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Congenital diaphragmatic hernia in pediatric patients: Open versus thoracoscopic repair: A systematic review and meta-analysis

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Abstract

PURPOSE: Repair of congenital diaphragmatic hernia (CDH) includes both mini-invasive and open approaches. We aimed to conduct a comprehensive meta-analysis comparing the outcomes of thoracoscopic and open CDH repairs in the pediatric population.

MATERIALS AND METHODS: A literature review using as keywords "thoracoscopy," "open surgery," and "CDH" was performed. The primary endpoints of the study were to evaluate mortality as well as major intraoperative and postoperative complications, including CDH recurrence. Secondary endpoints were the use of a patch, the length of stay, and operative time.

RESULTS: On 88 papers, 20 met the inclusion criteria (902 patients: 458 treated thoracoscopically and 444 undergone open surgery). There was no significant difference in major postoperative complications ($P = 0.695$) or use of patch ($P = 0.282$). Conversely, the thoracoscopic approach significantly reduces mortality ($P = 0.001$) and length of stay ($P < 0.001$). Open surgery reduces the incidence of major intraoperative complications ($P < 0.001$), recurrences ($P = 0.025$), and operative time ($P < 0.001$).

CONCLUSION: According to our analysis, open surgery seems to reduce intraoperative complications and recurrences. Moreover, thoracoscopy seems to show an improvement in mortality and length of stay. However, the lack of randomization in all the analyzed studies could represent a potential bias in the final conclusion and need a careful evaluation.

Keywords:

CDH, CDH repair, congenital diaphragmatic hernia, minimally invasive surgery, open surgery, thoracoscopy

Introduction

Congenital diaphragmatic hernia (CDH) results from inadequate closure of the fetal diaphragm during embryonic development. Typically, CDH occurs on the left side, forming a hernial sac that contains abdominal organs.[1] The etiology of CDH remains mostly unclear and is probably multifactorial.

The incidence of CDH is 1:2500 to 1:3500 live births. Three distinct types of hernias can be identified in humans: a posterolateral, Bochdalek type, being the most common type (approximately 70% of the cases); an anterior, Morgagni type (accounts for approximately 27% of the cases); and a central hernia, septum transversum type (approximately 2–3% of the cases). In the Bochdalek type, the diaphragm defect is most frequently found on the left side (85%), while it can also be on the right side (13%)

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or happen bilaterally (2%).[2] The overall mortality rate is 40%–50%.[3]

The diaphragm typically forms between the fourth and the 12th week of pregnancy. In the past, it was believed that, in Bochdalek type, a patent pleuroperitoneal canal caused by the failure of different diaphragm portions to fuse allowed stomach contents to herniate into the thorax as they reentered the abdomen from the extraembryonic coelom.[4]

Some researchers propose a dual-hit hypothesis based on a nitrogen-induced CDH model in rats and mice. According to this model, the first hit affects both lungs independently of diaphragm development before and during diaphragm formation, against a backdrop of genetic and environmental factors. The second hit affects only the ipsilateral lung due to improper diaphragm development, leading to abdominal organ herniation.[5]

Surgical repair of CDH is usually performed during the neonatal period, and minimally invasive surgery (MIS) is considered an alternative to open surgery for CDH repair. Both laparoscopic and thoracoscopic approaches are taking hold across different centers.[6] Historically, CDH repair has been performed via left or right transverse or subcostal laparotomy, as this approach provides optimal exposure of both the diaphragm and the esophageal hiatus. Moreover, an abdominal incision facilitates easy resection of a hernia sac, allows direct access to the ribs for peri-costal sutures if needed, and enables the secure placement of an underlay patch or an abdominal wall muscle flap.[7] By 2017, within the CDH study group consortium, approximately 16% of CDH repairs were performed by MIS. Of these, 89% were thoracoscopic, and 11% were laparoscopic.[8] Unlike the laparoscopic approach, thoracoscopy offers excellent exposure of the diaphragm, and thoracic insufflation aids in the reduction of the abdominal viscera, making it the preferred MIS approach.[8] In particular, the thoracoscopic approach is considered more suitable than the laparoscopic approach for most posterolateral (Bochdalek type) defects, as thoracic insufflation not only facilitates the reduction of herniated contents but also improves intraoperative visibility, especially when diaphragmatic closure requires the use of a patch.[8] In particular, the thoracoscopic approach is considered more suitable than the laparoscopy approach for most posterolateral (Bochdalek type) defects, as thoracic insufflation not only facilitates the reduction of herniated contents but also improves intraoperative visibility, especially when diaphragmatic closure requires the use of a patch.[8] Thoracoscopic repair for CDH is increasingly performed worldwide, but its superiority over traditional open procedures remains uncertain. Surgeon expertise and institutional resources are key factors in choosing the approach. Ongoing research aims to refine our understanding of the benefits and drawbacks of minimally invasive CDH repair, with the goal of optimizing patient outcomes. Long-term follow-up is essential for monitoring potential issues as the child grows.

