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REVIEW

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Perioperative outcomes of thoracoscopic versus non-thoracoscopic minimally invasive repair of pectus excavatum: a systematic review and meta-analysis

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Abstract

Background Pectus excavatum is the most common chest wall deformity, with the Nuss procedure being the preferred surgical approach for correction. However, the decision to use thoracoscopic assistance remains challenging. This study aimed to evaluate the perioperative outcomes of thoracoscopic-assisted versus non-thoracoscopic-assisted minimally invasive repair of pectus excavatum (TA-MIRPE vs. NTA-MIRPE).

Methods A comprehensive search was conducted across PubMed, Medline, Embase, WOS, and CBM databases for studies published from 2010 to the present related to this topic. Meta-analysis was performed using RevMan 5.0 and STATA 15.0, with primary comparisons focusing on postoperative complications and the incidence of poor incision healing.

Results Eighteen studies involving a total of 5933 patients were included in the analysis, with 1670 undergoing non-thoracoscopic surgery and 4263 receiving thoracoscopic surgery. The meta-analysis revealed that, compared to the NTA-MIRPE group, the TA-MIRPE group had longer operation times [SMD = 1.71, 95% CI (1.14, 2.28), $P < 0.001$] and extended postoperative hospital stays [SMD = 0.12, 95% CI (0.04, 0.20), $P = 0.004$]. However, the TA-MIRPE group showed a lower incidence of postoperative complications [OR = 0.48, 95% CI (0.35, 0.65), $z = 4.63$, $P < 0.001$] and higher patient satisfaction [OR = 1.88, 95% CI (1.32, 2.67), $z = 3.51$, $P < 0.001$].

Conclusion While TA-MIRPE is associated with longer operation times and hospital stays, it offers greater patient satisfaction, reduces postoperative complications, and enhances surgical safety.

Keywords Pectus exavatum (PE), Minimally invasive repair of pectus excavatum (MIRPE), Nuss procedure, Thoracoscopy, Meta-analysis, Systematic review

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Background

Pectus excavatum (PE) has the highest incidence among congenital chest wall morphological disorders, and its incidence rate is approximately 1‰-3‰ [1, 2]; however, there is no unified statement about its etiology. At present, there are two widely accepted hypotheses. One is the hypothesis of unbalanced development of the sternum, ribs, and costal cartilage. This hypothesis states that because the lower part of the ribs grows faster than the upper part, the sternum is pressed toward the rear, thus leading to a retrosternal concave deformity. The second hypothesis involves hypoplasia of the central tendon of the diaphragm, which suggests that due to the short central tendon of the diaphragm, the diaphragm attached below the sternum pulls the growing sternum backward to cause a depressed deformity to form [3].

Before Dr. Nuss pioneered the MIRPE (also known as NUSS) procedure in 1997, most clinicians used Ravitch or other osteotomies to treat pectus excavatum. These surgical methods need to correct posterior concave deformities by cutting off the costal cartilage, which can cause trauma to the patient, and the incidence of correction failure due to postoperative incision infection is high [4]. The MIRPE operation is a minimally invasive operation. One or more orthopedic plates are used to pass through the depth of the depression in the chest wall, and the plates are fixed on the ribs on both sides to correct the depression [5]. Compared with previous procedures involving Ravitch surgery and sternal inversion, this surgery is associated with less trauma, greater patient acceptance, and satisfactory curative effects [4, 6, 7], which have led to the rapid adoption of MIRPE surgery by surgeons and widespread use in clinical practice. With the increase in practice and continuous improvement of surgery, some physicians believe that thoracoscopy not only is convenient for helping surgical operators visually identify potential bleeding points but also provides visual aids that can effectively improve the safety of instruments crossing the mediastinum, reduce the probability of mediastinal complications during and after surgery, and reduce the probability of damage to the pericardium and even the heart when the orthopedic steel plate passes through the precordial area [1, 2, 8]. For the above reasons, TA-MIRPE surgery has gradually been carried out clinically. The safety and efficacy of this method remain controversial; however, some researchers believe that the use of thoracoscopy is more pronounced than the widely debated protective effect, resulting in increased morbidity and adverse events caused by disruption of the integrity of the pleural space [6]. To objectively and accurately evaluate the role of thoracoscopy in MIRPE, this article compares the perioperative outcomes of patients who underwent TA-MIRPE surgery or NTA-MIRPE surgery, through meta-analysis to increase the reliability of the findings.

Main text

Information and methodology

Inclusion and exclusion criteria

Inclusion criteria

(1) Since 2010, all studies comparing TA-MIRPE surgery with NTA-MIRPE surgery were eligible for inclusion.
(2) Research indicators: (1) the report contains statistical data on the short-term effect of surgery (1) the time of surgery; (2) intraoperative blood loss(IBL); (3) length of postoperative hospital stay(LPHS); 4),Postoperative complications: <1 > infection of the surgical site; <2 > Postoperative lung infection; <3 > Postoperative pneumothorax; <4 > Pleural effusion or empyema; <5 > Bloody pleural effusion; 5)length of hospital stay(LHS); groups incidence one of the postoperative complications is included in the total complication statistics. (2) Long-term effect indicators of surgery: (1) Postoperative patient satisfaction evaluation indicators: <1 > Postoperative chest X-ray showed no depression in the sternum; <2 > flatness and symmetry of the appearance of the thoracic cage; <3 > Satisfaction of postoperative orthopedics for children and families; <4 > Thoracic fullness, stretchability, and elasticity. Compliance with clause 3 or more is excellent, and compliance with clause 3 or less is nonexcellent. (2) Surgery-related unplanned readmission rate and reoperation rate.

Exclusion criteria

(1) Patients were not divided into experimental and control groups.
(2) The baseline status of the participant was unclear or was not compared.

