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Robot-assisted thoracic surgery versus video-assisted thoracic surgery for treatment of patients with thymoma: A systematic review and meta-analysis

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Abstract

Background: Surgical resection of the thymus is indicated in the presence of primary thymic diseases such as thymoma. Video-assisted thoracoscopic surgery (VATS) and robot-assisted thoracic surgery (RATS) offer a minimally invasive approach to thymectomy. However, there is no clear conclusion whether RATS can achieve an equal or even better surgical effect when compared with VATS in treatment of thymoma. We performed this meta-analysis to explore and compare the outcomes of RATS versus VATS for thymectomy in patients with thymoma.

Methods: PubMed, Cochrane Library, EMBASE, China National Knowledge Infrastructure (CNKI), Medline, and Web of Science databases were searched for full-text literature citations. The quality of the articles was evaluated using the Newcastle–Ottawa Scale and the data analyzed using Review Manager 5.3 software. Fixed or random effect models were applied according to heterogeneity. Subgroup analysis was conducted.

Results: A total of 11 studies with 1418 patients, of whom 688 patients were in the RATS group and 730 in the VATS group, were involved in the analysis. Compared with VATS, RATS was associated with less blood loss in operation, lower volume of drainage, fewer postoperative pleural drainage days, shorter postoperative hospital stay, and fewer postoperative complications. There was no significant difference in operative time and patients with or without myasthenia gravis between the two groups.

Conclusions: RATS has more advantages over VATS, indicating that RATS is better than VATS in terms of postoperative recovery. We look forward to more large-sample, high-quality randomized controlled studies published in the future.

KEYWORDS
robot-assisted thoracic surgery, thymoma, video-assisted thoracic surgery

INTRODUCTION

Surgical resection of the thymus is indicated in the presence of primary thymic diseases such as thymomas, thymic cysts, suspicious anterior mediastinal lesions, and myasthenia gravis (MG).[1] The traditional surgical approaches are median sternotomy, anterolateral dissection, or posterolateral dissection.[2] In recent years, with the development of video-assisted thoracoscopic surgery (VATS) and da Vinci robot-assisted thoracic surgery (RATS), thoracic surgeons have had new surgical options when performing thymectomy.[3] The advantage of the robotic system is that it provides the operator with 10× magnification and three-dimensional (3D) image effects in physical conditions. It also has a very highly mobile operating arm that can move in seven dimensions. The surgeon can perform surgery in a sitting position during the operation. This technology offers great advantages to thoracic surgeons, especially for the excision of lesions that are situated in regions with a narrow space and regions where important neurovascular structures are located, such as the mediastinum.[4,5]

A number of studies have confirmed the feasibility and safety of VATS or RATS in the treatment of thymoma.[6–10] However, these studies are single-center and only include some small sample size, retrospective evaluation system studies, which limits their ability to obtain objective results. Therefore, there is no clear conclusion whether RATS can achieve an equal or even better surgical effect when compared with VATS in the treatment of thymoma. We performed this meta-analysis to explore and compare the outcomes of RATS versus VATS for thymectomy in patients with thymoma.

METHODS

Search strategy

A systematic literature search was performed in Pubmed, Cochrane Library, EMBASE, CNKI, Medline, and Web of Science for studies published before July 2021. The key words used were "robot-assisted OR robot-assisted thoracic surgery OR robot OR robotic OR computer assisted surgery OR da Vinci", "video-assisted OR video assisted thoracic surgery OR video OR thoracoscopic", "thymectomy", and "thymoma". Additionally, to avoid duplication of data from different publications from the same author or research team, we further studied these articles to ensure that there was no duplication of research.

Inclusion criteria and exclusion criteria

Inclusion criteria: (1) clinical studies comparing RATS with VATS for thymectomy in patients with thymoma; (2) full-text articles that reported necessary data for statistical analysis, including at least one of the following outcomes: operation time, estimated blood loss, volume of drainage, length of postoperative hospital stay, postoperative duration of drainage, postoperative complications.

Exclusion criteria: (1) type of article does not include a review articles, case reports, letters to the editor, comments and meeting reports; (2) nonhuman subject studies; (3) studies without necessary data for statistical analysis.

Quality assessment

The guideline of the Newcastle–Ottawa Scale (NOS) was used for evaluating this research, including three perspectives of selection, comparability and exposure. The assessment tool including the star system, a maximum of 9 stars, was used in this research. The specific evaluation system was 8–9 stars denotes high quality, 6–7 stars denotes reasonable quality (Table 1).

Data collection

Two reviewers collected data from each study. Any unclear or inconsistent issues were dealt with through discussion. Excel was used to collect the following information (Table 1): author, publication year, country, study design, study period, detection method, follow-up time, included first author, publication year, country, study design, sample size (RATS group and VATS group), mean age, sex, surgical techniques, tumor site, myasthenia gravis, Masaoka stages, histologic classification, operative time, estimated blood loss, volume of drainage, length of postoperative hospital stay, postoperative duration of drainage, and postoperative complications.

Statistical analysis

All statistical analyses were performed using Review Manager 5.3 software (Cochrane Collaboration, Oxford, UK). The dichotomous variables were assessed by using odds ratios (OR) with a 95% confidence interval (CI) and the continuous variables using weighted mean difference (WMD) with a 95% CI. The I^2 statistics were used to evaluate the heterogeneity. $I^2 < 25\%$, $25\% \leq I^2 \leq 50\%$, and $I^2 > 50\%$ were considered to be low, moderate, and high heterogeneity, respectively. If the test of heterogeneity was high ($I^2 > 50\%$ or $p < 0.05$), a random-effect model was adopted. Otherwise, we used a fixed-effect model. The potential publication bias was evaluated by visually inspecting the funnel plots. $p < 0.05$ was regarded as statistically significant.