The aim of this study was to perform a systematic review of international literature and to develop a meta-analysis comparing perioperative outcomes of patients undergoing open versus thoracoscopic surgery (TS) for the treatment of CDH. Our study specifically focused on the comparison between thoracoscopy and laparotomy, as laparotomy has historically been the gold standard for open CDH repair and remains widely used in many centers.

Materials and Methods

A computerized search of the literature was conducted from PubMed, Cochrane, and Ovid from January 2005 to January 2025, and checks of relevant reference lists were performed using the search terms "thoracoscopy" AND "open surgery" OR "laparotomy" AND "CDH." The bibliographic research has led to 73 articles; papers comparing both open and thoracoscopic approaches for the treatment of CDH in children and reporting more than five patients were included in the study. Abstracts, papers reporting adult and/or mixed adult and pediatric populations, studies including patients undergoing different mini-invasive approaches with unclear datasets, or studies with duplicated data were excluded from the study. In the latter case, just the more recent article was considered. Language restriction only to English articles was applied.

The grading of recommendations, assessment, development, and evaluation (GRADE) approach was used to assess the quality of evidence in this study. This method evaluates studies based on key domains, including risk of bias, inconsistency, imprecision, indirectness, and publication bias, ensuring a comprehensive and systematic evaluation of the overall strength of the evidence.

Data extraction

Two reviewers independently examined all study abstracts in duplicate, with disagreements resolved by consensus. Full-text articles appearing to meet selection criteria were reviewed, and study data were abstracted in the same manner. All the included studies were registered in an electronic datasheet to analyze the study-level factors (country of origin and year of publication), a procedure performed, number of patients, mean age, and outcome measures analyzed in each study. Then, data on primary outcomes, including mortality, recurrence, and major intraoperative and postoperative complications, as well as secondary outcomes, such as considering the length of stay, the mean operative time, and the need for a patch for diaphragmatic reconstruction, were collected from each study. Minor intraoperative complications were classified according to the Satava classification grades I and II. These include conversion from laparoscopy to open surgery. Satava grade III complications, which represent more severe, were categorized as major intraoperative complications.[9] For postoperative complications, the Clavien–Dindo classification was employed, with grade I and II complications considered minor and grade IIIa, IIIb, IV, and V complications classified as major.[10] Conversion of thoracoscopy to open surgery and recurrence have been considered major intraoperative and postoperative complications, respectively.

Risk of bias assessment

A bias assessment was performed by two study authors using the Cochrane Collaboration checklist. Differences were resolved by consensus discussion.

In this study, the risk of bias in non-randomized studies of interventions tool was used to assess the risk of bias in non-randomized studies. The evaluation covered seven key areas as follows: confounding, participant selection, intervention classification, deviations from planned interventions, missing outcome data, outcome measurement, and selective reporting. Each domain was assigned a score of low, moderate, or high risk, based on the potential impact on the study's validity.

Funnel plots were visually assessed for evidence of publication bias.

Statistics

Descriptive statistical analyses of quantitative and nonquantitative items were performed using OR and 95% confidence intervals, as appropriate. Study heterogeneity was assessed using the Higgins–Thompson *I*-squared (I^2) method. To determine if significant heterogeneity occurred, we looked for the P value of the chi-squared test of heterogeneity. Because statistical tests are so powerful, we considered a P value > 0.1 as a cutoff for a decision about clinical heterogeneity. Heterogeneity has been represented graphically using the funnel plot. All statistical analyses were performed using Comprehensive Meta-analysis Software version 2.0. A P value < 0.05 was considered as significant.

Results

In our systematic review, we identified studies through a comprehensive PubMed search. Initially, 88 records were located, with 71 moving forward after screening. We removed duplicate records (n = 3) and those not meeting our criteria, including abstracts (n = 1), case reports (n = 8), and reviews (n = 5). Following a screening process, 42 records were excluded based on relevance. From 46 full-text articles, six were excluded for reasons such as unsegregated data by surgical approach (n = 4), lack of distinction between thoracoscopic and open groups (n = 21), and mixed adult/pediatric populations (n = 2). Ultimately, 20 studies met the inclusion criteria and were analyzed quantitatively, covering a total of 902 patients who underwent thoracoscopic (n = 458) or open surgery (n = 444) [Figure 1]. All included studies were retrospective; these are detailed in Table 1.

