World J Surg (2015) 39:940–952
DOI 10.1007/s00268-014-2900-9

World Journal of Surgery

ORIGINAL SCIENTIFIC REPORT

A comparison of Video-Assisted Thoracoscopic Surgery with Open Thoracotomy for the Management of Chest Trauma: A Systematic Review and Meta-analysis

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Published online: 2 December 2014

Abstract

Background This study aimed to systematically review and compare the perioperative outcomes of video-assisted thoracoscopy (VATS) with open thoracotomy for chest trauma patients.

Methods We conducted a systematic review and meta-analysis of randomized control trials and cohort studies comparing the perioperative outcomes of VATS with open thoracotomy for chest trauma patients. Clinical endpoints included postoperative complications, perioperative mortality rate, chest tube drainage volume, duration of tube drainage, duration of hospitalization, operation time, and amount of bleeding and transfusion volume in operation. A subgroup analysis was performed to explore the potential source of heterogeneity.

Results Twenty-six studies were included. Pooled analyses showed significant reductions in the incidence of postoperative complications (risk ratio [RR] [95 % confidence interval (CI)], 0.47 [0.35, 0.64]), chest tube drainage volume (mean difference [MD] [95 % CI], −146.88 ml [−196.04, −97.72]), duration of tube drainage (MD, −1.71 days; 95 % CI −2.16 to −1.26), duration of hospitalization (MD, −4.67 days; 95 % CI −5.19 to−4.14), operation time (MD, −41.18 min; 95 % CI −52.85 to −29.51), and amount of bleeding (MD, −119.10 ml; 95 % CI −147.28 to −90.92) and transfusion volume (MD, −379.51 ml; 95 % CI −521.24 to−237.77) in chest trauma patients treated with VATS compared with open thoracotomy. The perioperative mortality rate was not significantly different between patients received VATS and open thoracotomy (RR, 0.52; 95 % CI 0.22–1.21).

Conclusions Compared to open thoracotomy, VATS is an effective and even better treatment for improving perioperative outcomes of hemodynamically stable patients with chest trauma and reduce the complications. However, caution should also be exercised in certain clinical scenarios.

Na Wu and Long Wu have contributed equally to this work and co-first authors.
Jun Jiang and Yafei Li have jointly directed the project.

Electronic supplementary material The online version of this article (doi:10.1007/s00268-014-2900-9) contains supplementary material, which is available to authorized users.

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Introduction

Trauma is the leading cause of death in people aged under 45 worldwide, causing over 15 million deaths per year [1–3]. The morbidity rate of chest trauma in all trauma victims is about 25.2 % [4] and represents 25 % of all fatalities of trauma [5]. A retrospective review of 888 cases indicated that 5.7 % of chest trauma patients required thoracotomy [6]. Although the majority of hemodynamically stable patients with chest trauma can initially be treated with tube thoracostomy, it may be ineffective, leading to an increased risk of conversion to open thoracotomy or a prolonged duration of hospitalization [7]. Open thoracotomy is one of the major surgical maneuvers, but its large incisions have been labeled as the most morbid of surgical incisions and are usually associated with a long and painful recovery.

Since 1946, thoracoscopy has been used as a method of exploration in the cases with chest trauma [8]. In 1981, thoracoscopy has been proved to be a valuable diagnostic and therapeutic measure in patients with chest trauma [9, 10]. Due to the potential advantages of small incisions and less pain, video-assisted thoracoscopy (VATS) becomes increasingly popular in both diagnosis and treatment of trauma in the 1990s [11–13]. Furthermore, minithoracotomy with simultaneous video-assisted thoracoscopy (VAMT) has been proposed. Its procedure is similar to conventional VATS, but the minimal incision wounds for introduction of instruments into the chest are replaced by one muscle-sparing minithoracotomy for quick and complete removal of blood clot [14, 15].

In addition to smaller incision and less pain, perioperative outcomes such as effectiveness, postoperative complications, perioperative mortality, and duration of hospitalization for VATS seem to be superior to open thoracotomy in treating chest trauma [7, 16–18]. However, most of the studies comparing VATS with open thoracotomy in patients with chest trauma are case reports or case series with limited number of patients. Recently, some randomized controlled clinical trials (RCT) and cohort studies have been published. However, several studies reported that VATS caused some adverse effects such as pneumonias, atelectasis, and iatrogenic diaphragmatic hernia [2, 19], making the results of previous studies inconsistent. Therefore, these studies need to be systematically analyzed. In addition, most of these studies had a small sample size in a single institution. A meta-analysis overcomes the limitation of small sample sizes of individual studies and increases the numbers of observations and the statistical power. We therefore conducted a systematic review and meta-analysis to compare the perioperative outcomes of patients with chest trauma receiving VATS with those underwent open thoracotomy.

Materials and methods

Search strategy

The meta-analysis was performed using the guidelines presented in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [20, 21]. Electronic database and manual searches were used to identify relevant studies. We systematically searched the PubMed, EMBASE, Web of Science, and Chinese Biomedical Literature database (CBM) for studies published up to December 2013 using a web-based search engine. Search terms were "thoracoscopy" or "thoracoscopic surgery," "video-assisted thoracoscopic surgery" or "VATS," "traumas," "posttraumatic," "traumatic," "injuries," and "wounds." We also manually searched the journals known to publish data relevant to our search. The literature retrieval was performed in duplication by two independent reviewers (N.W. and L.W.). There was no restriction on publication language.

Selection of studies

Human studies, regardless of sample size, were included if they met the following criteria: (1) the studies compared the outcomes of VATS or VAMT with open thoracotomy in treating patients with chest trauma; (2) the study design was a cohort study or RCT. When multiple publications were based on the same or overlapping data, we used the most recent or largest population.

Quality assessment

Quality assessment of studies was conducted by two reviewers independently (N.W. and C.Q.). The quality of cohort studies was assessed based on the Newcastle–Ottawa criteria [22]. A "score system" was developed based on the Newcastle–Ottawa criteria (Supplementary Table 1). The total scores ranged from 0 (worst) to 9 (best) for cohort studies. The quality of RCT studies was assessed using the Cochrane Collaboration's risk of bias assessment tool; selection bias (random sequence generation and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessment), attrition bias (incomplete outcome data), and reporting bias (selective outcome reporting) were evaluated for each study [23]. Each criterion for the bias risk was assessed as low, high, or uncertain risk. Any disagreements were discussed by two reviewers (J.J. and Y.L.).

