x	x	x	x	x	x
Comparability							
Comparability of cohorts	x	x	x	x	x	x	x
Outcome							
Assessment of outcome	x	x	x	x	x	x	x
Follow-up long enough		x			x	x	x
Adequacy of follow-up		x			x	x	x
NOS score total (/9)	7	9	7	6	9	9	9

longer.

The cost findings identified in the U.S. studies also hold true in international studies. A single-center study in China examined lobectomies (n=145) and segmentectomies (n=39) performed in 2014 and 2015 (30). There were 71 RATS and 113 VATS procedures, which were then matched into 69 propensity-matched pairs. Seven each (10.1%) of the RATS and VATS matched procedures were segmentectomies. The authors did not separate lobectomy and segmentectomy procedure costs, which again serve as a cost confounder for lobectomies. Mean combined RATS cost for the matched pairs was 44.9% ($3,739) higher and mean OR time was 25 minutes (22.7%) longer. Depreciation was not included in calculations. Differences in complication rates and stay length were not statistically significant.

In Italy, a single-center investigation compared patients undergoing open (n=38), VATS (n=42) and RATS (n=23) procedures (31). Two RATS and one open segmentectomy were included in the cohort. Mean total cost for RATS was $10,045. This was 21.4% higher than VATS ($8,271) and 19.7% higher than open lobectomy ($8,393). These figures did include depreciation, which accounted for 4.6% of the cost of robotic procedures. The authors' detailed breakdown also revealed that cost of materials was almost four times higher for RATS than VATS and open procedures. The authors further found that RATS had the shortest length of stay and largest number of lymph nodes resected, while OR time was longest.

Cost comparison across studies

We compiled cost data from the seven included studies, including total cost and individual charges where available (*Table 3*). Differing methodologies among the seven included articles precluded several direct comparisons. Only two studies [Deen *et al.* (27) and Novellis *et al.* (31)], for instance, included depreciation costs. Augustin and colleagues (26) did not measure non-operative costs such as inpatient stay costs that were included elsewhere, which also precluded comparison. Neither Deen *et al.* nor Bao *et al.* (30) separated lobectomy and segmentectomy costs. For Deen *et al.*, 12.3% of RATS and 22.4% of VATS procedures were segmentectomies. Due to the lower cost of segmentectomies, their inclusion confounded our lobectomy cost comparison by exacerbating the mean cost difference between VATS and RATS procedures. A much smaller number of segmentectomies were included in Novellis *et al.* (total n=3).

For the six studies that provided total cost amounts, the total cost of RATS ultimately ranged from 18.4% to 44.9% greater than VATS (mean 25.7%), with a mean dollar cost difference of $3,335. Mean cost of VATS was $13,310, and mean cost of RATS was $16,645. Three studies provided non-operative costs, and four studies provided OR and supply costs. From these studies, we found that the non-operative costs of RATS ranged between 12.4% lower and 2.1% higher than VATS (mean −6.5%), while operative costs ranged between 8.6% and 112.0% higher (mean

Table 3 Cost outcomes of included studies

Authors	Type of surgery	Number of patients	Total cost ($)	% difference *vs.* VATS	Standard deviation ($)	Robot depreciation included	Nonoperative charges ($)	% difference *vs.* VATS	Operative charges ($)	% difference *vs.* VATS	Supplies ($)	% difference *vs.* VATS	Supplies as % of total	Depreciation ($)
Augustin *et al.*[†‡]	Open	–	–	–	–	–	–	–	–	–	–	–	–	–
	VATS	26	–	–	–	–	–	–	2,358	–	600	–	–	–
	RATS	26	–	–	–	N	–	–	3,406	44.4%	1,339	123.2%	–	–
Swanson *et al.*	Open	–	–	–	–	–	–	–	–	–	–	–	–	–
	VATS	3,818	20,477	–	10,978	–	–	–	–	–	–	–	–	–
	RATS	335	25,041	19.9%	13,164	N	–	–	–	–	–	–	–	–
Deen *et al.*[§]	Open	69	15,036	8.7%	–	–	8,638	33.7%	7,934	−14.1%	3,634	−22.9%	24.2%	–
	VATS	58	13,829	–	–	–	6,459	–	9,237	–	4,716	–	34.1%	166
	RATS	57	17,011	23.0%	–	Y	6,595	2.1%	10,036	8.6%	4,793	1.6%	28.2%	1,200
Paul *et al.*[¶]	Open	–	–	–	–	–	–	–	–	–	–	–	–	–
	VATS	37,595	17,874	–	–	–	–	–	–	–	–	–	–	–
	RATS	2,498	22,582	26.3%	–	N	–	–	–	–	–	–	–	–
Bao *et al.*[§]	Open	–	–	–	–	–	–	–	–	–	–	–	–	–
	VATS	69	8,328	–	1,004	–	–	–	–	–	–	–	–	–
	RATS	69	12,067	44.9%	1,610	N	–	–	–	–	–	–	–	–
Novellis *et al.*[§]	Open	38	8,393	1.5%	–	–	6,582	9.3%	1,811	−19.5%	648	−8.7%	7.7%	0
	VATS	42	8,271	–	–	–	6,020	–	2,251	–	710	–	8.6%	0
	RATS	23	10,045	21.4%	–	Y	5,273	−12.4%	4,772	112.0%	2,777	291.1%	27.6%	563
Worrell *et al.*	Open	–	–	–	–	–	–	–	–	–	–	–	–	–
	VATS	73	11,080	–	3,291	–	6,107	–	4,973	–	2,804	–	25.3%	–
	RATS	25	13,122	18.4%	3,277	N	5,547	−9.2%	7,575	52.3%	5,757	105.3%	43.9%	–