Primary outcomes

Thoracoscopic and open groups of patients undergoing surgery were statistically non-heterogeneous for all of the four outcomes "postoperative major complications," "mortality," "recurrence," and "intraoperative major complications" (P = 0.135, I^2 = 29.495; P = 0.996, I^2 = 0.000; P = 0.841, I^2 = 0.000; P = 0.827, I^2 = 0.000, respectively). The type of postoperative and intraoperative major complications is summarized in Table 2.

The overall mortality rate in the open group (OG) and thoracoscopic group (TG) has been 13.1% and 1.83%, respectively, group (P = 0.001). "Major intraoperative complications," including the conversion of thoracoscopy to open surgery, were found to be significantly less (P = 0.000) in the open group (2.55%) compared with the TS group (14.9%). Conversely, the "major postoperative complications" were found to have no statistically significant difference in the two groups (P = 0.695) (23.16% and 15.19% in OG and TG, respectively), with a significant difference (P = 0.02) in "recurrence" rate, favoring OG (7.8%) as comparing with TG (12.6%). Additionally, we performed an analysis of major postoperative complications, excluding both mortality (grade V of Clavien–Dindo classification) and recurrence (grade IIIb or higher of Clavien–Dindo classification). In this subset, the P value was 0.053 (12.75% and 5.36% in OG and TG, respectively, of the overall patients in studies that report the data). The results are shown in Figure 2A–E, and the funnel plot is shown in Figure 3.

Secondary outcomes

Considering the length of stay, the mean operative time and the need for a patch for diaphragmatic reconstruction were collected from each study; between-study non-heterogeneity was high for the outcome "length of stay" (P = 0.755, I^2 = 0.000). Differently, significant heterogeneity was found for "operative time" and "patch" (P = 0.000, I^2 = 90.924 and P = 0.000, I^2 = 79.070, respectively). The "length of stay" results were significantly lower (P = 0.000) after thoracoscopic (median days = 17) as compared with