Search strategy

The "(Thoracoscopy OR Nonthoracoscopic) AND pectus excavatum OR funnel chest" were identified in the PubMed, Medline, Embase, Science of the Web, nad CBM databases to search for all studies of controlled clinical trials published from 2010 to present without language restrictions.

Literature screening and data extraction

After removing duplicate studies, two authors independently judged eligibility for inclusion. Controversial literature was judged by an independent third party to decide whether to include it in the analysis.

The following data were extracted: (1) basic information about the research, such as the name of the first author of the document, the journal and the date of publication; (2) key information on the type of study and quality evaluation; (3) characteristics of the preoperative group of patients, such as age, sex, and the Haller index between different groups; and (4) outcome indicators, such as surgery-related data, including OT, IBS, the PC rate and LPHS, the unplanned readmission rate and the unplanned surgical rate.

Quality evaluation

The quality of the eligible papers was assessed using ROBINS-I tools and methods [9]. It consists of five evaluation steps: (1) Randomization process evaluation. The evaluation of the randomization process included whether the allocation was randomized, whether the allocation process was blinded, and whether there were obvious differences in the basic situation between the groups. (2) Deviations from planned interventions were actually implemented. This step included determining whether the study participants were aware of their own grouping, whether the investigator was aware of the study subject's grouping, whether additional interventions were taken, etc.; (3) loss to follow-up; and (4) measurement error evaluation. The assessment of measurement errors included whether the measurement statistics were carried out as originally planned and the ability of the surveyor to measure; (5) Selective reporting. This includes whether the analysis was carried out as originally planned and whether multiple analysis methods were used.

Statistical analysis

The statistical indicators, such as the mean (M) and standard deviation (σ), were included for all measurement and counting data in all eligible studies and for the number of people. In addition, if the research report used medians and interquartile intervals (IQRs) to report the concentration and dispersion trends of the samples, the BC method was used (Box Cox Method) was used [10]. is used to estimate M and σ from known data. Second, if the heterogeneity index I^2 value was greater than 50%, a random effects model (RM) was used to evaluate the data with high heterogeneity. Otherwise, a fixed effects model (FM) was used for statistical analysis, and a p value$>$0.05 indicated statistical significance. Prospective subgroup analysis was conducted based on whether the study was an RCT or a nonrandomized clinical controlled trial (NRCT) and whether the hospital being studied was a teaching hospital (a hospital directly affiliated with an undergraduate university) or a non-teating hospital (a hospital directly affiliated with an undergraduate university). If an asymmetric funnel-shaped distribution and a unilateral $P \geq 0.05$ (Egger test) were detected during the statistical analysis process, Duval and Tweedie's "pruning and filling" method was used to calculate the adjusted effect values to conduct sensitivity analysis and reduce the impact of publication bias [11]. Ravmen 5.0 was used to conduct all of the analyses.

Results

Literature search results and basic characteristics of the included studies

A total of 2045 articles were identified—2042 from the initial search and an additional 3 from the literature review. After 35 duplicates were removed, 2010 remained. A total of 1962 publications that did not satisfy the objectives and inclusion criteria of this study were eliminated by reviewing the titles and abstracts, and the remaining 48 were excluded. After further reading the full texts, 13 articles lacked specific data, 5 articles with inconsistent statistical results and 2 crossover studies were eliminated; ultimately, 18 articles were included, including 3 RCTs, 15 RCTs on the NRCT, 13 on the TP and 5 on the NTP. Figure 1 displays the procedure of screening the literature as well as the outcomes. Table 1 lists the fundamental traits and information of the included studies. Moreover, using the ROBINS-I tool, the caliber of the studies was evaluated, and the results showed that the studies included in this paper were of good quality (Fig. 2).

Overall meta-analysis results

Surgical operation time (OT)

Seventeen studies [1, 2, 4, 6, 8, 12–23] compared the standard deviation of the operative time between the two groups (Mennie 2018 [7] did not report the operative time in the two groups and were not included in the statistical analysis). Kauffman 2019 [22] and Sacco-Casamassima 2015 [23] did not report the mean or median time or interquartile range for statistical analysis; these data were converted using the BC method for analysis. The RM was used to assess heterogeneity, which revealed statistical heterogeneity between trials. (Cochran's Q=857.35, df=16, $P<0.001$, I^2=98%). [pooled SMD=1.71, 95% CI (1.14 to 2.28), $P=0.001$] (Fig. 3).

Amount of blood loss (BL)

Thirteen studies [1, 2, 4, 8, 12, 13, 15–19, 21, 22] reported data on blood loss, and tests for heterogeneity revealed statistical heterogeneity between studies analyzed using an RM (Cochran's Q=289.70, df=12, P). <0.001, I^2 = 96%). There was no significant difference in the results between the two groups [pooled SMD = -0.05, 95% CI (-0.49, 0.39), $P=0.82$].

Length of hospital stay (LHS)

Seventeen studies reported LHS. Of these, 12 studies [1, 2, 4, 6, 8, 12–14, 16, 18, 20, 21] compared the difference in