Data extraction

Data extraction was performed independently by two reviewers (N.W. and L.W.) using a standardized data

Table 1 Overview of included studies

First author	Year	Country	Subtype of chest trauma	Indications	Study design	Treatment method		Number of participants	
						VATS/VAMT	Control treatment	VATS/VAMT	Control
Lian [33]	2008	China	Fractured rib, lung contusion, diaphragmatic laceration, diaphragmatic hernia	Hemostasis of bleeders, repair of lung and diaphragmatic laceration	Cohort	VATS	Thoracotomy	37	33
Ben-Nun [17]	2007	Israel	Chest trauma (no description in detail)	Hemostasis of bleeders, repair of lung and diaphragmatic laceration, wedge lung resection	Cohort	VATS	Thoracotomy	37	40
Long [25]	2010	China	Lung laceration, intercostal bleeders	Hemostasis of bleeders, repair of lung laceration	RCT	VAMT	Thoracotomy	29	31
Li F [27]	2009	China	Clotted hemothorax, lung laceration, intercostal bleeders, pericardial bleeding	Repair of lung and diaphragmatic laceration, evacuation of clotted hemothorax	RCT	VATS	Thoracotomy	53	61
Liao [30]	2012	China	Chest trauma (no description in detail)	Evacuation of clotted hemothorax, hemostasis of bleeders, repair of lung and diaphragmatic laceration, fixation of fractured rib	RCT	VATS	Thoracotomy	56	57
Li[a] [29]	2008	China	Chest trauma (no description in detail)	Repair of lung laceration, wedge lung resection, hemostasis of bleeders, removal of foreign body in myocardium	RCT	VATS	Thoracotomy	40	36
Lu [42]	2011	China	Hemothoraces	Evacuation of hemothorax, hemostasis of bleeders, repair of lung and diaphragmatic laceration	Cohort	VATS	Thoracotomy	20	20
Yu [46]	2013	China	Pneumothorax and hemothorax	Hemostasis of bleeders, repair of lung laceration	Cohort	VATS	Thoracotomy	31	29
Chen [41]	2013	China	Pneumothorax and hemothorax	Hemostasis of bleeders, repair of lung and diaphragmatic laceration, wedge lung resection	RCT	VATS	Thoracotomy	38	38
Jiang[a] [26]	2010	China	Chest trauma(no description in detail)	–	RCT	VATS	Thoracotomy	40	36
Yuan [37]	2012	China	Lung laceration, fractured rib, diaphragmatic laceration	Hemostasis of bleeders, repair of lung and diaphragmatic laceration	Cohort	VAMT	Thoracotomy	32	30
Yang [39]	2012	China	Hemothorax	Evacuation of hemothorax, hemostasis of bleeders	Cohort	VATS	Thoracotomy	28	28
Hao [35]	2010	China	Hemothoraces	Hemostasis of bleeders, repair of lung laceration, wedge lung resection	RCT	VATS	Thoracotomy	39	34
Zhao [31]	2010	China	Fractured rib, lung contusion, diaphragmatic laceration, diaphragmatic hernia, thoracoabdominal trauma	Hemostasis of bleeders, repair of lung laceration	RCT	VATS	Thoracotomy	44	43

Table 1 continued

First author	Year	Country	Subtype of chest trauma	Indications	Study design	Treatment method		Number of participants	
						VATS/ VAMT	Control treatment	VATS/ VAMT	Control
Huang[a] [48]	2012	China	Traumatic diaphragmatic hernia	Repair of diaphragmatic laceration	Cohort	VATS	Thoracotomy	23	27
Lu [43]	2013	China	Clotted hemothoraces	Evacuation of hemothorax, hemostasis of bleeders	Cohort	VATS	Thoracotomy	35	33
Hu [40]	2009	China	Hemothoraces	Evacuation of hemothorax, decortication and drainage	RCT	VATS	Thoracotomy	58	58
Liu [38]	2012	China	Pneumothorax and hemothorax	Evacuation of hemothorax, hemostasis of bleeders, repair of lung laceration, decortication of empyema	Cohort	VATS	Thoracotomy	62	62
Li [36]	2012	China	Pneumothorax and hemothorax	Evacuation of hemothorax, hemostasis of bleeders, repair of lung and diaphragmatic laceration	RCT	VAMT	Thoracotomy	30	32
Yu [45]	2012	China	Pneumothorax and hemothorax	Hemostasis of bleeders, repair of lung and diaphragmatic laceration, widen pericardial lacerations	Cohort	VATS	Thoracotomy	21	35
Xie [34]	2009	China	Lung contusion, intercostal bleeders	Evacuation of hemothorax, hemostasis of bleeders, repair of lung and diaphragmatic laceration	Cohort	VAMT	Thoracotomy	29	31
Cao [32]	2011	China	Lung contusion, intercostal bleeders, thoracoabdominal trauma	Evacuation of hemothorax, hemostasis of bleeders, repair of lung and diaphragmatic laceration	RCT	VAMT	Thoracotomy	63	63
Li [47]	2012	China	Hemothoraces	Evacuation of hemothorax, hemostasis of bleeders, control air leak	Cohort	VATS	Thoracotomy	40	40
Peng [28]	2008	China	Lung contusion, diaphragmatic laceration	Evacuation of hemothorax, hemostasis of bleeders, repair of lung and diaphragmatic laceration	RCT	VATS	Thoracotomy	38	38
Wang [44]	2011	China	Pneumothorax and hemothorax	Evacuation of hemothorax, hemostasis of bleeders, repair of lung and diaphragmatic laceration, wedge lung resection, control air leak	Cohort	VATS	Thoracotomy	105	95
Samiatina [49]	2004	Lithuania	Open chest trauma (no description in detail)	repair of diaphragmatic laceration, control air leak	Cohort	VATS	Thoracotomy	33	88

[a] Studies included in the systematic review but not included in the meta-analysis

extraction form. First author's name, publication year, demographics, patients' characteristics, indications for VATS, and outcome information were extracted from each study. The numbers of patients with postoperative complications or perioperative mortality, and the means and standard deviations (SDs) of continuous variables in each group were also extracted. Any disagreements were discussed to reach a consensus.

Statistical analysis

We used the pooled risk ratio (RR) as a summary statistic to estimate the relative risk of postoperative complications and perioperative mortality after VATS compared with open thoracotomy. The mean difference (MD) was used as a summary statistic of continuous variables including chest tube drainage volume, duration of tube drainage, duration of hospitalization, operation time, and amount of bleeding and transfusion volume in operation. Statistical heterogeneity was tested using χ^2 test and the I^2 statistic. An $I^2 \geq 50$ % indicated a significant heterogeneity between studies, and meta-analyses were conducted using a random effects model. An $I^2 < 50$ % suggested that the heterogeneity might be accepted, and a fixed effects model was applied. Subgroup analyses were performed to explore the potential source of heterogeneity from study design and subtypes of chest trauma. We evaluated the potential publication bias using Begg's test [24]. All of the statistical analyses were conducted using RevMan 5.2 software (Cochrane Collaboration, RevMan software, Oxford, UK).