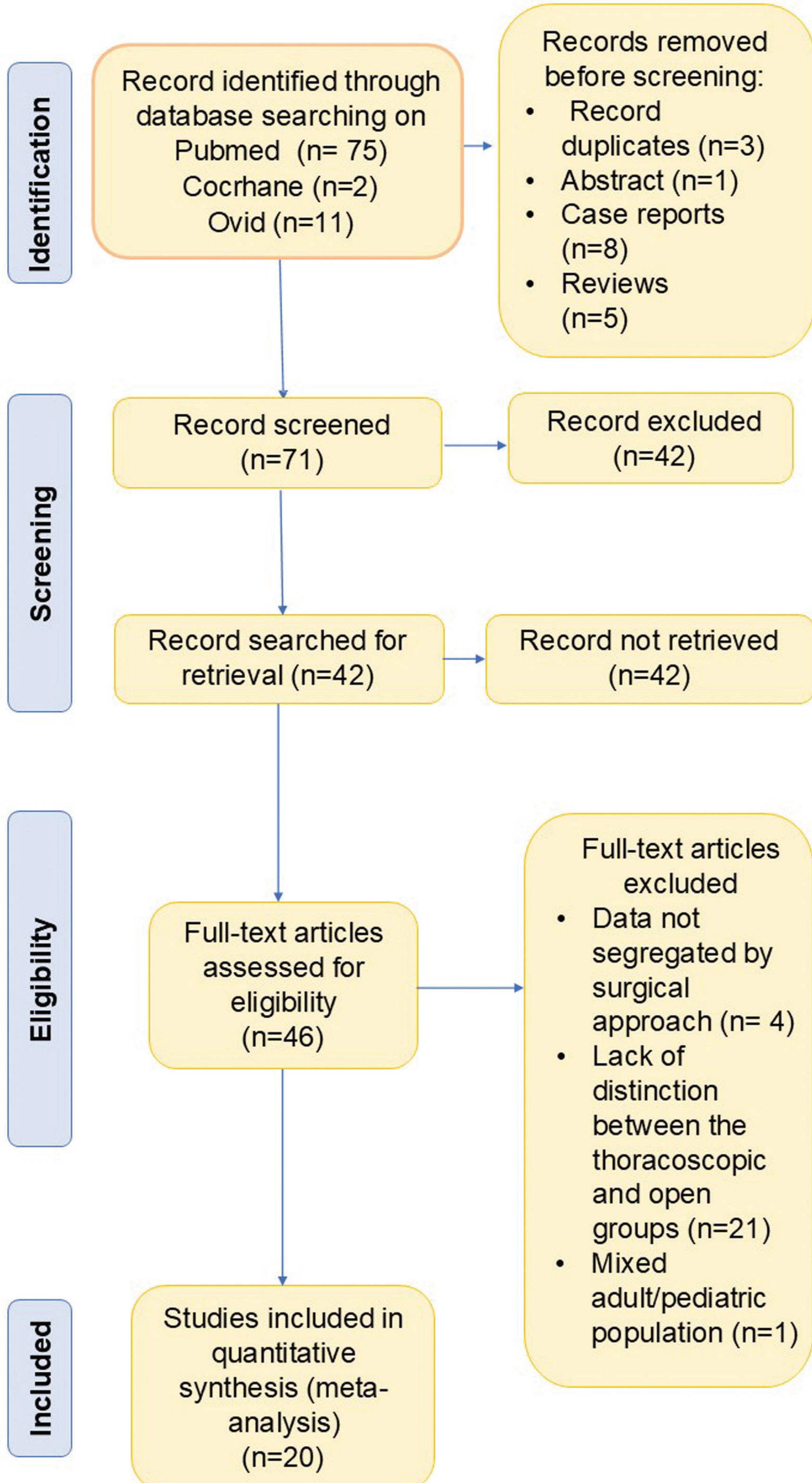

Figure 1: Preferred reporting items for systematic reviews and meta-analyses flow diagram

OG (median days = 29.8) approach, while the "mean operative time" was significantly less ($P = 0.000$) in OG (median times in minutes = 128.5) than in TG (median times in minutes = 155) approach. No difference ($P = 0.282$) has been found in the use of "patch" (33.95% and 33.7% in OG and TG, respectively). The

Table 1: Characteristics of the included studies

Study name	Risk of bias in non-randomized studies of interventions	Grading of recommendations, assessment, development, and evaluations	Number of patients OG *n* = 444	Number of patients TG *n* = 458
Tyson, 2017[11]	Moderate	High	29	25
Okazaki, 2015[12]	Moderate	Moderate	10	15
Bawazir, 2021[1]	Moderate	Moderate	30	11
Szavay, 2012[13]	Moderate	Moderate	12	21
Romnek, 2020[14]	Moderate	Moderate	20	8
Qin, 2019[15]	Moderate	Moderate	44	26
Hosokawa, 2019[16]	Moderate	Low	3	5
Schlager, 2018[17]	Moderate	Moderate	34	6
Criss, 2017[5]	Moderate	Moderate	16	37
Weaver, 2016[18]	Moderate	Moderate	26	83
Costerus, 2017[19]	Moderate	Moderate	34	75
Inoue, 2015[20]	Moderate	Moderate	16	8
Nam, 2013[21]	Moderate	Moderate	34	16
Bishay, 2013[2]	Low	Moderate	5	5
Gander, 2010[22]	Moderate	Moderate	19	26
Fishman, 2010[23]	Moderate	Moderate	9	12
Keijzer, 2010[24]	Moderate	Moderate	23	23
McHoney, 2010[25]	Hight	Moderate	35	13
Cho, 2008[26]	Moderate	Moderate	28	29
LAO, 2010[27]	High	Low	17	14

OG = open group, TG = thoracoscopic group

results are shown in Figure 4A–C, and the funnel plot is shown in Figure 3.

Discussion

Bochdalek first described posterolateral CDH in 1848, with the first successful surgical repair performed in 1902[28]; despite advancements, mortality remained high due to limited options for infant respiratory failure.[17]

Antenatal diagnosis involves ultrasound or maternal assessments, and ultrafast fetal magnetic resonance imaging (MRI) helps in diagnosis, evaluation of lungs, and detection of chromosomal abnormalities. Left-sided CDH, which shows stomach and bowel in the chest near the heart, is more common and easier to diagnose than right-sided cases.[29,30]. Extensive prenatal assessments identify factors indicating an unfavorable outcome, considering factors like associated anomalies, liver protrusion, and lung underdevelopment. The lung area/head circumference ratio and fetal lung volume measurements via MRI assess pulmonary hypoplasia severity.[13]

Severe cases may require fetal endoscopic tracheal occlusion, which aims to promote lung growth and development by temporarily obstructing the fetal trachea, which increases intrathoracic pressure and lung fluid production. Additionally, optimizing intervention timing and balloon removal is crucial for better outcomes.[31]

Table 2: Major intraoperative and postoperative complications

		Major complications	
		OG *n* (%)	TG *n* (%)
Intraoperative	"Open" conversions	0	38 (8.3%)
	Intraoperative bleeding	5 (1.1)	0
Postoperative	Abdominal hernia	4 (0.9)	0
	Pleural effusion	8 (1.8)	1 (0.2)
	Pneumothorax	3 (0.7)	4 (0.9)
	Intestinal obstruction	17 (3.8)	0
	Recurrence	29 (6.5)	50 (10.9)
	Mortality	27 (6.1)	4 (0.9)
	Laceration of solid organs	0	0
	Hemothorax	0	1 (0.2)
	Sepsis	0	0
	Perforation	0	0