[†], using EUR to USD exchange rate at date of submission 1/31/2013; [‡], included only operative costs; [§], lobectomy and segmentectomy combined; [¶], median costs treated as mean costs given sample size. VATS, video-assisted thoracoscopic surgery; RATS, robot-assisted thoracoscopic surgery; Y, yes; N, no.

54.4%). Average cost of supplies was 130.3% higher than VATS. As a percentage of total cost, VATS supplies constituted an average of 22.7%, whereas RATS supplies constituted an average of 33.2% of the total cost.

The mean cost difference among these studies is put into perspective when compared to the mean overall lobectomy cost in the U.S. A 2017 study conducted a cost analysis of 23,858 patients in the nationwide Premier Hospital Database who underwent a lobectomy between 2008 and 2014 (32). They found that the mean total cost for a lobectomy was $26,661. The authors noted that 59.4% of cases were open and 40.6% minimally invasive, but did not delineate cost based on procedure types. The mean total costs in our study of both VATS and RATS were substantially lower than the $26,661 amount. This difference raises the question of how representative our study data actually is, and how useful it can be for departmental decisions about robotics.

Outcome analysis

In addition to our primary outcomes of cost, we also compared OR time, length of hospital stay, conversion rate to open procedures, complication rate and mortality rate as secondary outcomes across all seven studies (*Table 4*). Novellis and colleagues found that RATS was associated with shorter OR times, whereas four studies found the opposite. Only Novellis *et al.* found a statistically significant difference in length of stay, again favoring RATS. There were no statistically significant differences in rates of mortality or conversion to open.

Next, we generated a pooled odds ratio of complication rates (minor and major combined) with VATS compared to RATS, using the DerSimonian and Laird random effects measure. Our pooled estimates suggest that VATS has a reduced risk of complications [odds ratio 0.83, 95% confidence interval (CI): 0.77–0.90, P<0.0001]. The chi-squared test for heterogeneity showed that the included studies were quite homogenous (I^2=0%; P=0.537). Funnel plots examined to look for bias showed no publication bias due to symmetry. When Swanson *et al.* and Paul *et al.* were removed due to their large sample sizes, the remaining single-site studies showed no statistically significant differences in complication rates (odds ratio 0.90, 95% CI: 0.57–1.40, P=0.626). Overall, examination of clinical outcomes across our included studies indicates that RATS does not lead to improved outcomes compared to VATS.

Discussion

We completed the most in-depth systematic review of the costs associated with VATS and RATS lobectomies. The data suggest that RATS did not result in superior outcomes but was consistently more expensive than VATS.

While other systematic reviews have found that the RATS approach is non-inferior or slightly superior to VATS from a clinical perspective (16,17,20), the same cannot be said from a cost perspective. There is a lack of data to suggest any impending break-even point where the RATS approach might become cost effective. This means that the continued spread of robotic surgery essentially constitutes a faith-based rather than evidence-based effort, given that its adoption is predicated on assumptions rather than any kind of trend line indicating that robotics will justify its cost. Only a few robotic procedures have so far shown themselves to have superior cost effectiveness (5), and these are likely procedures where basic laparoscopy had lacked the fine control in tight spaces to be superior to open surgery (e.g., prostatectomy) (33).

A counterargument would be that the quality of current data is insufficient to pass judgment. Our original intent had been to conduct a statistically rigorous meta-analysis. However, differing methodologies, small sample sizes and limited number of eligible studies precluded us from conducting the kind of rigorous statistical analysis that would have given us more definite insight into the cost effectiveness of RATS lobectomy *vs.* VATS. We chose not to pool any of these studies for cost analysis due to lack of homogeneity. All included articles had NCO quality scores within appropriate limits; none were RCTs and all suffered from further limitations discussed above. No studies included long-term follow-up to adequately assess postoperative outcomes beyond 30 days. We hope that these limitations will be addressed to a certain extent in the coming years. We found four planned or active RCTs comparing VATS to RATS lobectomy registered at clinicaltrials.gov, based in Brazil, Canada, France and Italy (34-37). Only the Canadian trial description explicitly includes cost analysis. None of the four RCTs will have sites in the United States. Given that the U.S. has dramatic fluctuations in procedural costs based on location, it may be difficult to apply any cost-effectiveness findings of these RCTs to the U.S. On the other hand, the relative rarity of surgical RCTs has been discussed extensively (38-41), so we expect that most cost-effectiveness data will continue to come from retrospective studies.