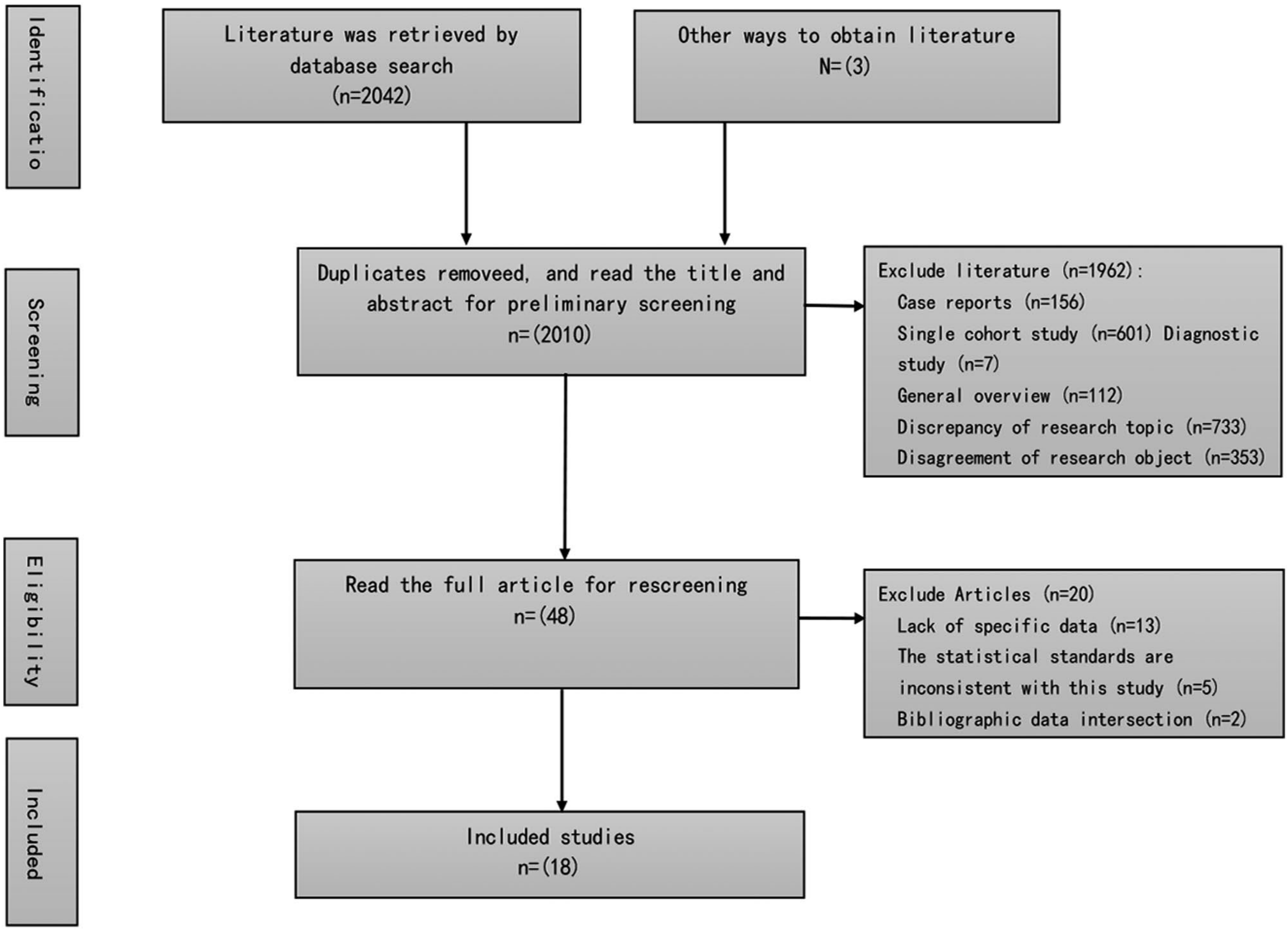

Fig. 1 Literature screening flowchart

total length of hospital stay. According to the RM results (Cochran's Q=111.35, df=11, $P<0.001$, $I^2 = 90\%$), there was no statistically significant difference in total hospital stay (pooled SMD = -0.17, 95% CI (-0.54, 0.20), z=0.9, $P=0.37$). The remaining six studies [7, 12, 15, 17, 19, 22] (Shen 2020 [12] reported TLHS and LPHS) reported LPHS, which were analyzed using an FM (Cochran's Q=8.75, df=5, $P=0.12$, $I^2 = 43\%$). The present analysis revealed that the TA-MIRPE group had a prolonged hospital stay [combined with SMD=0.12, 95% CI=0.04, 0.20; $P=0.004$] (Fig. 4).

Patient satisfaction

Nine studies [2, 4, 8, 12, 13, 15, 16, 18, 19] reported on postoperative patient satisfaction. Using a fixed-effect model analysis (Cochran's Q=8.27, df=7, $P=0.31$, $I^2 = 15\%$) showed that the TA-MIRPE group was more satisfied than the NTA-MIRPE group after surgery [OR=1.88, 95% CI (1.32 to 2.67), z=3.51, $P<0.001$] (Fig. 5).

Postoperative complications

Thirteen studies [1, 2, 4, 6–8, 12, 13, 15, 16, 18, 19, 22] have reported the incidence of postoperative complications. Using FM for analysis (Cochran's Q=10.63, df=12, $P=0.56$; I^2 = The results showed that the incidence of postoperative complications in the TA-MIRPE group was lower than that in the NTA-MIRPE group [OR=0.48, 95% CI=0.35, 0.65; z=4.63, $p<0.001$]. Analysis of specific complications revealed a decreased incidence of poor healing at the surgical incision site in the TA-MIRPE surgery group [OR=0.41, 95% CI (0.23, 0.73), z=2.99, $P=0.003$] (Fig. 6). Kang Chao 2020 [13], Mennie 2018 [7], and Cui Yaya 2018 [1] reported 1 patient with bloody pleural effusion (2%, 1.6%, and 2.4% of the total number of patients, respectively) in their NTA MIRPE group, while Kauffman JD 2019 [22] and Cui Yaya 2018 [1] reported 1 patient with bloody pleural effusion (0.1% and 1.3%, respectively, of the total number of patients) in their TA MIRPE group (Table 2).