OG = open group, TG = thoracoscopic group

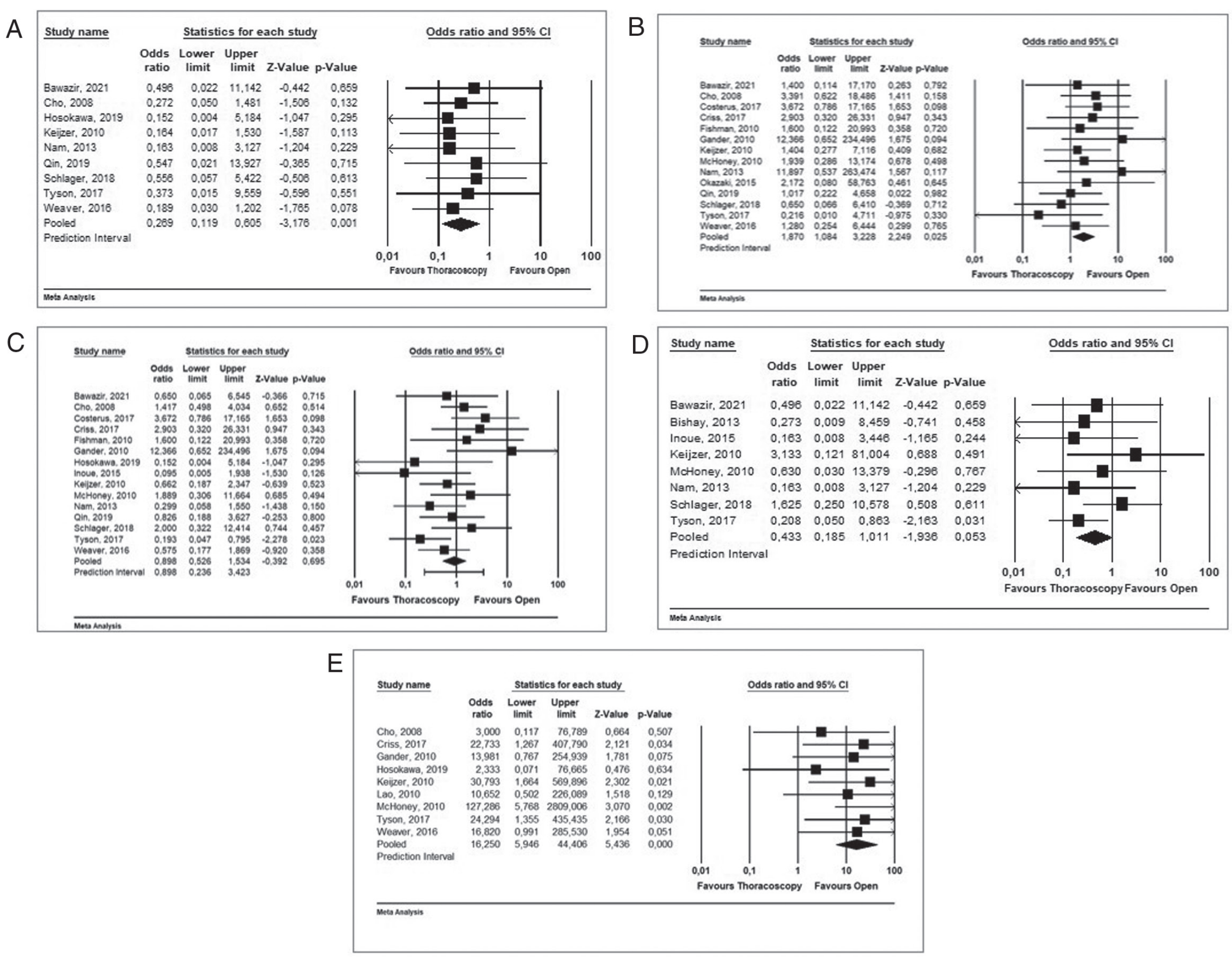

Figure 2: Comparison of primary outcomes between the thoracoscopic group and the open group. A: mortality (*P* value = 0.001); B: congenital diaphragmatic hernia recurrence (*P* value = 0.025); C: postoperative major complications (*P* value = 0.695); D: postoperative major complications without recurrence and mortality (*P* value = 0.053); E: intraoperative major complications (*P* value < 0.001)

Postnatally, symptoms include rapid breathing and chest retractions, confirmed by X-rays showing mediastinal shift and bowel in the chest. Advanced imaging techniques and preoperative planning are essential for optimizing outcomes, particularly in cases of complex CDH presentations.