Subgroup analysis

The uneven distribution of the surgical approach between the groups could affect the outcomes. Therefore, to eliminate the bias, a subgroup analysis of the unilateral thoracic approach or the subxiphoid approach was conducted.

RESULTS

The selection of included studies

We searched four electronic databases, PubMed, EMBASE, Web of Science, and CNKI, and the total number of studies was 424 before July 2021. After duplicates were removed, 339 articles were evaluated carefully. Two hundred and twenty-two studies were excluded because they were review articles, case reports, animal experimental studies, letters, meeting abstracts, comments, and other nonrelated studies. Later, 117 potential articles were further assessed through reading the full texts and 106 papers were excluded due to inclusion and exclusion criteria. In our meta-analysis, 11 retrospective qualified papers were included finally (Figure 1).

TABLE 1 Characteristics of the included studies

Author (year)	Country	Design	Study period	Group	Cases	Sex M/F	Age	Surgical approach	Surgical technique	Tumor size (cm)	Masaoka stage			Histologic classification						NOS
											I	II	III	A	AB	B1	B2	B3	C	
Li (2020)	China	R	2009–2014	RATS	60	30/30	53.72 ± 13.11	Unilateral	Four arms	5.50 ± 2.38	16	42	2	4	6	12	24	9	6	8
				VATS	60	30/30	51.22 ± 12.21	Unilateral	Three ports	5.28 ± 2.94	20	39	1	5	4	8	27	14	2	
Şehitogullari (2020)	USA	R	2010–2018	RATS	21	13/8	41.29 ± 7.05	Unilateral	Four arms	2.58 ± 0.56	9	11	0	9	3	6	2	1	0	7
				VATS	24	14/10	42.52 ± 7.45	Unilateral	Three ports	2.73 ± 0.57	11	12	2	8	4	5	6	1	0	
Yang (2020)	USA	R	2010–2014	RATS	77	31/46	60.9 ± 10.7	–	Four arms	4.5	46	21	10	16	23	11	23	4	0	8
				VATS	77	32/45	61.1 ± 12.2	–	Three ports	5.2	48	19	10	12	23	15	16	11	0	
Qian (2017)	China	R	2009–2014	RATS	51	21/30	48.8 ± 13.3	Unilateral	Four arms	3.8 ± 1.1	19	32	0	10	14	12	11	2	1	7
				VATS	35	19/16	50.3 ± 13.1	Unilateral	Three ports	3.9 ± 1.1	10	25	0	4	15	7	5	3	1	
Kamel (2019)	USA	R	2010–2014	RATS	300	51/249	63	–	Four arms	4.5	–	–	–	–	–	–	–	–	–	7
				VATS	280	50/230	62	–	Three ports	5	–	–	–	–	–	–	–	–	–	
Suda (2016)	Japan	R	2011–2015	RATS	7	4/3	55.5 ± 9.9	Subxiphoid	One port	4.1 ± 2.1	4	3	0	0	0	6	0	0	1	7
				VATS	18	12/6	53.4 ± 14.8	Subxiphoid	One port	3.2 ± 1.7	14	4	0	1	10	7	0	0	0	
Ye (2013)	China	R	2009–2012	RATS	21	13/12	53.4 ± 5.4	Unilateral	Four arms	2.91 ± 0.77	21	0	0	–	–	–	–	–	–	7
				VATS	25	9/12	52.7 ± 7.8	Unilateral	Three ports	3.04 ± 0.79	25	0	0	–	–	–	–	–	–	
Jun (2014)	China	R	2010–2012	RATS	55	25/30	41.4(16–65)	Unilateral	Four arms	–	–	–	–	–	–	–	–	–	–	7
				VATS	60	30/30	43.5(18–66)	Unilateral	Three ports	–	–	–	–	–	–	–	–	–	–	
Rowse (2015)	USA	R	1995–2015	RATS	11	6/5	52.2(23–74)	Unilateral	Four arms	3.5 × 2.5 × 1.8	–	–	–	–	–	–	–	–	–	7
				VATS	45	19/26	50.6(23–87)	Unilateral	Three ports	2.6 × 2.0 × 1.3	–	–	–	–	–	–	–	–	–	
Wang (2020)	China	R	2006–2019	RATS	58	38/20	45.31 ± 12.62	Subxiphoid	Four arms	5.3 ± 2.1	28	29	1	9	20	14	14	1	0	7
				VATS	70	45/25	46.5 ± 15.32	Subxiphoid	Three ports	6.9 ± 1.9	37	31	2	10	25	17	16	2	0	
Fu (2013)	China	R	2009–2013	RATS	27	–	50.4 ± 12.1	Unilateral	Four arms	3.2 ± 1.2	25	2	–	–	–	–	–	–	–	7
				VATS	36	–	51.3 ± 13.4	Unilateral	Three ports	3.9 ± 0.8	24	12	–	–	–	–	–	–	–	

Abbreviations: –, not available; F, female; M, male; R, retrospective study; RATS, robot-assisted thoracic surgery; VATS, video-assisted thoracic surgery.