Results

Qualitative analysis

We identified a total of 2,132 potentially relevant studies. After reviewing the titles, abstracts, and full text, 26 studies [17, 25–49] met the study inclusion criteria and were included for the final analysis (Supplementary Fig. 1). The characteristics of the included studies were extracted (Table 1). Five studies were on VAMT, and 21 studies were on VATS. The type of chest trauma mainly involved in pneumothorax, hemothorax, rib fractures, lung contusion, diaphragm injury, and cardiac injury. The indications for VATS included hemostasis of bleeders, evacuation of clotted hemothorax, repair of lung laceration, wedge lung resection, repair of diaphragmatic laceration, removal of foreign body, widening of pericardial lacerations, decortication of empyema, and control of air leak.

Most studies indicated that injury severity and characteristics between two groups were comparable. The majority of studies included patients with multiple injuries involving both penetrating and blunt trauma. The investigated outcomes involved postoperative complications, perioperative mortality rate, tube drainage, duration of tube drainage, duration of hospitalization, operation time, and amount of bleeding in operation.

There were 14 cohort studies and 12 RCTs. For quality score of cohort studies, one study scored 6, two studies scored 7, and the others scored 8 (Supplementary Table 2). The risk of bias for each RCT was assessed, as shown in Supplementary Table 3. Most of RCTs did not report the detailed information about the methods of random sequence generation and allocation concealment.

	VATS		Open thoracotomy			Risk Ratio
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Fixed, 95% CI
Lu H 2011	0	20	0	20		Not estimable
Peng Y 2008	0	38	0	38		Not estimable
Hao Q 2010	0	39	0	34		Not estimable
Lian A 2008	0	37	0	33		Not estimable
Hu W 2009	0	58	0	58		Not estimable
Yu H 2013	0	31	0	29		Not estimable
Li Y 2012	0	40	0	40		Not estimable
Li F 2009	0	53	4	61	4.6%	0.13 [0.01, 2.32]
Lu T 2013	1	35	7	33	7.8%	0.13 [0.02, 1.04]
Liu W 2012	0	62	2	62	2.7%	0.20 [0.01, 4.08]
Wang Y 2011	1	105	3	95	3.4%	0.30 [0.03, 2.85]
Liao F 2012	3	56	10	57	10.8%	0.31 [0.09, 1.05]
Li X 2012	1	30	3	32	3.2%	0.36 [0.04, 3.23]
Ben-Nun A 2007	3	37	9	40	9.4%	0.36 [0.11, 1.23]
Samiatina D 2004	15	33	73	88	43.2%	0.55 [0.37, 0.81]
Chen J 2013	3	38	4	38	4.3%	0.75 [0.18, 3.13]
Yu X 2012	7	21	13	35	10.6%	0.90 [0.43, 1.89]
Total (95% CI)		**733**		**793**	**100.0%**	**0.47 [0.35, 0.64]**
Total events	34		128			

Heterogeneity: Chi² = 7.23, df = 9 (P = 0.61); I² = 0%
Test for overall effect: Z = 4.78 (P < 0.00001)

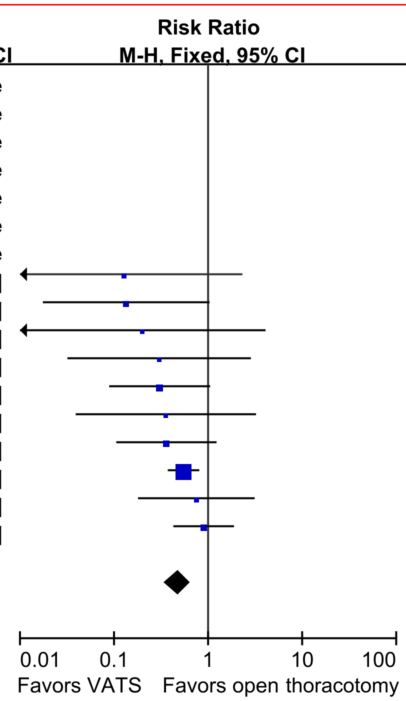

Fig. 1 Comparison of risk of postoperative complications of VATS with open thoracotomy in treating patients with chest trauma. Forest plots of RR and overall RR with 95 % CI between group of VATS and group of open thoracotomy. *Blue square* indicates the RR, with the size of the *square* inversely proportional to its variance, and *horizontal lines* represent 95 % CI. The pooled results are indicated by the *black diamond*. *VATS* video-assisted thoracoscopy, *RR* risk ratio, *CI* confidence interval

Meta-analysis

Thirteen cohort studies and ten RCTs with adequate data were included in the meta-analysis (Table 1). The risk of postoperative complications in patients treated with VATS was significantly lower than that of patients who underwent open thoracotomy with a pooled RR of 0.47 (95 % CI 0.35–0.64; $P < 0.001$) (Fig. 1). The subgroup analysis showed consistent result between RCTs (RR, 0.34; 95 % CI 0.16–0.75; $P = 0.007$) and cohort studies (RR, 0.52; 95 % CI 0.37–0.72; $P < 0.001$) (Table 2).

The perioperative mortality rate was not significantly different between the two groups with a pooled RR of 0.52 (95 % CI 0.22–1.21; $P = 0.13$) (Fig. 2). Consistent results were observed in RCTs (RR, 0.82; 95 % CI 0.22–2.99; $P = 0.76$) and cohort studies (RR, 0.39; 95 % CI 0.12–1.21; $P = 0.10$) (Table 2).

Chest tube drainage volume and amount of bleeding and transfusion volume in operation were found significantly lower in patients with VATS compared to open thoracotomy with pooled MD −146.88 ml (95 % CI −196.04 to −97.72; $P < 0.001$), −119.10 ml (95 % CI −147.28 to −90.92; $P < 0.001$), and −379.51 ml (95 % CI −521.24 to −237.77; $P < 0.001$), respectively (Figs. 3, 4, 5). The duration of tube drainage, hospitalization, and operation time were significantly shorter in patients with VATS with pooled MD −1.71 days (95 % CI −2.16 to −1.26; $P < 0.001$), −4.67 days (95 % CI −5.19 to −4.14; $P < 0.001$), and −41.18 min (95 % CI −52.85 to −29.51; $P < 0.001$), respectively (Figs. 6, 7, 8). Consistent results were also found in both RCT and cohort studies for chest tube drainage volume, amount of bleeding, transfusion volume, and duration of tube drainage, hospitalization, and operation time (Table 2).

Since there were different subtypes of chest trauma, we also performed a subgroup analysis of patients with traumatic hemothoraces and pneumothoraces. Results demonstrated that the perioperative outcomes of VATS group were significantly superior to open thoracotomy group for treating traumatic hemothoraces and pneumothoraces; VATS group had a lower risk of postoperative complications, smaller chest tube drainage volume, and amount of bleeding, and shorter duration of tube drainage, hospitalization, and operation time (Table 3).