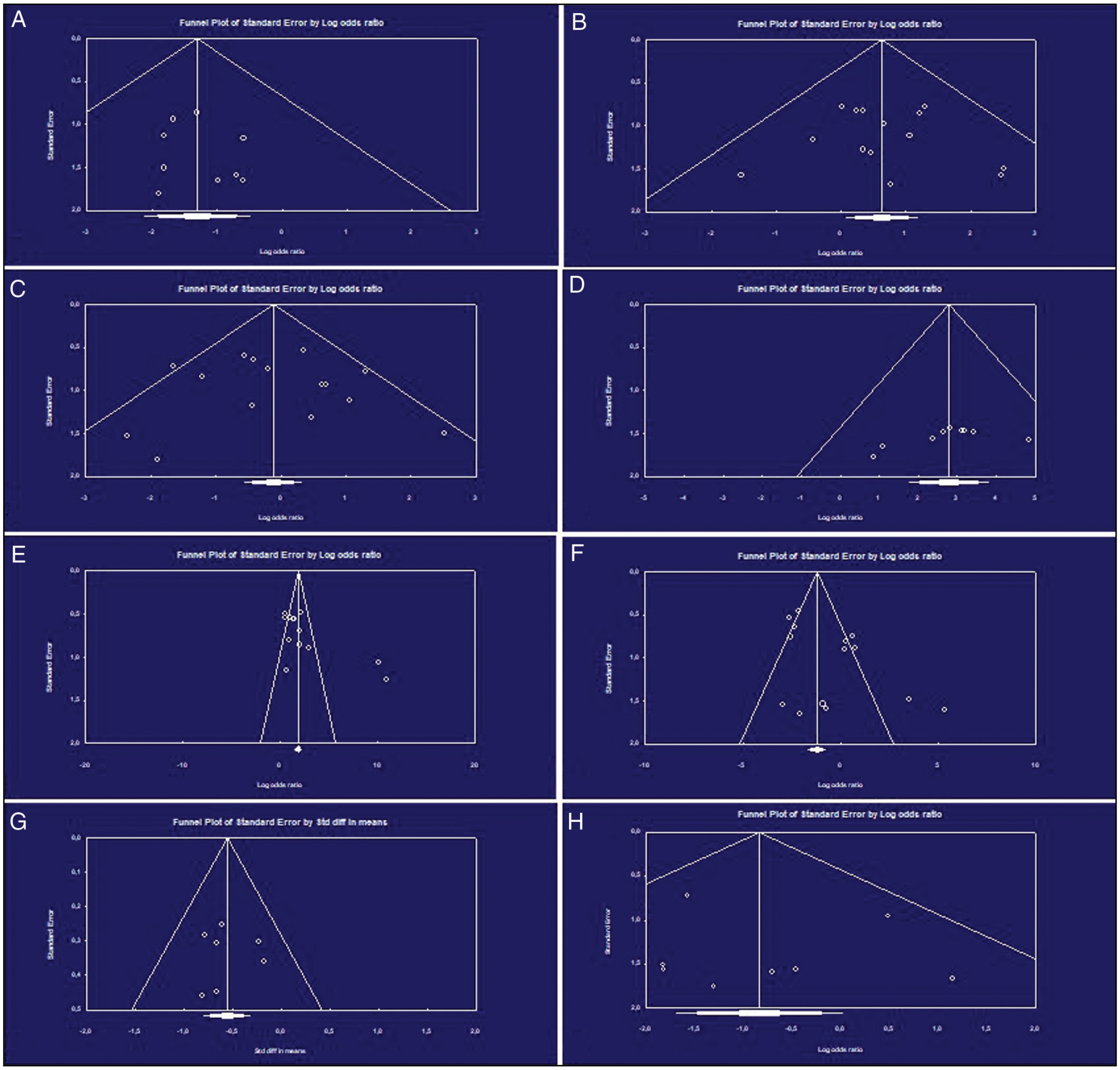

Figure 3: Funnel plot of all the outcomes. A: Mortality; B: congenital diaphragmatic hernia recurrence; C: postoperative major complications; D: intraoperative major complications; E: operative time; F: use of patch; G: length of stay; H: postoperative major complications without recurrence and mortality

The mortality rate can vary due to factors such as the severity of herniation, associated anomalies, gestational age at diagnosis, and the specific treatment approach. Postoperative complications, such as hernia recurrence or pulmonary hypertension, can also influence mortality rates. Some infants with CDH experience a transient "honeymoon" phase of cardiovascular stability, followed by a decline in respiratory function.[11,18] Various surgical techniques are available, including traditional open methods like left subcostal or thoracotomy incisions, and minimally invasive options like laparoscopic or TS. The choice between thoracoscopic and laparotomic approaches has been a focus of research with both aiming to repair the defect and prevent herniation. The laparotomic approach provides direct access, allowing better tactile manipulation and visualization. Conversely, TS uses small incisions and a camera, reducing tissue trauma and postoperative pain.