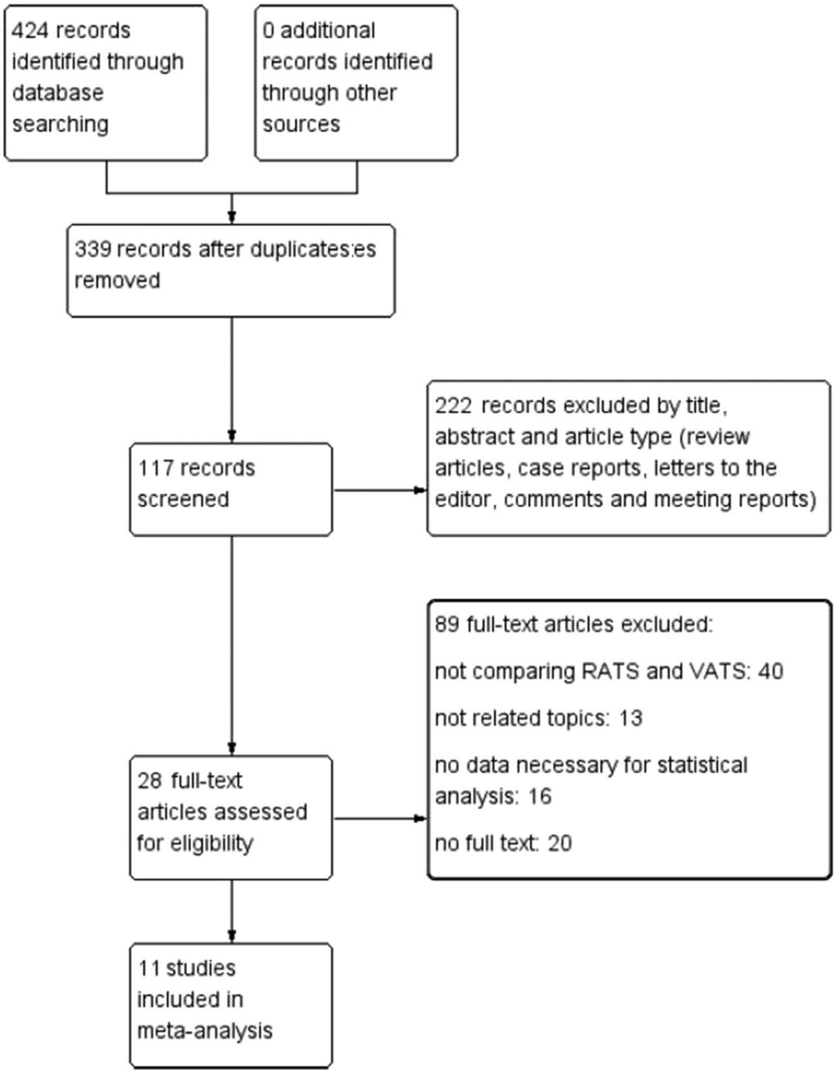

FIGURE 1 Flow chart of literature search strategies

The characteristics of included studies

A total of 11 studies with 1418 patients, of whom 688 patients were in the RATS group and 730 in the VATS group, were involved in the analysis. The basic characteristics of the 11 qualified literature sources are recorded in Table 1. Li et al.[11] revealed short-term clinical outcomes in patients undergoing RATS or VATS by comparing the two matched groups. Şehitogullari et al.[12] enrolled 45 patients and analyzed the outcomes of 24 patients with VATS and 21 patients with RATS. Yang et al.[13] summarized the perioperative outcomes in patients with thymoma resected by RATS and VATS. A retrospective study including 123 patients with early-stage thymomas who underwent thymectomy was reported in Qian et al.[14] Among them, VATS was performed on 35 patients and RATS was performed on 51 patients. A series of outcome measures was compared between these two approaches. Kamel et al.[15] evaluated the difference between a robotic approach and VATS. Suda et al.[16] reported on patients with thymoma who underwent thymectomy via a subxiphoid approach by RATS and VATS. Ye et al.[17] evaluated the short-term outcomes of 46 patients who underwent surgery for Masaoka stage I thymoma. Of these patients, 25 received VATS and the other 21 received RATS. The clinical data of the da Vinci robot-assisted thymectomies (55 patients) were compared with the VATS data from June 2010 to December 2012 in the report by Jun et al.[18] The study of Rowse et al.[19] reviewed the data of 45 patients who underwent minimally invasive thymectomy (45 video-assisted, 11 robotic-assisted). Wang et al.[20] mentioned the clinical efficacy and prognosis of RATS compared with traditional VATS in the treatment of thymoma in 128 patients. Fu et al.[21] analyzed the clinical data of patients who underwent thymectomy by RATS and VATS, and assessed the clinical application value of RATS in China.

Meta-analysis results

Operative time

Operation time was reported in nine studies. The pooled data revealed no significant difference between the groups of RATS and VATS (WMD = 12.14, 95% Cl −1.45–25.72, $p = 0.08$, $I^2 = 90\%$) (Figure 2a).