Table 1 Basic features of the included literature

Included studies	Design	Type of hospital	number(male/female)		Age(years)		Average Haller index		Type of malformation (symmetry / asymmetry)		Difference in non-thoracoscopic pectus repair
			TM	NTM	TM	NTM	TM	NTM	TM	NTM	
Shen tao 2020 [12]	NRCT	TP	26 (25/1)	33 (29/4)	25.38±21.21	20.91±17.02	4.05±0.98	4.28±1.33	23/3	28/5	Adding one subxiphoid incision
Durry A 2017 [20]	NRCT	TP	11(11/0)	16(14/2)	15.5 ± 1.9	15.8 ±1.9	3.9 ± 1.4	4.4 ± 1.2	NA	NA	Traditional MIRPE
Kang chao 2020 [13]	RCT	N-TP	50 (41/9)	50(39/11)	10.89±2.16	10.75±2.93	5.91±2.36	5.82±2.24	20/30	19/31	Traditional MIRPE
Kauffman JD 2019 [22]	NRCT	TP	1780[*1]	327[*1]	NA	NA	NA	NA	NA	NA	Traditional MIRPE
Xie kai 2018 [2]	NRCT	N-TP	350 (278/72)	350 (276/74)	9.02±1.17	9.27±1.23	5.54±0.86	5.58±0.93	257/93	256/94	Adding one subxiphoid incision
Cui yazhou 2018 [1]	NRCT	N-TP	77 (64/13)	42 (33/9)	12.90±5.20	12.30±4.70	5.92±2.37	5.78±2.09	31/46	16/26	Traditional MIRPE
Tetteh O 2018 [6]	NRCT	TP	1320 (1089/231)	249 (217/32)	15.10±1.68	15.03±1.75	NA	NA	NA	NA	Traditional MIRPE
Mennie N 2018 [7]	NRCT	TP	95 (83/12)	122 (100/22)	15.39±1.12	14.59±2.27	NA	NA	63/32	78/44	Traditional MIRPE
Ni jichen 2017 [16]	RCT	N-TP	42[*1]	45[*1]	NA	NA	NA	NA	NA	NA	Traditional MIRPE
Yang jiaheng 2016 [19]	RCT	N-TP	40 (28/12)	40 (29/11)	9.80±2.60	9.90±2.60	3.9±1.5	4.1±2.1	NA	NA	Traditional MIRPE
Wu minhua 2016 [18]	NRCT	TP	24 (14/10)	23 (13/10)	12.80±3.50	12.50±3.80	6.7±1.2	6.1±1.5	15/9	12/11	Traditional MIRPE
Sacco-Casamassima MG 2015 [23]	NRCT	TP	221[*1]	43[*1]	NA	NA	NA	NA	NA	NA	Traditional MIRPE
Wang kaibiao 2014 [4]	NRCT	TP	31 (22/9)	35 (23/12)	9.33±5.29	9.52±5.33	4.01±1.87	3.89±1.64	19/12	21/14	Traditional MIRPE
Liu wenliang 2013 [15]	NRCT	TP	85 (56/29)	182 (129/53)	9.50±5.30	8.30±6.70	3.9±1.6	4.2±1.8	51/34	107/75	Adding one subxiphoid incision
Du jie 2012 [8]	NRCT	TP	45 (33/12)	30 (21/9)	18.85±1.12	18.67±1.05	3.43±0.15	3.39±0.21	NA	NA	Traditional MIRPE
Wang yunhai 2011 [17]	NRCT	TP	24(19/5)	35 (27/8)	12.60±6.00	13.20±5.30	4.15±0.85	3.91±0.7	NA	NA	Traditional MIRPE

Table 1 (continued)

Included studies	Design	Type of hospital	number(male/female)		Age(years)		Average Haller index		Type of malformation (symmetry / asymmetry)		Difference in non-thoracoscopic pectus repair
			TM	*N* TM	TM	*N* TM	TM	*N* TM	TM	*N* TM	
Li xiaofei 2010 [14]	NRCT	TP	22[*1]	26[*1]	NA	NA	NA	NA	NA	NA	Traditional MIRPE
Han Y 2010 [21]	NRCT	TP	20[*1]	22[*1]	NA	NA	NA	NA	NA	NA	Traditional MIRPE

TM: Thoracoscopic MIRPE, NTM: Non-thoracoscopic MIRPE, MIRPE: minimally invasive repair of pectus excavatum ; RCT: Randomized controlled trials; NRCT: Non-Randomized controlled trials; TP : Teaching hospital; N-TP: Non-teaching hospitals