In our review, we primarily focused on comparing mortality rates between patients treated with open and thoracoscopic repair. A study of newborns with CDH undergoing extracorporeal membrane oxygenation (ECMO) showed no statistically significant difference in mortality between the thoracoscopic and OGs.[17] Similarly, Keijzer *et al*.[24] reported a slightly higher mortality rate in the OG, but the difference was not significant between the two groups.

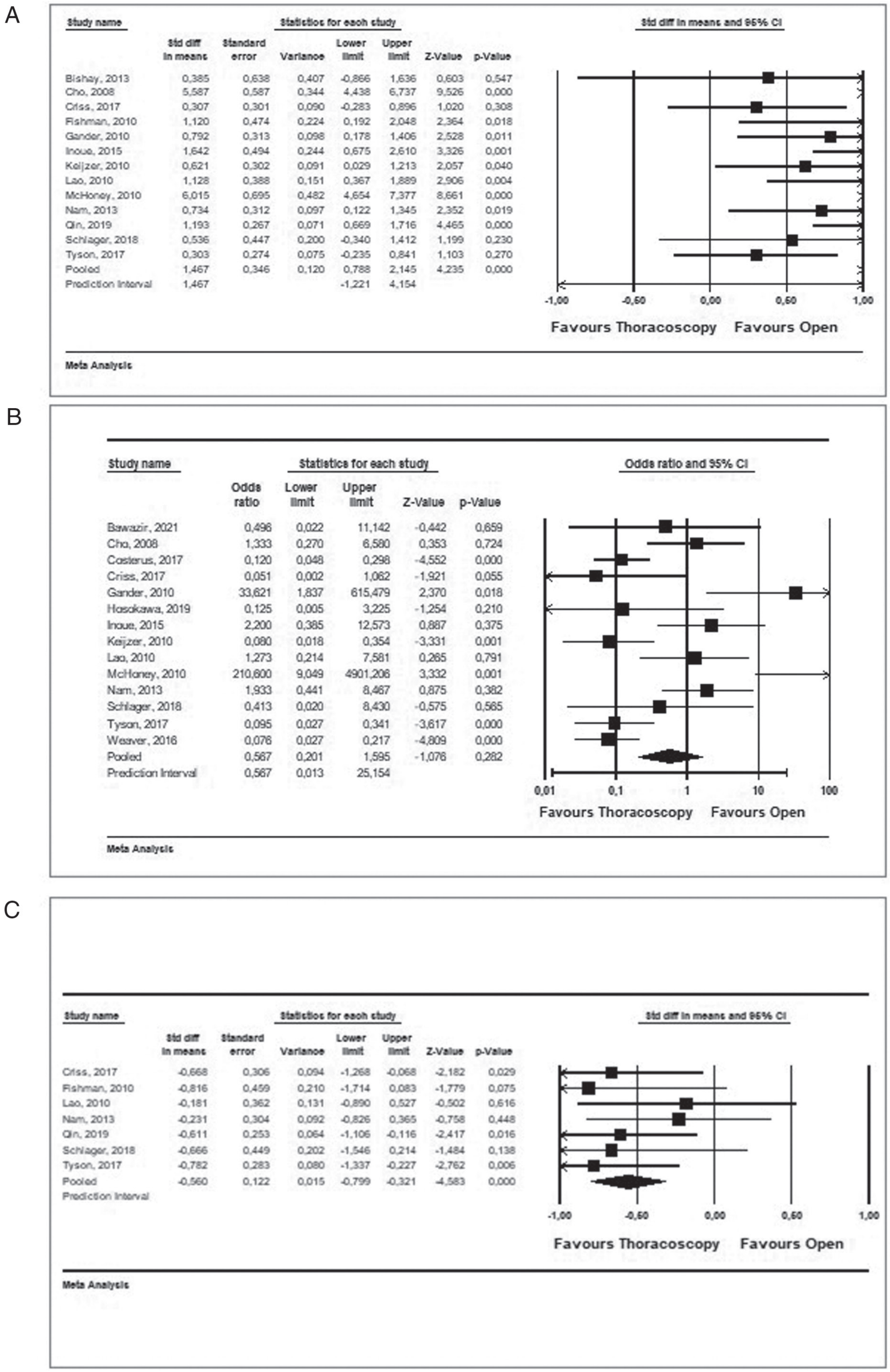

Figure 4: Comparison of secondary outcomes between the thoracoscopic group and the open group. A: Operative time (P value < 0.001); B: use of patch (P value = 0.282); C: length of stay (P value < 0.001)

In our investigation, although no significant difference in mortality rate was found between the thoracoscopic and OGs in all included studies, the comprehensive meta-analysis revealed increased mortality in the open group compared with the TG ($P = 0.001$).