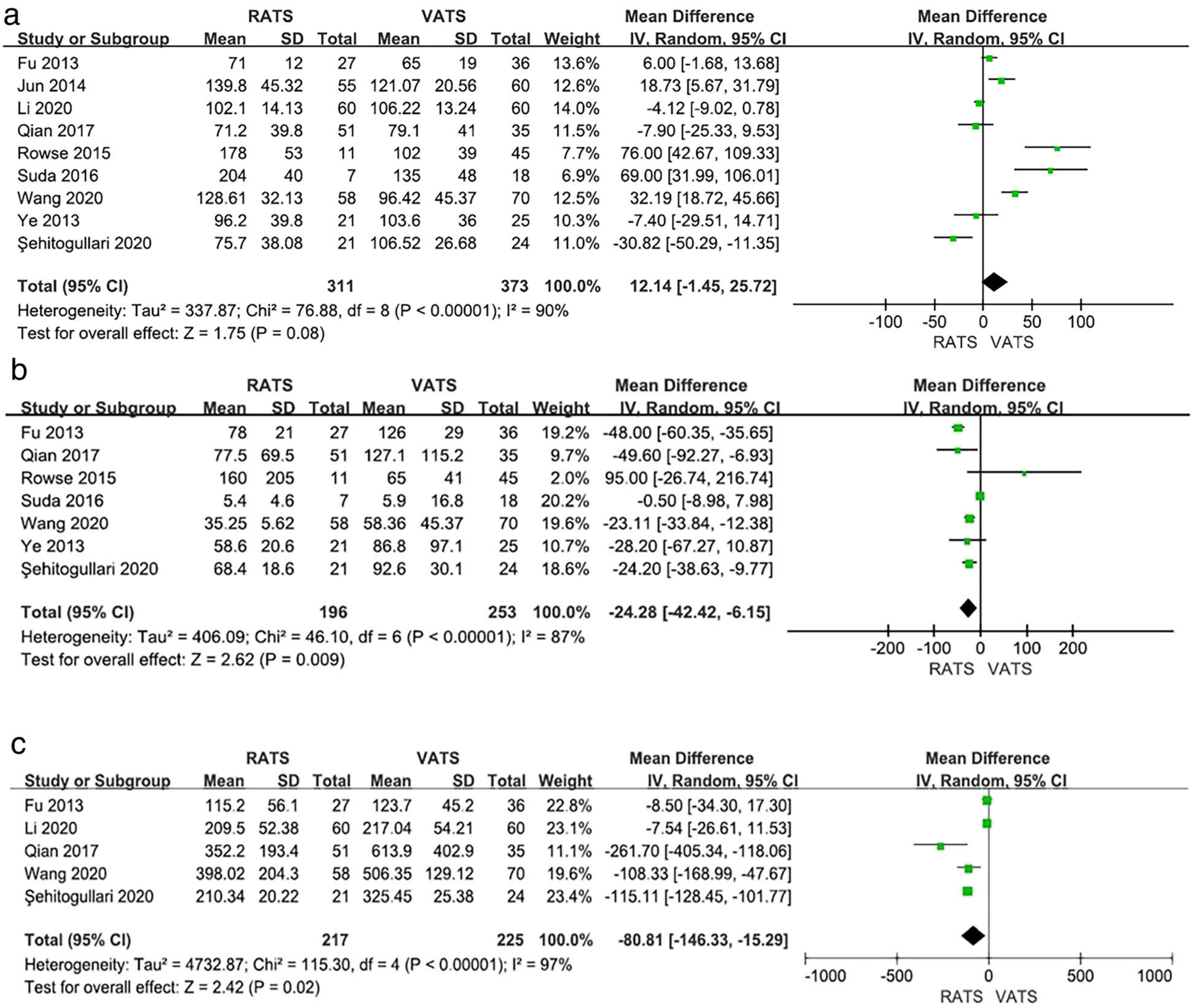

FIGURE 2 Forest plot of the meta-analysis: (a) operation time, (b) estimated blood loss, and (c) volume of drainage

Estimated blood loss during the operation

The data regarding the estimated blood loss were reported in seven studies. The results show that the estimated blood loss in RATS was lower than in VATS (WMD $= -24.28$, 95% Cl -42.42 to -6.15, $p = 0.009$, $I^2 = 87\%$) (Figure 2b).

Volume of drainage

The volume of drainage in the RATS group was lower than in the VATS group in five studies (WMD $= -80.81$, 95% Cl -146.33 to -15.29, $p = 0.02$, $I^2 = 97\%$) (Figure 2c).

Postoperative pleural drainage days

The pooled results of seven studies revealed that the postoperative pleural drainage days were fewer in the RATS group than in the VATS group (WMD $= -1.01$, 95% Cl -1.48 to -0.54, $p < 0.001$, $I^2 = 92\%$) (Figure 3a).

Length of postoperative hospital stay

The results of all studies showed that the length of postoperative hospital stay was shorter in the RATS group than in the VATS group (WMD $= -1.07$, 95% Cl -1.74 to -0.41, $p = 0.002$, $I^2 = 97\%$) (Figure 3b).

Myasthenia gravis

Myasthenia gravis was reported in seven studies between the RATS group and the VATS group. There was no significant difference between the two groups (OR $= 0.92$, 95% Cl 0.56–1.51, $p = 0.73$, $I^2 = 0\%$) (Figure 3c).