Considering VAMT as a special type of VATS, a subgroup analysis was also conducted by VAMT and VATS. Lower perioperative mortality rate, smaller chest tube drainage volume, amount of bleeding and transfusion volume in operation, and shorter hospitalization and operation time were observed in patients who underwent VATS or VAMT compared with those who underwent open thoracotomy (Table 4).

Table 2 Subgroup analysis by study design

Outcome	Number of studies	Number of participants		Effect estimate RR/MD (95 % CI)	Heterogeneity		Test for overall effect
		VATS	Control		*P* value	I^2 (%)	*P* value
RCT							
Postoperative complications	8	374	380	0.34 (0.16, 0.75)	0.78	0	0.007
Perioperative mortality rate	7	296	303	0.82 (0.22, 2.99)	0.47	0	0.76
Chest tube drainage volume	8	364	370	−167.45 ml (−244.24,−90.67)	<0.001	99	<0.001
Amount of bleeding	9	418	415	−106.39 ml (−136.45, −76.34)	<0.001	98	<0.001
Transfusion volume	2	100	99	−376.74 ml (−613.65, −139.82)	<0.001	97	0.002
Duration of tube drainage	5	243	239	−2.75 days (−4.02, −1.48)	<0.001	96	<0.001
Duration of hospitalization	10	456	453	−5.13 days (−5.96, −4.29)	<0.001	83	<0.001
Operation time	10	456	453	−40.11 min (−57.14, −23.09)	<0.001	98	<0.001
Cohort							
Postoperative complications	9	359	413	0.52 (0.37, 0.72)	0.35	9	<0.001
Perioperative mortality rate	9	348	368	0.39 (0.12, 1.21)	0.89	0	0.10
Chest tube drainage volume	5	215	221	−110.52 ml (−157.41, −63.63)	<0.001	89	<0.001
Amount of bleeding	8	321	315	−135.77 ml (−204.09, −67.44)	<0.001	98	<0.001
Transfusion volume	3	98	94	−382.47 ml (−642.01, −122.94)	<0.001	99	0.004
Duration of tube drainage	8	322	380	−1.32 days (−1.75, −0.89)	<0.001	89	<0.001
Duration of hospitalization	10	387	386	−4.25 days (−4.99, −3.51)	<0.001	92	<0.001
Operation time	9	358	355	−42.42 min (−58.77, −26.06)	<0.001	95	<0.001

VATS video-assisted thoracoscopy, *RR* risk ratio, *MD* mean difference

Study or Subgroup	VATS Events	VATS Total	Open thoracotomy Events	Open thoracotomy Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Li F 2009	0	53	0	61		Not estimable
Li G 2008	0	40	0	36		Not estimable
Li X 2012	1	30	0	32	3.1%	3.19 [0.14, 75.49]
Li Y 2012	0	40	0	40		Not estimable
Lian A 2008	0	37	0	0		Not estimable
Liu W 2012	0	62	0	62		Not estimable
Long C 2010	0	29	2	31	15.3%	0.21 [0.01, 4.26]
Lu H 2011	0	20	0	20		Not estimable
Peng Y 2008	0	38	0	38		Not estimable
Samiatina D 2004	0	33	3	88	12.2%	0.37 [0.02, 7.05]
Wang Y 2011	2	105	2	95	13.2%	0.90 [0.13, 6.30]
Xie X 2009	0	29	2	31	15.3%	0.21 [0.01, 4.26]
Yu H 2013	0	31	0	29		Not estimable
Yu X 2012	0	21	2	35	12.0%	0.33 [0.02, 6.51]
Yuan K 2012	0	32	2	30	16.3%	0.19 [0.01, 3.76]
Zhao Q 2010	2	44	2	43	12.8%	0.98 [0.14, 6.63]
Total (95% CI)		**644**		**671**	**100.0%**	**0.52 [0.22, 1.21]**
Total events	5		15			

Heterogeneity: Chi² = 3.26, df = 7 (P = 0.86); I² = 0%
Test for overall effect: Z = 1.51 (P = 0.13)

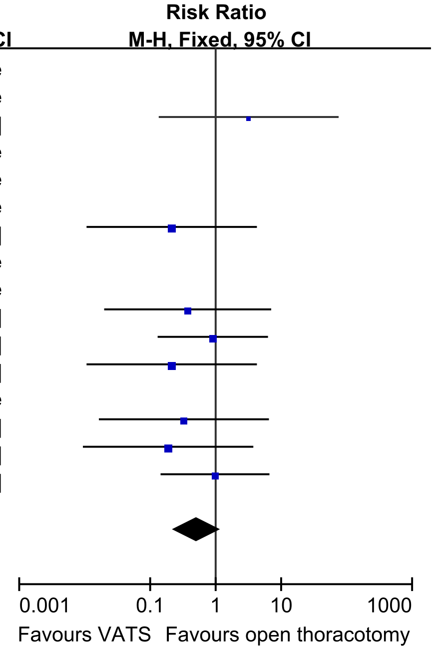

Fig. 2 Comparison of perioperative mortality rate of VATS with open thoracotomy in treating patients with chest trauma. Forest plots of RR and overall RR with 95 % CI between group of VATS and group of open thoracotomy. *Blue square* indicates the RR, with the size of the *square* inversely proportional to its variance, and *horizontal lines* represent 95 % CI. The pooled results are indicated by the *black diamond*. *VATS* video-assisted thoracoscopy, *RR* risk ratio, *CI* confidence interval

Study or Subgroup	VATS Mean	VATS SD	VATS Total	Open thoracotomy Mean	Open thoracotomy SD	Open thoracotomy Total	Weight	Mean Difference IV, Random, 95% CI
Chen J 2013	304.6	150.2	38	486.3	198.5	38	6.7%	-181.70 [-260.84, -102.56]
Hao Q 2010	185.4	15	39	249.5	14.6	34	8.1%	-64.10 [-70.90, -57.30]
Hu W 2009	178.2	35.8	58	255.6	62.5	58	8.0%	-77.40 [-95.94, -58.86]
Li F 2009	150	43	53	260	65	61	8.0%	-110.00 [-130.00, -90.00]
Li X 2012	253	65.91	30	471.88	76.18	32	7.8%	-218.88 [-254.28, -183.48]
Li Y 2012	155.75	23.18	40	212.35	30.17	40	8.1%	-56.60 [-68.39, -44.81]
Liao F 2012	512.1	50.9	56	937.4	85.2	57	7.9%	-425.30 [-451.13, -399.47]
Liu W 2012	400.5	56.9	62	589.7	68.4	62	8.0%	-189.20 [-211.35, -167.05]
Lu H 2011	160.2	40.8	20	280.6	55.5	20	7.9%	-120.40 [-150.59, -90.21]
Wang Y 2011	158.8	75.2	105	248.2	191.7	95	7.7%	-89.40 [-130.54, -48.26]
Xie X 2009	435.2	92.1	29	610.7	91.3	31	7.6%	-175.50 [-221.94, -129.06]
Yang L 2012	178.2	35.8	28	255.6	62.5	28	7.9%	-77.40 [-104.08, -50.72]
Yu X 2012	380	150	21	510	213	35	6.2%	-130.00 [-225.37, -34.63]
Total (95% CI)			**579**			**591**	**100.0%**	**-146.88 [-196.04, -97.72]**