[*1]: Not listed

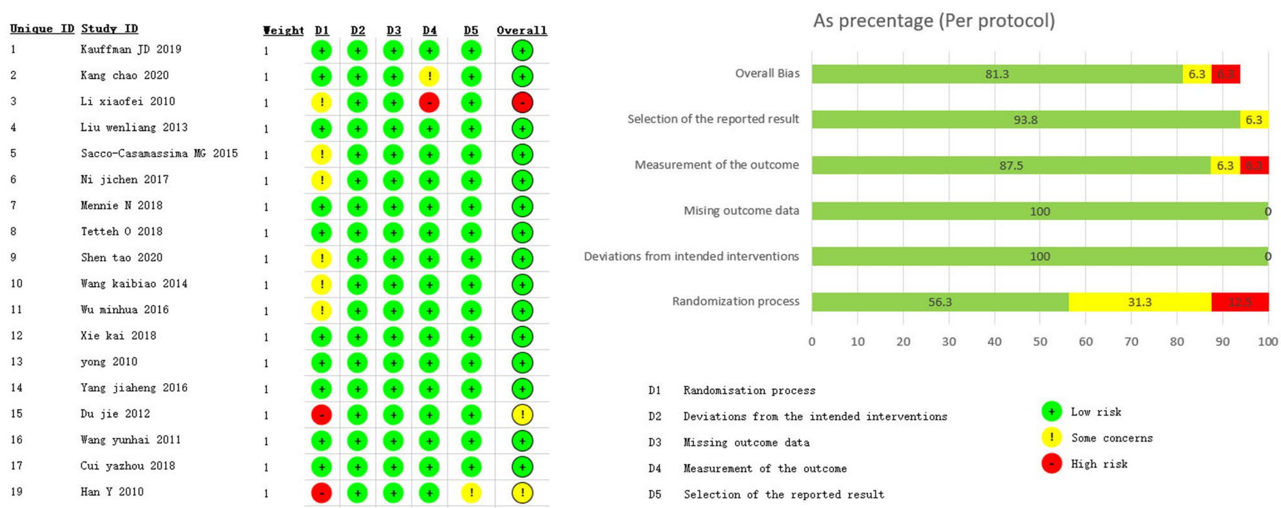

Fig. 2 Quality evaluation diagram

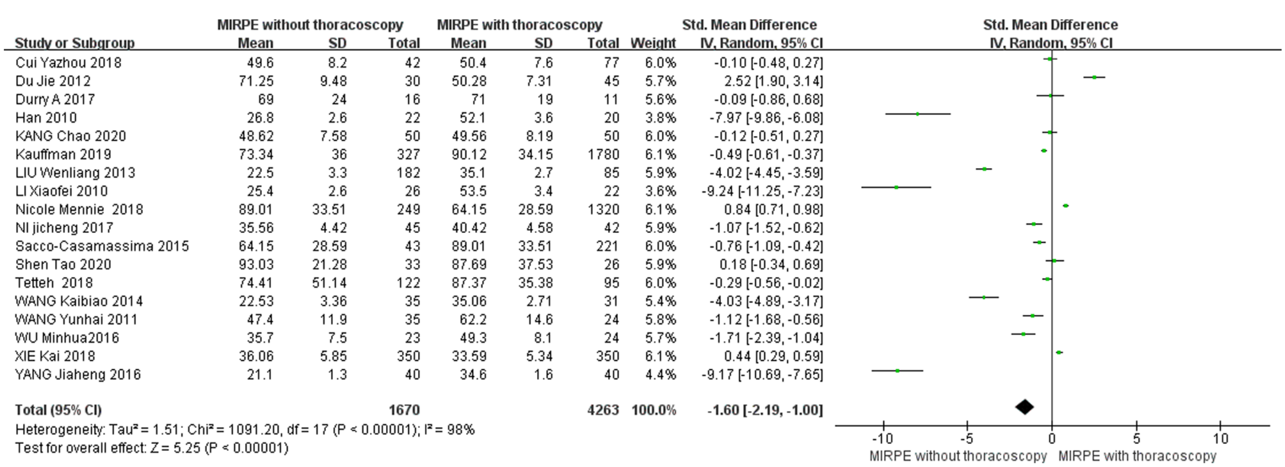

Fig. 3 Analysis of surgical time for thoracoscopic versus non-thoracoscopic surgery

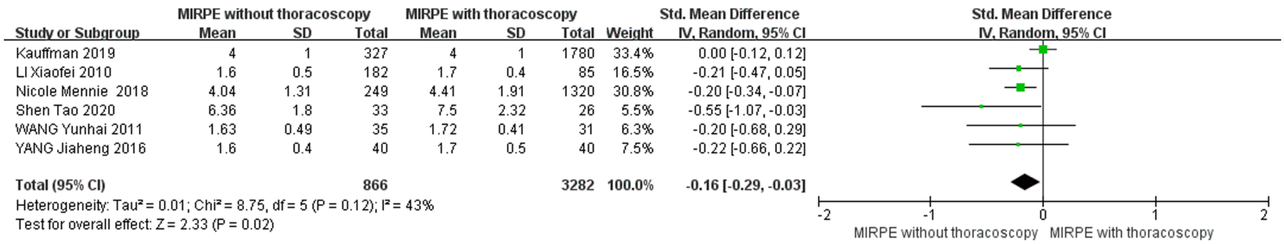

Fig. 4 Analysis of postoperative length of hospital stay for thoracoscopic versus non-thoracoscopic surgery

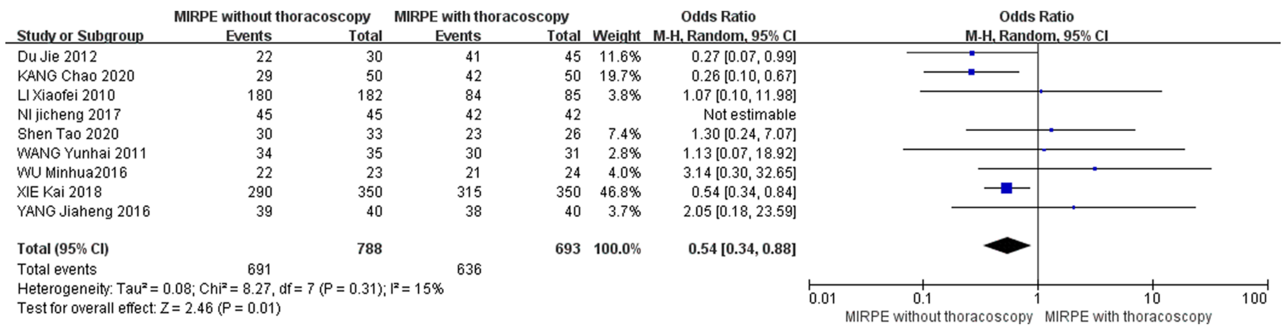

Fig. 5 Patient satisfaction analysis of thoracoscopic versus non-thoracoscopic surgery