Postoperative complications

Eight studies showed that the rate of overall postoperative complication was lower in the RATS group than in the VATS

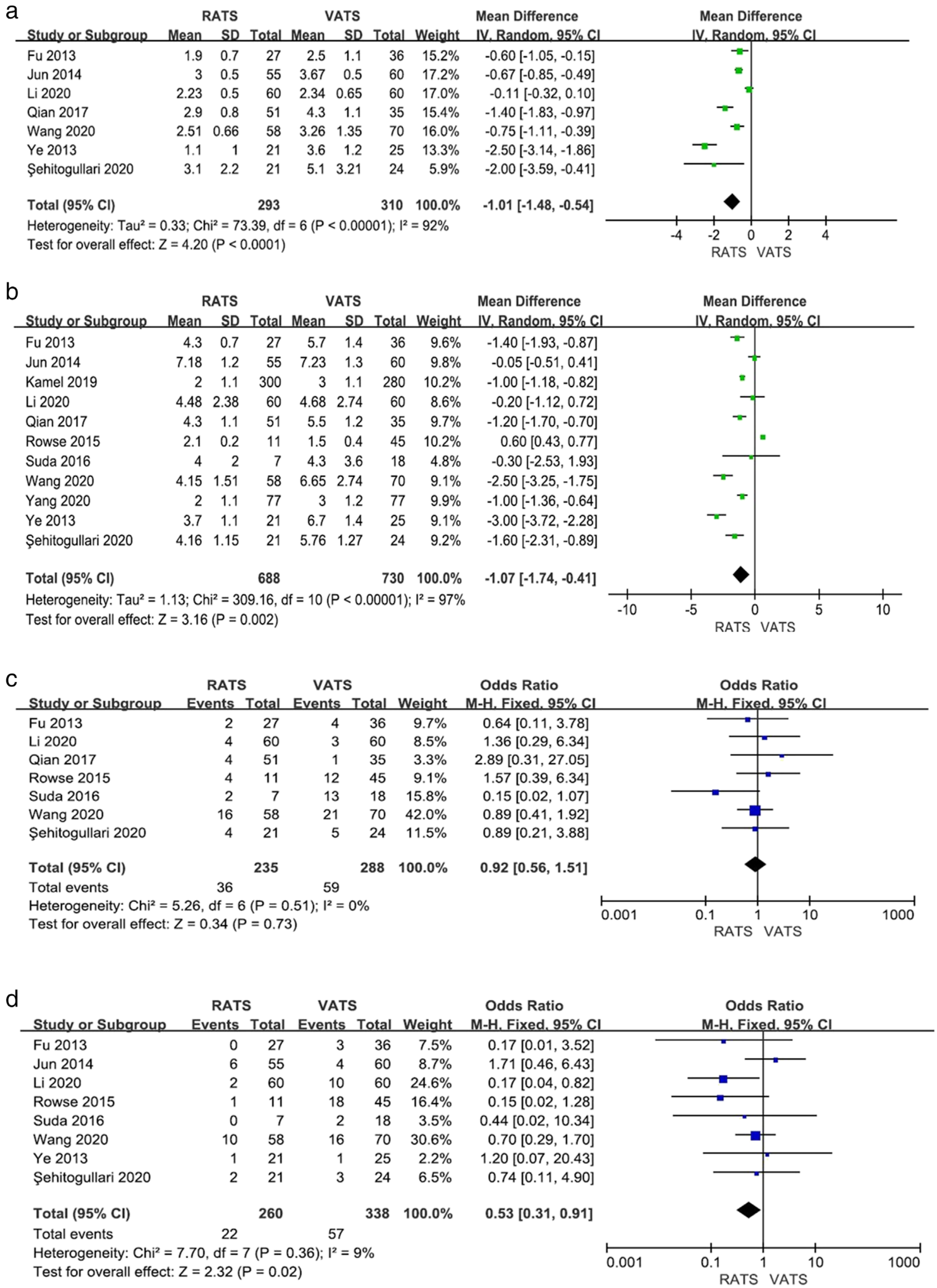

FIGURE 3 Forest plot of the meta-analysis: (a) postoperative pleural drainage days, (b) length of postoperative hospital stay, (c) myasthenia gravis, and (d) postoperative complications

Study or Subgroup	RATS Mean	RATS SD	RATS Total	VATS Mean	VATS SD	VATS Total	Weight	Mean Difference IV, Random, 95% CI
Fu 2013	3.2	1.2	27	3.9	0.8	36	16.6%	-0.70 [-1.22, -0.18]
Li 2020	5.5	2.38	60	5.28	2.94	60	10.3%	0.22 [-0.74, 1.18]
Qian 2017	3.8	1.1	51	3.8	1.1	35	17.4%	0.00 [-0.47, 0.47]
Suda 2016	4.1	2.1	7	3.2	1.7	18	4.5%	0.90 [-0.84, 2.64]
Wang 2020	5.3	2.1	58	6.9	1.9	70	13.7%	-1.60 [-2.30, -0.90]
Ye 2013	2.91	0.77	21	3.04	0.79	25	17.8%	-0.13 [-0.58, 0.32]
Şehitogullari 2020	2.58	0.56	21	2.73	0.57	24	19.7%	-0.15 [-0.48, 0.18]
Total (95% CI)			**245**			**268**	**100.0%**	**-0.33 [-0.74, 0.09]**

Heterogeneity: Tau² = 0.20; Chi² = 21.30, df = 6 (P = 0.002); I² = 72%
Test for overall effect: Z = 1.53 (P = 0.13)

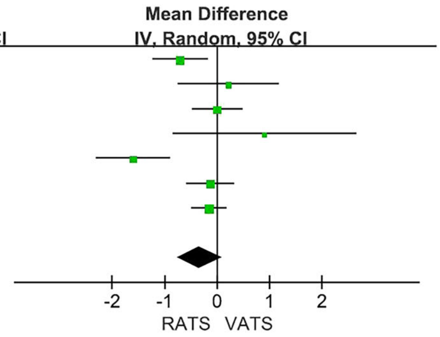

FIGURE 4 Forest plot of the meta-analysis for tumor size

group (OR = 0.53, 95% Cl 0.31 ∼ 0.91, $p = 0.02$, $I^2 = 9\%$) (Figure 3d).