Table 4 Clinical outcomes of included studies

Study	Operating room time (in minutes)				Length of stay (in days)				Conversion rate (in %)				Complication rate (in %)				Mortality rate (in %)			
	VATS	RATS	% difference	P value	VATS	RATS	% difference	P value	VATS	RATS	% difference	P value	VATS	RATS	% difference	P value	VATS	RATS	% difference	P value
Augustin *et al.*	183	215	17.5	0.0362	9.0	11.0	22.2	0.1584	8.4	19.2	128.6	0.4189	38.4	42.3	10.2	1	0	0	0	1
Swanson *et al.*†	254	269	5.9	0.0959	5.8	6.1	4.1	0.6131	Excluded	Excluded	N/A	N/A	47.5	51.1	3.9	0.5977	NR	NR	N/A	N/A
Deen *et al.*†	202	223	10.4	0.045	4.8	4.6	–2.7	0.777	ITT	ITT	N/A	N/A	31	31.6	1.9	0.95	NR	NR	N/A	N/A
Paul *et al.*	NR	NR	N/A	N/A	5.0	5.0	0	0.23	NR	NR	N/A	N/A	45.2	50.1	10.8	0.032	1.3	0.7	–53.8	0.15
Bao *et al.*	111	136	22.5	<0.001	6.4	7.6	18.8	0.078	Excluded	Excluded	N/A	N/A	30.4	42.0	38.2	0.157	NR	NR	N/A	N/A
Novellis *et al.*	191	150	–21.5	<0.001	5.0	4.0	–20.0	<0.001	11.9	8.7	–26.9	0.076	50.0	34.8	–15.2	0.744	2.4	4.4	2.0	1
Worrell *et al.*	183	231	20.8	0.011	4.0	3.0	–25.0	0.36	12.3	20.0	7.7	0.34	27.4	24.0	–3.4	0.74	NR	NR	N/A	N/A

†, minor and major complications combined for this table and pooled analysis. VATS, video-assisted thoracoscopic surgery; RATS, robot-assisted thoracoscopic surgery; ITT, intention to treat; NR, not recorded; N/A, not applicable.

Lastly, one might argue that longer time periods are still required to understand the whole cost picture. For perspective, it took laparoscopic surgery over a decade after its broad clinical introduction in the early 1990s to reliably show superior cost effectiveness to open surgery in studies such as the 2004 results of the Clinical Outcomes of Surgical Therapy (COST) Study Group published in the *New England Journal of Medicine* (42). However, the advance from open to laparoscopic surgery was arguably more dramatic than from laparoscopic to robotic, at least given current technology. As described by Lin, the advance to RATS is more evolutionary than revolutionary (43). Therefore, we expect that it would take substantially longer for robotic surgery to broadly establish itself as more cost effective—if ever—compared to how long it took laparoscopy.

Considering that the costs and learning curve involved are significant, robotics advocates and hospital administrators may ultimately find themselves at odds over further use of robotic systems unless costs go down. If robotics advocates can neither identify strong examples of cost effectiveness at present, nor provide data to predict cost effectiveness in the future, then the adoption of robotic surgery at the systems level ultimately becomes a fad, rather than practice of evidence-based medicine. In the worst-case outcome, continued use of the robotic approach despite lack of evidence for cost effectiveness may even lead to lead to medical reversal (44,45) if the robotic approach is ultimately proven inferior to laparoscopic and/or open approaches. Some have already begun to argue for safeguards against further adoption of the robotic approach without better evidence (7). The authors' institution is currently undergoing a long-term effort to determine the cost effectiveness of robotic surgery across multiple departments and procedure types, in order to determine optimal allocation of robotic resources. Such optimal allocation cannot ultimately occur without a willingness to walk away from using robotics for certain procedures. Over time and as new robotic platforms are developed, the cost of robotics should decline, but it is unclear when that will occur.

Conclusions

This review presents a review of the current evidence for the cost effectiveness VATS *vs.* RATS lobectomy. Our findings show minimal differences in outcomes coupled with consistently higher cost of RATS procedures. Nevertheless, the quality and quantity of existing primary literature may still be insufficient to draw definitive conclusions, particularly due to a lack of RCTs comparing the approaches.

The key question that providers and administrators may have to ask themselves is when they are willing to walk away from robotics—for specific procedures in the case of surgeons or from robotics as a whole in the case of administrators. We expect such decisions to include career, skill, economic and political considerations for the surgeons and departments involved. Precisely because of the complexity of such decision making, we hope that future studies will expand upon the current, limited knowledge base with the routine inclusion of in-depth cost breakdowns. This would provide an appropriate evidence-based understanding of how hospitals can best allocate their surgical resources and the extent to which robotics should play a part.

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Footnote

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/vats.2019.12.07). The series "Robotic Surgery for Lung Cancer" was commissioned by the editorial office without any funding or sponsorship. RM Reddy has received consulting/speaking fees from Intuitive Surgical, Inc., consulting fees from Auris Surgical, Inc., and serves on an Advisory Board for Medtronic/Covidien. 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. This review occurred as part of a broader study approved by the University of Michigan Institutional Review Board (HUM00089766).

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