Heterogeneity: Tau² = 7742.93; Chi² = 890.51, df = 12 (P < 0.00001); I² = 99%
Test for overall effect: Z = 5.86 (P < 0.00001)

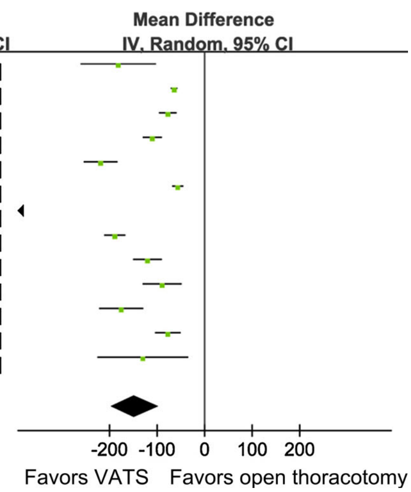

Fig. 3 Comparison of chest tube drainage volume of VATS with open thoracotomy in treating patients with chest trauma. Forest plots of MD and overall MD with 95 % CI between group of VATS and group of open thoracotomy. *Green square* indicates the MD, with the size of the *square* inversely proportional to its variance, and *horizontal lines* represent 95 % CI. The pooled results are indicated by the *black diamond*. *VATS* video-assisted thoracoscopy, *MD* mean difference; *CI* confidence interval

There was no significant heterogeneity for studies investigating the risk of postoperative complications and perioperative mortality with $I^2 = 0$ % (Figs. 1, 2). However, significant heterogeneity was observed among studies on chest tube drainage volume, duration of tube drainage, duration of hospitalization, operation time, and amount of bleeding and transfusion volume in operation with I^2 values above 90 %. Heterogeneity was markedly reduced after grouping by study design, subtype of chest trauma, and operation method (Figs. 3, 4, 5, 6, 7, 8).

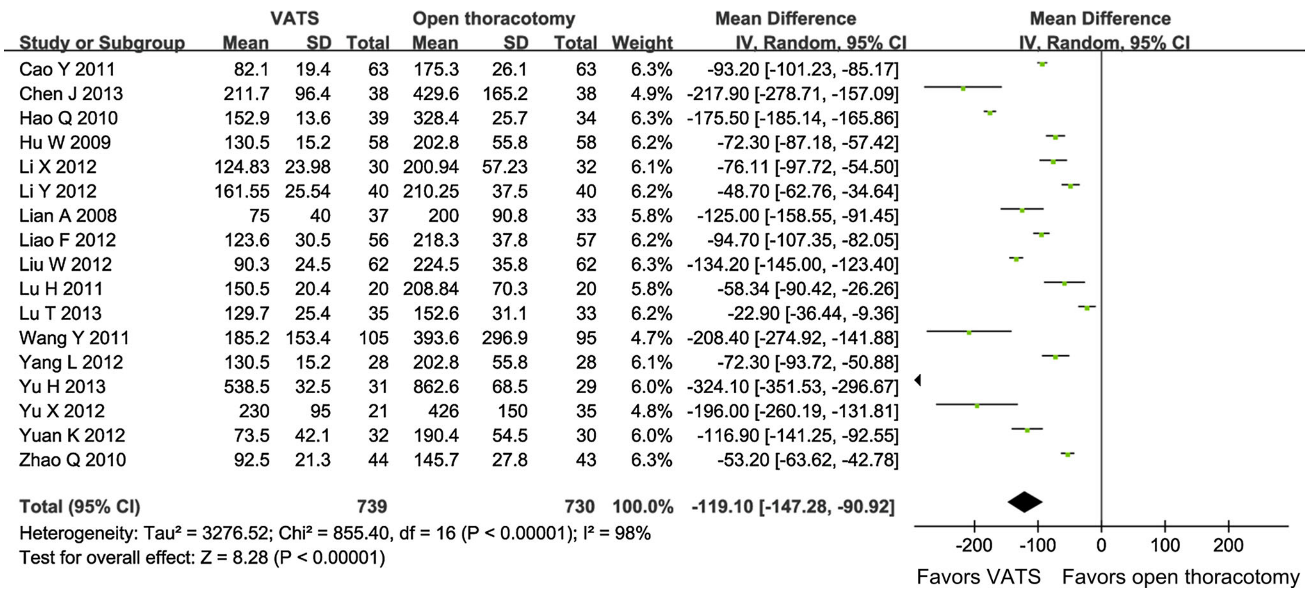

Fig. 4 Comparison of amount of bleeding of VATS with open thoracotomy in treating patients with chest trauma. Forest plots of MD and overall MD with 95 % CI between group of VATS and group of open thoracotomy. *Green square* indicates the MD, with the size of the *square* inversely proportional to its variance, and *horizontal lines* represent 95 % CI. The pooled results are indicated by the *black diamond*. *VATS* video-assisted thoracoscopy, *MD* mean difference, *CI* confidence interval

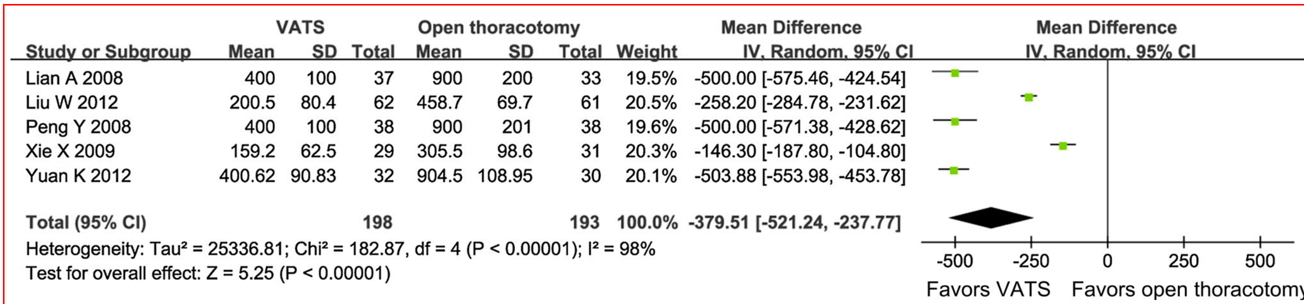

Fig. 5 Comparison of transfusion volume of VATS with open thoracotomy in treating patients with chest trauma. Forest plots of MD and overall MD with 95 % CI between group of VATS and group of open thoracotomy. *Green square* indicates the MD, with the size of the *square* inversely proportional to its variance, and horizontal lines represent 95 % CI. The pooled results are indicated by the *black diamond*. *VATS* video-assisted thoracoscopy, *MD* mean difference, *CI* confidence interval

Discussion

This systematic review and meta-analysis explored whether the perioperative outcomes of VATS in treatment of patients with proper indications of chest trauma were superior to conventional open thoracotomy treatments. Our results suggested that VATS could significantly reduce the risk of postoperative complications, chest tube drainage volume, duration of tube drainage, duration of hospitalization, operation time, and amount of bleeding and transfusion volume in operation in the management of chest trauma. Subgroup analysis indicated that both VAMT (visualization through the incision) and VATS (visualization only through a monitor) were significantly superior to open thoracotomy.