Tumor size

The tumor size was reported in seven studies for the RATS and VATS groups. There was no significant difference between the two groups (WMD = −0.33, 95% Cl −0.74 to −0.09, $p = 0.13$, $I^2 = 72\%$) (Figure 4).

Subgroup analysis

For the subgroup analysis of the unilateral thoracic approach, the RATS group was associated with lower blood loss, shorter length of postoperative hospital stay and postoperative duration of drainage, and fewer postoperative complications ($p < 0.05$), and there was no significant difference in operation time, volume of drainage, patients with myasthenia gravis or not, and tumor size compared with VATS ($p > 0.05$). As for the subxiphoid approach, however, there was no significant difference in blood loss, duration of postoperative hospital stay, patients with myasthenia gravis or not, postoperative complications, and tumor size ($p > 0.05$). On the contrary, the RATS group had shorter duration of postoperative drainage time, lower volume of drainage, and more operative time compared with the VATS group. The subgroup analysis results for surgical extension are summarized in Table 2 and Supporting Information Figures S1–S8.

Publication of bias

A funnel plot of the overall complication was used to assess publication bias. The bilaterally symmetrical funnel plot of overall complication showed that no obvious evidence of publication bias was observed (Figure 5).

DISCUSSION

Thymoma is a thymic epithelial tumor and is the most common tumor in the anterior superior mediastinum, accounting for 20–30% of adult mediastinal tumors.[22] Early thymoma is usually asymptomatic and is difficult to detect due to its small size. It is often found only when chest computed tomography (CT) is performed during physical examination in a patient. When a thymoma reaches a certain size, it can cause chest pain and compression of the innominate vein or right superior vena cava, causing obstruction syndrome.[23] In severe cases, thymoma may invade the innominate vein or pleural adhesions, causing severe chest paint. Around 70–80% of thymoma are pathologically benign, showing swelling growth. The lesion has a complete envelope and can be completely removed, while a small part of thymoma is prone to malignant growth due to poor pathological differentiation and shows obvious metastatic tendency.[8,24] Surgery is the main treatment for thymoma. Both benign and malignant thymoma should be surgically removed as soon as possible. All thymus tissues, including the tumor, should be removed. At the same time, the fatty tissue around the anterior mediastinal thymoma also needs to be cleaned. Compared with open thymectomy, minimally invasive surgery has more advantages.[25]

In the early stage, previous studies have compared VATS and sternotomy in the treatment of thymoma, and the results showed that VATS is usually associated with reduced blood loss, and shortened operation time and length of hospital stay. Minimally invasive treatment options can also reduce the incidence of postoperative complications by reducing the risk of tissue damage, postoperative pain and infection.[1,6,8,26] In 2001, Yoskino performed the first robotic thymectomy in a 74-year-old man with 3.5-cm thymoma, laying the foundation for a surgical robot to perform precise surgery in narrow areas in the mediastinum.[27] With the da Vinci system, a surgeon manipulates the robotic arms inserted via the surgical ports used in conventional VATS.[28] In addition, the system includes an endoscope that provides a 3D high-resolution binocular view of the surgical field; this view is 12-fold enlarged relative to that of VATS and thereby enhances the convenience and safety of the procedure.[29] Moreover, the Endo-Wrist system can articulate and rotate 360°, thus improving maneuverability around anatomic structures.[3] In addition, the Endo-Wrist system has various functions and eliminates the physiological vibrations of the hands of the surgeon.[30] Many studies have compared the safety and short-term efficacy of VATS with open

TABLE 2 Results of the subgroup analysis of the subxiphoid approach or the unilateral thoracic approach

Outcome	No. of studies	Sample size RATS	Sample size VATS	Heterogeneity I2 (%)	Heterogeneity *p* value	Overall effect size	95% CI of overall effect	*p* value
Operation time								
Subxiphoid approach	2	65	88	70	0.07	WMD = 46.39	11.27 to 81.51	0.01
Unilateral thoracic approach	7	246	285	86	<0.00001	WMD = 3.48	−9.20 to 16.16	0.59
Estimated blood loss								
Subxiphoid approach	2	65	88	90	0.001	WMD = −11.56	−33.71 to 10.60	0.31
Unilateral thoracic approach	5	131	165	64	0.03	WMD = −33.71	−53.46 to −13.96	0.0008
Volume of drainage								
Subxiphoid approach	1	58	70	NA	NA	WMD = −108.33	−168.99 to −47.67	0.0005
Unilateral thoracic approach	4	159	155	97	<0.00001	WMD = −74.84	−149.90 to 0.23	0.05
Postoperative pleural drainage days								
Subxiphoid approach	1	58	70	NA	NA	WMD = −0.75	−1.11 to −0.39	<0.0001
Unilateral thoracic approach	6	235	240	93	<0.00001	WMD = −1.08	−1.64 to −0.52	0.0002
Length of postoperative hospital stay								
Subxiphoid approach	2	65	88	70	0.07	WMD = −0.166	−3.75 to 0.43	0.12
Unilateral thoracic approach	9	623	642	97	<0.00001	WMD = −0.97	−1.66 to −0.27	0.007
Myasthenia gravis								
Subxiphoid approach	2	65	88	63	0.1	OR = 0.69	0.34 to 1.39	0.29
Unilateral thoracic approach	5	170	200	0	0.84	OR = 1.23	0.61 to 2.50	0.56
Postoperative complications								
Subxiphoid approach	2	65	88	0	0.78	OR = 0.68	0.29 to 1.57	0.36
Unilateral thoracic approach	6	195	250	33	0.19	OR = 0.46	0.23 to 0.91	0.03
Tumor size								
Subxiphoid approach	2	65	88	85	0.009	WMD = −0.48	−2.92 to 1.95	0.7
Unilateral thoracic approach	5	180	180	22	0.28	WMD = −0.33	−0.43 to 0.05	0.13