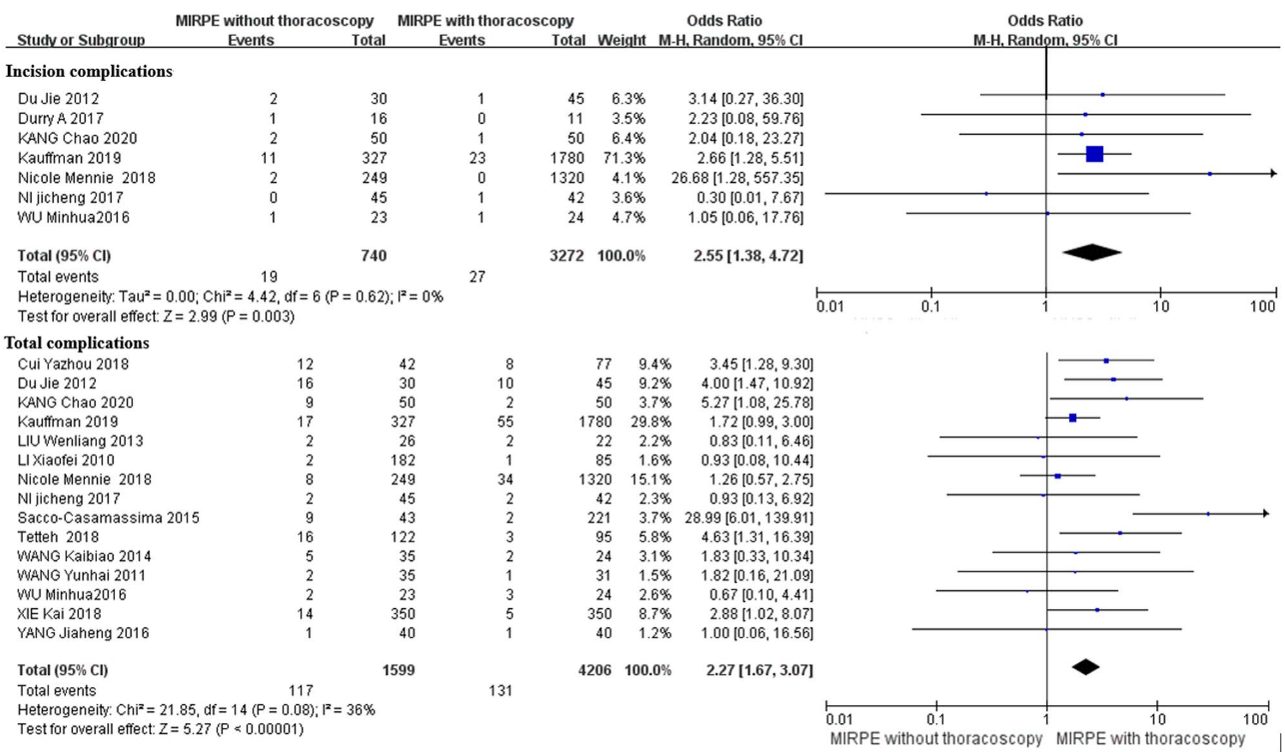

Fig. 6 Analysis of incision complications and total complications in thoracoscopic and non-thoracoscopic surgery

Table 2 Major complications

Included studies	Pneumothorax (%)		Incision infection (%)		Pleural effusion (%)		Pneumonia (%)		Cardiopulmonary injury (%)		hemothorax (%)	
	TM	NTM	TM	NTM	TM	NTM	TM	NTM	TM	NTM	TM	NTM
Shen tao 2020 [12]	11 (42.31)	9 (27.30)	0 (0.00)	0 (0.00)	4 (15.39)	11 (33.30)	NA	NA	1 (3.85)	0 (0.00)	NA	NA
Kang chao 2020 [13]	1 (2.00)	2 (4.00)	NA	NA	0 (0.00)	2 (4.00)	NA	NA	NA	NA	0 (0.00)	1 (2.00)
Kauffman JD 2019 [22]	7 (0.40)	4 (1.20)	24 (1.40)	11 (3.40)	7 (0.40)	1 (0.30)	8 (0.50)	1 (0.30)	NA	NA	1 (0.10)	0 (0.00)
Xie kai 2018 [2]	2 (0.57)	5 (1.43)	NA	NA	1 (0.29)	2 (0.57)	1 (0.29)	4 (1.14)	0 (0.00)	1 (0.29)	NA	NA
Cui yazhou 2018 [1]	4 (5.2)	4 (9.5)	NA	NA	0 (0.00)	2 (4.8)	NA	NA	NA	NA	1 (1.3)	1 (2.4)
Tetteh O 2018 [6]	NA	NA	NA	NA	NA	NA	NA	NA	2 (0.2)	0 (0.00)	NA	NA
Mennie N 2018 [7]	0 (0.00)	1 (1.60)	0 (0.00)	6 (4.92)	NA	NA	NA	NA	0 (0.00)	2 (1.60)	0 (0.00)	2 (1.60)
Ni jichen 2017 [16]	1 (2.38)	0 (0.00)	1 (2.38)	0 (0.00)	0 (0.00)	1 (2.22)	NA	NA	NA	NA	NA	NA
Wu minhua 2016 [18]	0 (0.00)	0 (0.00)	1 (4.17)	1 (4.38)	NA	NA	NA	NA	NA	NA	NA	NA
Wang kaibiao 2014 [4]	1 (3.23)	1 (2.86)	0 (0.00)	0 (0.00)	NA	NA	NA	NA	NA	NA	NA	NA
Liu wenliang 2013 [15]	1 (1.18)	2 (1.10)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Du jie 2012 [8]	2 (4.44)	4 (13.33)	1 (2.22)	2 (6.67)	NA	NA	NA	NA	0 (0.00)	1 (3.33)	NA	NA
Wang yunhai 2011 [17]	1 (4.17)	2 (5.71)	NA	NA	1 (4.17)	3 (8.57)	NA	NA	NA	NA	NA	NA

Surgery-related 30-day readmission and reoperation rates

Seven studies [1, 2, 6, 8, 13, 14, 22] reported surgery-related 30-day readmission and reoperation rates, and the analysis showed that patients with pectus excavatum who underwent TA-MIRPE surgery had a lower probability of readmission or resurgery within 30 days after discharge [OR=0.50, 95% CI (0.29 to 0.84), z = -2.60, P=0.009].