A previous systematic review demonstrated that VATS was useful in the treatment of retained hemothoraces and persistent pneumothoraces which were two major subtypes of chest trauma, and it was able to reduce associated complications [2, 50]. However, meta-analysis was not performed in this study and the majority of included studies were case series. Up to now, there is no meta-analysis comparing the perioperative outcomes of patients who underwent VATS with those who underwent open thoracotomy. Our study for the first time provided quantitatively synthetical evidence on this issue.

Study or Subgroup	VATS Mean	VATS SD	VATS Total	Open thoracotomy Mean	Open thoracotomy SD	Open thoracotomy Total	Weight	Mean Difference IV, Random, 95% CI
Ben-Nun A 2007	3	1.5	37	5	2.1	40	7.3%	-2.00 [-2.81, -1.19]
Hao Q 2010	1.8	1.3	39	4.3	1.1	34	8.3%	-2.50 [-3.05, -1.95]
Hu W 2009	2.4	0.8	58	3.2	0.9	58	9.1%	-0.80 [-1.11, -0.49]
Li Y 2012	2.5	0.4	40	3.2	0.2	40	9.4%	-0.70 [-0.84, -0.56]
Liao F 2012	4.3	1.8	56	7.2	2.4	57	7.4%	-2.90 [-3.68, -2.12]
Liu W 2012	33.2	5.6	62	42.3	6.4	62	3.1%	-9.10 [-11.22, -6.98]
Lu H 2011	3	1.2	20	4	1.5	20	7.1%	-1.00 [-1.84, -0.16]
Lu T 2013	2.8	0.9	35	3.4	0.9	33	8.8%	-0.60 [-1.03, -0.17]
Samiatina D 2004	4.57	2.42	33	6.88	5.76	88	4.8%	-2.31 [-3.77, -0.85]
Wang Y 2011	2.2	0.8	105	3	0.9	95	9.3%	-0.80 [-1.04, -0.56]
Yang L 2012	2.4	0.8	28	3.2	0.9	28	8.7%	-0.80 [-1.25, -0.35]
Yu H 2013	3.2	1.4	31	5.3	1.2	29	7.9%	-2.10 [-2.76, -1.44]
Yu X 2012	2.5	0.5	21	4.5	1	35	8.9%	-2.00 [-2.39, -1.61]
Total (95% CI)			**565**			**619**	**100.0%**	**-1.71 [-2.16, -1.26]**

Heterogeneity: Tau² = 0.55; Chi² = 177.87, df = 12 (P < 0.00001); I² = 93%
Test for overall effect: Z = 7.43 (P < 0.00001)

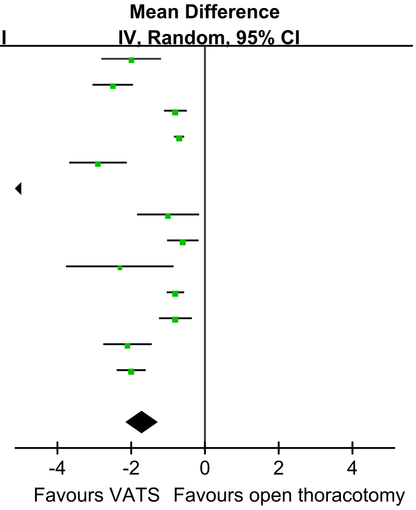

Fig. 6 Comparison of duration of tube drainage of VATS with open thoracotomy in treating patients with chest trauma. Forest plots of MD and overall MD with 95 % CI between group of VATS and group of open thoracotomy. *Green square* indicates the MD, with the size of the *square* inversely proportional to its variance, and *horizontal lines* represent 95 % CI. The pooled results are indicated by the *black diamond*. *VATS* video-assisted thoracoscopy, *MD* mean difference, *CI* confidence interval

Study or Subgroup	VATS Mean	VATS SD	VATS Total	Open thoracotomy Mean	Open thoracotomy SD	Open thoracotomy Total	Weight	Mean Difference IV, Random, 95% CI
Ben-Nun A 2007	6	2	37	8	3	40	5.4%	-2.00 [-3.13, -0.87]
Cao Y 2011	8.9	2.4	63	15.3	1.7	63	6.3%	-6.40 [-7.13, -5.67]
Chen J 2013	11.2	3.9	38	15.6	4.7	38	3.6%	-4.40 [-6.34, -2.46]
Hao Q 2010	12.1	3	39	18.4	4.5	34	3.9%	-6.30 [-8.08, -4.52]
Hu W 2009	11.8	2.2	58	17.6	8.2	58	3.2%	-5.80 [-7.98, -3.62]
Li X 2012	7.98	2.17	30	15.09	2.75	32	5.1%	-7.11 [-8.34, -5.88]
Li Y 2012	6.5	1.5	40	14.5	4.55	40	4.6%	-8.00 [-9.48, -6.52]
Lian A 2008	7	2.18	37	12	2.68	33	5.3%	-5.00 [-6.15, -3.85]
Liao F 2012	6.6	1.7	56	10.6	2.6	57	6.1%	-4.00 [-4.81, -3.19]
Liu W 2012	5.8	1.1	62	10.9	2.1	62	6.6%	-5.10 [-5.69, -4.51]
Lu H 2011	10.8	3.2	20	16.6	7.6	20	1.6%	-5.80 [-9.41, -2.19]
Lu T 2013	8.7	2.1	35	9.8	2.3	33	5.6%	-1.10 [-2.15, -0.05]
Peng Y 2008	7	2	38	11	2	38	5.9%	-4.00 [-4.90, -3.10]
Wang Y 2011	8	2.2	105	11.2	2.3	95	6.5%	-3.20 [-3.83, -2.57]
Xie X 2009	7.2	0.5	29	12.2	0.6	31	7.0%	-5.00 [-5.28, -4.72]
Yang L 2012	11.8	2.2	28	17.5	8.6	28	1.9%	-5.70 [-8.99, -2.41]
Yu H 2013	10.3	2.4	31	15.8	2.6	29	5.1%	-5.50 [-6.77, -4.23]
Yu X 2012	12.5	3	21	16.5	5.5	35	3.1%	-4.00 [-6.23, -1.77]
Yuan K 2012	7.31	0.43	32	11.83	0.35	30	7.1%	-4.52 [-4.71, -4.33]
Zhao Q 2010	7.3	1.8	44	10.7	2.2	43	6.0%	-3.40 [-4.25, -2.55]
Total (95% CI)			**843**			**839**	**100.0%**	**-4.67 [-5.19, -4.14]**