Abbreviations: OR, odds ratio; WMD, weighted mean difference.

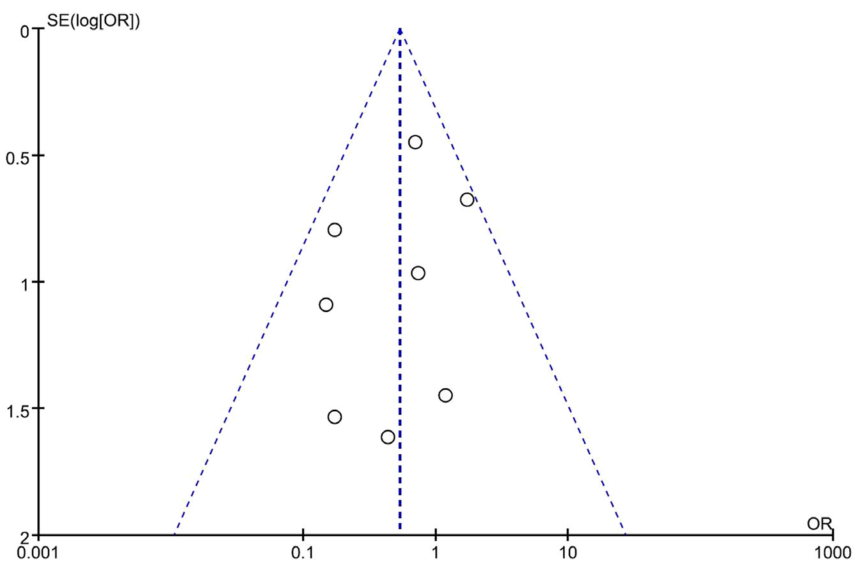

FIGURE 5 Funnel plot of the meta-analysis

thymectomy, but studies on RATS have not been sufficient to prove its benefits. Therefore, we included 11 studies and conducted a meta-analysis to explore and compare the clinical efficacy of RATS and VATS in patients with thymoma.

First, the results of meta-analysis for operative time showed that it was similar between the two groups and there was no statistical difference between RATS and VATS. However, several previous studies described a longer operative time for RATS compared to VATS, which is contrary to our results.[18,20,21] The main reason for this might be differences in the experience of surgeons. Thymectomy by RATS in some medical centers was relatively late and the number of related operations performed by surgeons was small. Most of the cases were still finished in the rising stage of the surgeon's learning curve, which might contribute to longer operative times. In our included studies, some surgeons had proficient operation experience in thoracoscopic thymoma resection, which made the learning curve for robot-assisted thymoma resection shorter and shortened the operative time significantly. Şehitogullari et al.[12] enrolled 45 patients and analyzed the outcomes of 24 patients with VATS and 21 patients with RATS. The mean operative time for robotic surgery was 75 min and was significantly shorter than that for the VATS group. Therefore, with increased experience of RATS, operative time for RATS would be comparable to VATS.

Regarding the blood loss in the operation, our meta-analysis data showed that the intraoperative blood loss was lower in the RATS group than in the VATS group ($p = 0.009$). The reason may be that RATS can provide 3D magnified vision and more flexible equipment during the operation.[7] At the same time, it can eliminate hand tremor and accurately expose the complex anatomy around the resection target, which helps the surgeon perform precise operations.[31] It is better at controlling the bleeding of small blood vessels during the surgery.

There is a clear difference in volume of drainage and postoperative pleural drainage days between the RATS and VATS groups. Two results in the RATS group were lower and shorter than those in the VATS group. We analyzed the research results and consider that the reason is that the robotic surgery system has more minimally invasive advantages than VATS. The da Vinci surgical operating system makes the surgical process more delicate, thoroughly hemostasis, and stimulates the surrounding tissues less.[32] At the same time, the lesion is completely resected and the surrounding adipose tissue can also be completely removed. Eventually, postoperative pleural effusion and postoperative drainage time can be reduced.