Subgroup meta-analysis

Subgroup analysis of surgical time

Subgroup analyses consistently demonstrated that TA-MIRPE surgery prolonged the duration of surgery (SMD=0.77, P<0.001; RCT group SMD=0.76, P<0.001; SMD=0.63, P=0.00 for the teaching hospital group; SMD=0.95, P=0.00 for the nonteaching hospital group).

Subgroup analysis of patient satisfaction

RCT versus NRCT subgroup analysis (NRCT group OR=1.764, P=0.004; RCT group OR=2.821 and P=0.016) revealed that people are more satisfied with the results of TA-MIRPE surgery. There was not much difference in patient satisfaction between the TH group (OR=1.30, P=0.57) and the NTH group in the subgroup analyses (OR=2.13, P=0.03).

Subgroup analysis of complications

The overall complication and incision complication rates in the TA-MIRPE surgery group were greater than those in the NTA-MIRPE surgery group (overall complication rate: OR=0.54, P=0.0009 in the TH group; OR=0.35, P=0.006 in the NTH group). Incision complication rates: OR=0.35, P=0.002 in the TH group; OR=0.98, P=0.98 in the NTH group. The remaining complication comparisons showed no advantage for one side. (Pneumothorax: OR=0.66, P=0.09 in the TH group; OR=0.55, P=0.22 in the NTH group.) Pleural effusion: OR=2.14, P=0.08 in the TH group and 3.95, P=0.06 in the NTH group.

Analysis of surgery-related 30-day readmission rates

Subgroup analysis of teaching hospitals showed that the performance of teaching hospitals was more satisfactory than that of nonteaching hospitals [OR=0.54, P=0.04], and there was no need to compare subgroups of non-teaching hospitals [OR=0.34, P=0.20].

Sensitivity analysis

Sensitivity analyses were performed using a single-exclusion approach, in which outcome measures were meta-analyzed and each study was removed sequentially. With respect to the time to surgery, reoperation rate, LPHS, and TLHS, the conclusions of the present study did not significantly change after the loss of included studies one by one; thus, the conclusions we summarize are trustworthy. However, in the statistical analysis of IBL, after the Shen Tao 2020 [12] study was deleted, IBL was found to be tilted like a thoracoscopic group [SMD=0.490, 95% CI (0.051, 0.929), z=2.189, *P*=0.029]. After Xie Kai was removed, the difference in intraoperative bleeding loss was significant (OR=1.877, 95% CI=0.974, 3.618).

Publication bias and pruning filling

The Egger test was used to calculate publication bias with unbiased operative time (t=6.25, $p<0.001$), unbiased IBL (t=6.32, $p=0.001$), and unbiased readmissions and reoperation rates (t=-3.34, $p=0.044$). There was bias for length of postoperative hospital stay (t=3.12, $p=0.052$), bias for total length of stay (t=3.74, $p=0.065$), and satisfaction bias t=-1.26, $p=0.256$. There was bias for overall complications (t=-1.54, $p=0.221$) and bias for incision complications (t=0.21, $p=0.844$) (Fig. 7).

Discussion

MIRPE surgery is the main means of clinicallyecting the pectus funnel and has the advantages of reliability, low trauma and strong patient acceptability. When MIRPE surgery was initially performed, thoracoscopy was not used. Thoracoscopic assisted surgery was originally used to meet the needs of serious infundibular thoracic surgery. With continuous practice, progress and improvement in surgical details, to increase the safety of surgery, many branches were born, such as routine use of thoracoscopy or subxiphoid small-incision assisted surgery. The application of these surgical methods is related to the experience and level of the surgeons and lack unified norms and tests. Routine use of thoracoscopy is the most common of these surgical modalities. In this paper, by searching the clinical research literature published since January 2010 and comparing the perioperative outcomes of two groups of patients who underwent MIRPE surgery with and without thoracoscopy, it was found that although TA-MIRPE surgery prolonged the operation time, it was associated with shorter hospital stays, greater patient satisfaction, and lower surgery-related complications. The remaining results showed no significant difference.

This meta-analysis aimed to determine the effects of thoracoscopy in MIRPE surgery. First, in general, the introduction of TA-MIRPE surgery has obvious benefits for patients in terms of short-term evaluation indicators. For complications such as pneumothorax, pleural effusion and incision infection, thoracoscopic surgery is highly advantageous. These benefits may be related to the fact that most thoracoscopic surgery operations are completed in a visual environment, which reduces tissue damage during the operation [13], increases the probability of timely detection of intraoperative injury sites, and prevents complications caused by untimely treatment of intraoperative vascular or other tissue damage. In the trials of Mennie 2018 [7] and Du Jie 2012 [8], serious adverse events such as intraoperative heart and peripheral macrovascular injury, pericardial injury, cardiopulmonary injury, and cardiopulmonary injury occurred more prominently in the NTA MIRPE surgery group than in the TA MIRPE surgery group. These findings also showed that the use of thoracoscopy improved the safety of surgery. Moreover, in terms of long-term evaluation indicators of surgery, since one or several orthopedic plates are implanted in the chest wall during MIRPE surgery, premature removal of the plates or displacement of the orthopedic plates for various reasons