Heterogeneity: Tau² = 1.00; Chi² = 173.17, df = 19 (P < 0.00001); I² = 89%
Test for overall effect: Z = 17.45 (P < 0.00001)

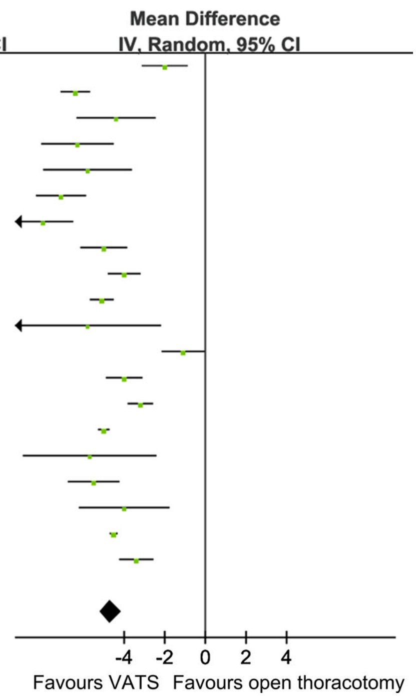

Fig. 7 Comparison of duration of hospitalization of VATS with open thoracotomy in treating patients with chest trauma. Forest plots of MD and overall MD with 95 % CI between group of VATS and group of open thoracotomy. *Green square* indicates the MD, with the size of the *square* inversely proportional to its variance, and *horizontal lines* represent 95 % CI. The pooled results are indicated by the *black diamond*. *VATS* video-assisted thoracoscopy, *MD* mean difference, *CI* confidence interval

For primary outcomes in our study, perioperative mortality rate was not significantly different between VATS group and conventional open thoracotomy group, verifying the safety of VATS. Infection of wound or thoracic cavity, atelectasis, and pneumonia were common postoperative complications of VATS and open thoracotomy. Our results indicated a lower rate of postoperative complications in group of VATS than open thoracotomy. For secondary

Study or Subgroup	VATS Mean	VATS SD	VATS Total	Open thoracotomy Mean	Open thoracotomy SD	Open thoracotomy Total	Weight	Mean Difference IV, Random, 95% CI
Ben-Nun A 2007	72	24	37	68	32	40	5.2%	4.00 [-8.58, 16.58]
Cao Y 2011	77.4	18.3	63	78.1	12.6	63	5.5%	-0.70 [-6.19, 4.79]
Chen J 2013	106.7	38.6	38	144.6	31.8	38	5.0%	-37.90 [-53.80, -22.00]
Hao Q 2010	65.2	14.1	39	130.2	16.2	34	5.4%	-65.00 [-72.02, -57.98]
Hu W 2009	50.5	22.5	58	118.6	45.4	58	5.2%	-68.10 [-81.14, -55.06]
Li X 2012	60.97	15.89	30	100.03	20.46	32	5.3%	-39.06 [-48.15, -29.97]
Li Y 2012	69.5	15.33	40	120.91	29.18	40	5.3%	-51.41 [-61.62, -41.20]
Lian A 2008	60	13.3	37	130	30.38	33	5.3%	-70.00 [-81.22, -58.78]
Liao F 2012	65.4	16.9	56	68.7	20.1	57	5.4%	-3.30 [-10.14, 3.54]
Liu W 2012	73.5	12.3	62	120.4	23.5	62	5.4%	-46.90 [-53.50, -40.30]
Lu H 2011	55.5	20.5	20	122.6	35.5	20	4.9%	-67.10 [-85.07, -49.13]
Lu T 2013	41.2	13.3	35	51.7	15.6	33	5.4%	-10.50 [-17.41, -3.59]
Peng Y 2008	69	12	38	125	28	38	5.3%	-56.00 [-65.69, -46.31]
Wang Y 2011	101.4	25.2	105	139.6	42.5	95	5.3%	-38.20 [-48.01, -28.39]
Yang L 2012	50.5	20.5	28	118.6	45.4	28	4.9%	-68.10 [-86.55, -49.65]
Yu H 2013	64.6	20.5	31	118.1	20.9	29	5.3%	-53.50 [-63.99, -43.01]
Yu X 2012	95	15	21	133	25	35	5.3%	-38.00 [-48.48, -27.52]
Yuan K 2012	69.1	12.1	32	128.4	29.4	30	5.2%	-59.30 [-70.63, -47.97]
Zhao Q 2010	83.2	13.5	44	103.4	19.7	43	5.4%	-20.20 [-27.31, -13.09]
Total (95% CI)			**814**			**808**	**100.0%**	**-41.18 [-52.85, -29.51]**

Heterogeneity: Tau² = 641.68; Chi² = 559.81, df = 18 (P < 0.00001); I² = 97%
Test for overall effect: Z = 6.92 (P < 0.00001)

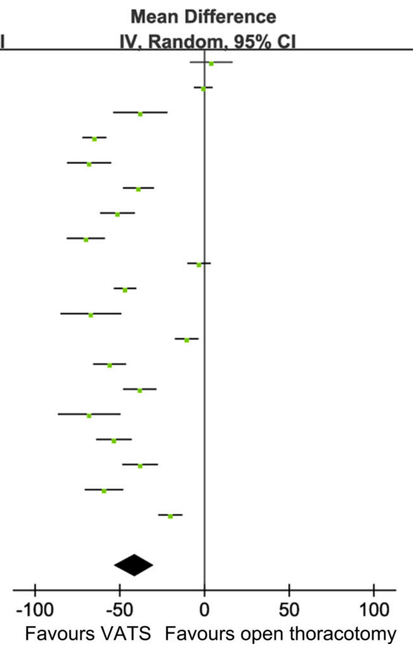

Fig. 8 Comparison of operation time of VATS with open thoracotomy in treating patients with chest trauma. Forest plots of MD and overall MD with 95 % CI between group of VATS and group of open thoracotomy. *Green square* indicates the MD, with the size of the *square* inversely proportional to its variance, and *horizontal lines* represent 95 % CI. The pooled results are indicated by the *black diamond*. *VATS* video-assisted thoracoscopy, *MD* mean difference, *CI* confidence interval

Table 3 Meta-analysis in studies with patients of traumatic hemothoraces and pneumothoraces