In the terms of the duration of postoperative hospital stay, the result of our meta-analysis revealed that patients in the RATS group has shorter stays than those in the VATS group ($p = 0.002$). This result is closely related to the application of minimally invasive surgery, which has potential advantages, including less postoperative pain, faster recovery, and a better cosmetic outcome. Enhanced recovery after surgery (ERAS) also had a significant impact in patients treated with a minimally invasive surgical approach.[33] ERAS is the result of the development of medical theory and surgical technology, and it not only pays more attention to reducing patient stress response, but also takes into account assessment and intervention of the surgical conduct risk. ERAS is a series of optimization measures using perioperative management with evidence-based medical evidence to reduce the physiological and psychological traumatic stress to surgical patients to achieve rapid rehabilitation.[33] In addition, patients recovered faster after surgery, which also shortens the postoperative hospital stay to a certain extent.[9]

The thoroughness of thymic tissue resection is an important factor in controlling the symptoms of myasthenia gravis, affecting the postoperative effect.[34] Minimally invasive surgery can not only satisfy the exposure of the surgical field, but also reduce surgical trauma and postoperative complications, making the treatment effect better.[30] The 3D imaging technology of RATS can provide clearer vision, flexibility, and stability of surgical operations, which takes minimally invasive technology to a new level.[4,35] According to our research, there is no statistically significant difference between RATS and VATS in terms of the curative effect of alleviating myasthenia gravis ($p = 0.73$).

The occurrence of postoperative complications is also an important indicator for evaluating short-term results after surgery. The pooled results of our meta-analysis showed that the incidence of postoperative complications in the RATS group was lower than that in the VATS group. This result may be related to the advancement of robotic surgery systems, and is also closely related to the gradual improvement of the surgical operation level of thoracic surgeons. We especially emphasize that the help of thoracic surgeons who are familiar with the equipment of the da Vinci surgical operating system and assistants with surgical experience is closely related to reducing postoperative complications and may affect the outcome of the operation. Therefore, further prospective randomized control needs to be studied to confirm its advantages.

The traditional opinion is that if the tumor is large (maximum tumor diameter >5 cm) or is a Masaoka III stage thymoma with external invasion, it may be more suitable for median sternotomy.[6] In recent years, with the development of endoscopic technology and surgical instruments, minimally invasive technology has become an important part of modern surgical technology. Minimally invasive surgery for thymectomy mainly includes VATS and RATS.[20] Compared with traditional open surgery, minimally invasive surgery does not require an incision of the sternum, therefore it is accepted by more and more thoracic surgeons. As seen in our results, tumor size was reported in seven studies. There was no significant difference between the two groups (WMD $= -0.33$, 95% Cl $-0.74 \sim -0.09$, $p = 0.13$, $I^2 = 72\%$). Second, the degree of tumor invasion is an important prognostic factor. In Masaoka stage, patients with stages I and II have a longer survival period, while patients with stages III and IV have a poor prognosis. From Table 1, we found that a large number of patients are Masaoka stages I and II, and early surgical treatment can help improve their survival rate.

The choice of surgical approach also affects the patient's postoperative short-term indicators. At present, the surgical approach can be divided into three methods: unilateral thoracic cavity (left or right), bilateral thoracic cavity, and subxiphoid process. The advantage of the right-side thoracic approach is that the right thoracic space is larger, not blocked by the pericardium, avoiding the aortic arch, and the visual field is clear, which increases the safety of the operation. The left-side thoracic approach is suitable where there thymoma is on the left side, as seen in preoperative CT, or the patient has a history of right thoracic surgery with dense adhesion. The surgical effect of the left-side approach is similar to that of the right-side approach, and the operation time for the bilateral approach is longer than that of the unilateral approach. Suda et al.[16] reported the use of subxiphoid thoracoscopic surgery to remove the thymus. The results showed that the advantage of the subxiphoid approach is to maintain the integrity and stability of the thoracic cage, helping to reduce the risk of postoperative myasthenia crisis. They also demonstrated that the robot-assisted subxiphoid approach was safe and effective. Several studies have found that by using the subxiphoid approach during surgery, the thymoma tissue, diagnosed as Masaoka III, invades the pericardium, lung tissue, and the left innominate vein can also completely be removed and reduce postoperative pain.[36–40]

In our subgroup analysis, the results showed that for surgery with the unilateral thoracic approach, the RATS group was still associated with lower blood loss, shorter length of postoperative hospital stay and postoperative duration of drainage, and fewer postoperative complications. For the subxiphoid approach, the RATS group had a shorter duration of postoperative drainage time, lower volume of drainage. and longer operative time compared with the VATS group.

There are several limitations in this meta-analysis. First, the number of studies included and the simple scale were relatively small. All studies included for meta-analysis were retrospective observational studies and lacked high-quality randomized controlled trials, with a greater risk of potential selection and publication bias. Second, the operative time, blood loss, volume of drainage, postoperative pleural drainage, and length of postoperative hospital stay had significant heterogeneity. Potential factors that could explain the heterogeneity included the different experience of surgeons and the shorter learning curve for the robotic group. Third, seven of the studies included in our analysis were Asian and the others were American, so there might be an ethnic bias.

CONCLUSION

In summary, RATS has more advantages over VATS in terms of blood loss, volume of drainage, length of postoperative hospital stay, postoperative duration of drainage, and postoperative complications, indicating that RATS is better than VATS in terms of postoperative recovery. There was no statistically significant difference in operative time, indicating that RATS has the same safety and effectiveness as VATS. There is currently a lack of long-term follow-up studies for patients after surgery. We look forward to more large-sample, high-quality randomized controlled studies being published in the future.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

CONSENT FOR PUBLICATION

All the authors consent to publish the paper.

AUTHOR CONTRIBUTIONS

C.S. was involved in drafting the manuscript. Ji.L and Ju.L were involved in acquisition of data. G.C. designed and revised the manuscript. All authors read and approved the final manuscript.

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SUPPORTING INFORMATION

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