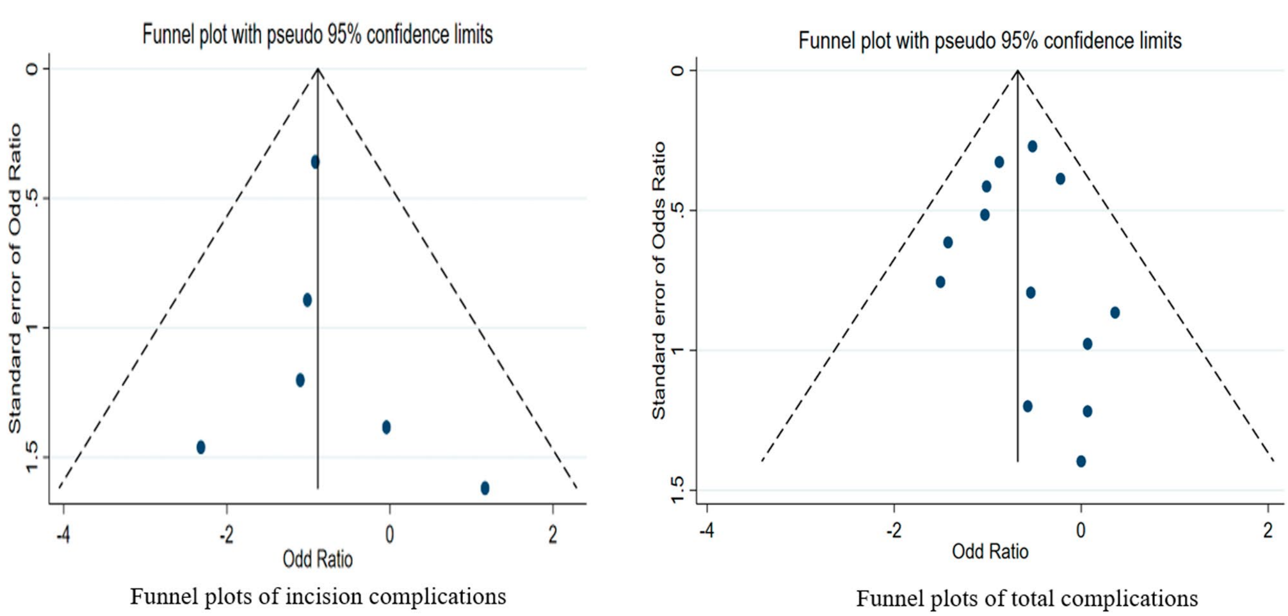

Fig. 7 Complication funnel plots

can lead to surgical failure, which is also a 30-day failure. One of the important factors in planning readmission or reoperation. According to the 7 studies that reported the operation-related readmission and reoperation rates, the readmission and reoperation rates of TA-MIRPE surgery were lower than those of NTA-MIRPE surgery, which was related to the incision TAused for TA-MIRPE surgery. These findings also indicate that the incidence of infection is significantly lower in these patients after surgery than in those after NTA-MIRPE surgery. This outcome could be explained by the ability of TA-MIRPE surgery to prevent, identify, and treat pleural gaps created during orthopedic plate fixation procedures. The incision exudate may only flow outward; air cannot enter or exit the thoracic cavity at this location. In addition to lowering the risk of pleural effusion and pneumothorax, this incision environment also promotes incision healing and inhibits bacterial growth and reproduction. Consequently, TA-MIRPE surgery can improve patients' immediate surgical outcomes while also decreasing their chance of early implant removal owing to incisional infection, which could result in treatment failure. This outcome may partially explain why patient satisfaction is greater in TA-MIRPE surgery than in NTA-MIRPE surgery despite the large number of surgical incisions, deep incisions, and pleural injury.

Although thoracoscopic surgery has a good reputation for safety, nonthoracic surgery also offers remarkable benefits in several areas, including less time spent recovering from surgery, less equipment needed for the procedure, and less expensive therapy. Moreover, favorable surgical outcomes and low rates of complications can be observed during nonthoracic surgery performed by a significant number of highly qualified and experienced medical professionals [24].

This paper has certain limitations. First, due to the low acceptance rate of randomly selected surgical methods, there were only three RCT trials in the subgroup analysis, Kang Chao 2019 [13], Ni Jihen 2017 [16], and Yang Jiaheng 2016 [19], with a total of 260 subjects. This approach reduces the reliability of the subgroup analysis results. Second, the effectiveness of NTA-related MIRPE surgery is closely related to the clinical experience and level of the surgeon, and there are differences between surgical procedures, such as Liu Wenliang 2013 [15], Shen Tao 2020 [12], and Xie Kai 2018 [2]. During surgery, a small incision under the xiphoid process was made, and fingers were used to assist the orthopedic plate in passing through the mediastinum during the operation. This is one of the possible reasons why no serious adverse complications occurred in these patients. However, due to the lack of data, this article did not evaluate the role and impact of the small subxiphoid incision. Therefore, we cannot ignore the potential influence of the above factors on the research results. Overall, the quality of the literature data included in this paper was good, and sensitivity analysis showed stable results.

Conclusion

The results of our meta-analysis revealed that, compared with NTA-MIRPE surgery, TA-MIRPE surgery had a longer operation time, but the incidence of PC, especially when the incision healed poorly, was significantly lower. Postoperative patient satisfaction was higher, and 30-day unplanned readmission rates were lower. These results indicate that thoracoscopic assistance plays a positive role in improving the safety of surgery in MIRPE patients. Future research needs to evaluate the improvement in cardiopulmonary function and psychological status of patients who underwent thoracoscopic or nonthoracoscopic surgery. The influence of differences in the education levels of surgeons and hospitals was excluded.

Abbreviations

TA-MIRPE	thoracoscopic-assisted minimally invasive repair of pectus excavatum
NTA-MIRPE	nonthoracoscopic-assisted minimally invasive repair of pectus excavatum
OT	operation time
PHS	postoperative hospital stay
PC	postoperative complications
IRC	incision-related complications
PE	Pectus exavatum
NA	Nonapplicable

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Author contributions

Haipeng Sun (First Author): Conceptualization, Methodology, Software, Formal Analysis, Writing - Original Draft; Yuchen Huang: Data Curation; Yunyan Han : Visualization; Feng Lin (Corresponding Author): Project administration; Supervision; Writing - Review & Editing. All authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

All authors have no competing interest or financial ties to disclose, and all data in this study come from published literature. At the same time, this study is secondary literature research and does not involve ethical disputes.

Competing interests

The authors declare no competing interests.

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