Outcome	Number of studies	Number of participants		Effect estimate RR/MD (95 % CI)	Heterogeneity		Test for overall effect
		VATS	Control		*P* value	I^2 (%)	*P* value
Postoperative complications	11	479	476	0.52 (0.29, 0.90)	0.44	0	0.02
Perioperative mortality rate	7	309	313	0.91 (0.24, 3.49)	0.58	0	0.89
Chest tube drainage volume	10	441	442	−116.14 ml (−147.16, −85.13)	<0.001	96	< 0.001
Amount of bleeding	12	507	504	−130.89 ml (−173.83, −87.95)	< 0.001	99	< 0.001
Duration of tube drainage	10	439	434	−1.51 days (−1.98, −1.04)	< 0.001	94	< 0.001
Duration of hospitalization	12	507	504	−44.26 days (−47.03, −41.49)	< 0.001	93	< 0.001
Operation time	12	507	504	−48.11 min (−59.05, −37.16)	< 0.001	93	< 0.001

VATS video-assisted thoracoscopy, *RR* risk ratio, *MD* mean difference

outcomes, VATS could significantly reduce duration of tube drainage and hospitalization. Although the procedure of VATS costs more than open thoracotomy and VATS once had been considered as a luxury tool in the armamentarium of the trauma team, in fact, the total cost of hospitalization might be even lower for patients who underwent VATS due to the reduced duration of drainage and hospitalization. VATS had already been shown to decrease hospital length of stay and cost when compared with tube thoracostomy in patients with blunt chest trauma [51]. VATS was increasingly accepted mainly due to the potential benefits of small wounds and less pain to patients [52]. In our study, only two studies evaluated pain intensity [30, 47] and length of incision [34, 36], respectively, so meta-analysis was not performed on these two issues. But these studies showed that mean score of Visual Analog Scale was significantly lower [30, 47] and length of incision was significantly shorter for VATS [34, 36]. Our

Table 4 Subgroup analysis by VATS and VAMT

Outcome	Number of studies	Number of participants		Effect estimate RR/MD (95 % CI)	Heterogeneity		Test for overall effect
		VATS	Control		*P* value	I^2 (%)	*P* value
VATS							
Perioperative mortality rate	12	524	547	0.66 (0.21, 2.02)	0.89	0	0.46
Chest tube drainage volume	11	520	528	−137.68 ml (−190.73, −84.63)	<0.001	99	<0.001
Amount of bleeding	14	614	605	−125.44 ml (−161.40, −89.47)	<0.001	98	<0.001
Transfusion volume	3	137	132	−416.99 ml (−604.96, −229.02)	<0.001	97	<0.001
Duration of hospitalization	16	689	683	−4.41 days (−5.20, −3.63)	<0.001	86	<0.001
Operation time	16	689	683	−42.78 min (−54.92, −30.65)	<0.001	96	<0.001
VAMT							
Perioperative mortality rate	4	120	124	0.39 (0.11, 1.43)	0.52	0	0.15
Chest tube drainage volume	2	59	63	−199.90 ml (−242.08, −157.72)	0.15	53	<0.001
Amount of bleeding	3	125	125	−118.90 ml (−138.25, -99.55)	<0.001	98	<0.001
Transfusion volume	2	61	61	−324.80 ml (−675.22, 25.62)	<0.001	99	0.07
Duration of hospitalization	4	154	156	−5.55 days (−6.30, −4.79)	<0.001	93	<0.001
Operation time	3	125	125	−32.77 min (−68.70, 3.16)	<0.001	98	0.07

VATS video-assisted thoracoscopy, *VAMT* minithoracotomy with simultaneous video-assisted thoracoscopy, *RR* risk ratio, *MD* mean difference

meta-analysis also demonstrated that the amount of bleeding, transfusion volume during operation, and the total operation time were smaller or shorter for VATS, suggesting smaller wounds and smoother process.

VATS was recommended for a variety of therapeutic purposes following chest trauma. In our study, we found that VATS was mostly applied to chest trauma cases involving hemostasis of bleeders, evacuation of clotted hemothorax, repair of lung laceration, wedge lung resection, repair of diaphragmatic laceration, and control of air leak. Removal of foreign body, widening of pericardial lacerations and decortication of empyema were also applied. Manlulu AV et al. investigated the current indications of VATS in 2004 [13]. Compared with our results, these indications seemed not to change much during the last ten years. Most of the included studies in our systematic review indicated that in spite of the superior perioperative outcomes of VATS, surgeons should bear in mind that the application of VATS was conditional. Contraindications to VATS included obliterated pleural spaces, inability to tolerate single-lung ventilation, hemodynamic instability, circulatory shock, and life-threatening thoracic injury. Procedure of VATS required experienced surgeons, anesthetists, and nurses. The optimal timing for performing VATS and its effects on outcomes were not clearly understood. However, none of the studies in our systematic review investigated the timing of VATS. The majority of previous reports advocated the early use of VATS within 5 days after trauma and more operative difficulties in patients if VATS was performed at a later time point [2].

We conducted a critical quality assessment for each included study. All cohort studies scored at least 6, suggesting that all of them had moderate or high quality. However, the original RCTs had uneven quality. The vast majority of included RCT studies had a low risk on performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessment), attrition bias (incomplete outcome data), and reporting bias (selective reporting). However, most of the included RCTs did not report the detailed information about methods of random sequence generation and allocation concealment. When randomization is not strictly carried out, characteristics of participants may not be comparable between two groups; bias may be introduced and may affect the reliability of the results. Thus, more high-quality RCTs are warranted in this field.

We need to acknowledge other limitations in this study. Firstly, the majority of included studies came from a single institution, and the number of participants in each study was limited. Only one study had more than 100 patients undergoing VATS. Secondly, most of the studies were from China, indicating VATS enjoyed great popularity in Chinese hospitals, but this limited the generalizability of our conclusion. More multi-center RCTs involving different counties are needed. Thirdly, VATS and open thoracotomy have different indications. The majority of patients suffered multiple injuries including both penetrating and blunt injury trauma. Injury severity might affect the eligibility for receiving VATS or thoracotomy and the outcomes of operation. Other factors such as age, sex, and medical history might also play a part. Although the majority of the cohort studies had reported that injury severity, age, and gender were comparable between two groups, other known and unknown confounding factors might introduce the bias. Included RCTs with poor randomization could not guarantee the comparability between two groups. High-quality RCTs with appropriate randomization can make up for this limitation in future studies.

In conclusion, our meta-analysis demonstrated that VATS was effective and superior for treatment of appropriate chest trauma than conventional open thoracotomy. But caution should also be exercised in certain clinical scenarios. Furthermore, well-designed, multi-center RCTs with large simple sizes need to be conducted to compare the efficacy of VATS with thoracotomy and identify the best indicators for VATS or VAMT treatment.

Acknowledgments This work was supported by the Special Project Fund of Health Research from National Health and Family Planning Commission, China (No. 201302016).

Disclosures None.

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