This data should be critically evaluated. Patients included in the analyzed studies were not randomized for the surgical procedure, and accompanying conditions, such as pulmonary hypertension or other congenital defects, may have influenced the choice of the minimally invasive approach. Without set standards for assigning patients to either technique, strict selection criteria are used to identify stable neonates capable of withstanding the strain of the operation and anticipated postoperative pulmonary function deterioration.[17,32] In some cases, ECMO therapy was a contraindication for TS.

Moreover, some authors[11] selected, newborns with smaller hernia defects for thoracoscopic procedure, likely those with less severe pulmonary hypoplasia and pulmonary hypertension. Regarding major intraoperative complications, the meta-analysis revealed a significantly lower incidence during open surgery compared with the thoracoscopic procedure. More frequent major intraoperative complications included bleeding requiring a blood transfusion for the patient, organ injury, and conversion to open surgery in a procedure initially treated thoracoscopically. In particular, Tyson *et al*.[11] recorded two splenic injuries, one in both groups. One patient who first approached thoracoscopically had a spleen lesion requiring a conversion in open surgery; another patient needed conversion to open for an intrathoracic colic volvulus with ischemia. Both Hosokawa *et al*.[16] and Lao *et al*.[27] described a conversion of the approach from thoracoscopic to open because of a too-large diaphragmatic defect. As a result, intraoperative complications in patients in the TG are frequently related not only to the surgical procedure but also to ventilatory complications. The study by McHoney *et al*.[25] reported that five infants who underwent thoracoscopy were converted to open surgery, one for intraoperative desaturation and four others for unspecified surgical complications. Keijzer *et al*.[24] observed conversions from thoracoscopic to open procedures as a consequence of an unbeatable large diaphragmatic defect and for the impossible reduction of herniated intrathoracic abdominal organs.

As a primary endpoint, we compared the incidence of major postoperative complications in both open and TGs. Postoperative complications included abdominal hernia, pleural effusion, pneumothorax, intestinal obstruction, lacerations and organ perforation, hemothorax, septicemia, recurrence, and mortality. Statistical analysis revealed no significant difference between the two groups ($P = 0.695$).

Focusing on recurrence, our meta-analysis found no significant difference between the two groups across all included studies. However, an overall significant difference favored the open approach.

Criss *et al*.[5] observed a slightly major incidence of recurrence in the TG, and they hypothesized that this could be related to including newborns with larger diaphragmatic defects in the TG (<50% portion of the chest wall devoid of diaphragm tissue).

Similarly, Cho *et al*.[26] noted an increased, but not significant, recurrence of CDH thoracoscopically treated.

Weaver *et al*.[18] reported no difference in preoperative comorbidities, side of hernia, duration of ventilation, initiation of enteral feeding, duration of follow-up, and survival between groups of patients treated thoracoscopically who did or did not experience CDH recurrence. Moreover, no statistically significant technical factors related to recurrence were identified to recommend a standardized surgical approach to thoracoscopic repair. The study of Criss *et al*.[5] observed that there was no linear correlation between reduced operative times and lower incidence of recurrence during the learning curve in the thoracoscopic approach of CDH.

Technical factors, such as excessive tension on the suture and inadequate mobilization of the diaphragm's rim during thoracoscopic repair, could contribute to the higher recurrence rate.

Gander *et al*.[22] described a significantly higher recurrence rate in the TG compared with the OG, even after considering factors such as patient severity of illness, postoperative length of stay, and patch use. Although Fishman *et al*.[23] and Cho *et al*.[26] did not show a statistically significant difference between the two groups in terms of recurrence, they observed a higher recurrence rate in patients with very large defects that required the use of patches. In contrast, Inoue *et al*.[20] suggested using a prosthetic patch for defect repair to prevent recurrence, emphasizing the inclusion of the rib periosteum during repair. The use of a patch was correlated with the need for preoperative inotropes and the presence of a presumed preoperative intrathoracic stomach. Certain types of patches, such as cone-shaped patches, may influence the recurrence rate, with some showing reduced recurrence rates in open repair compared with thoracoscopic repair.[16]

Although some authors reported significantly higher use of patches during open surgery compared with thoracoscopic repair.[18] Our analysis indicated that, overall, there was no statistically significant difference between the two groups regarding patch usage distribution ($P = 0.282$). The need for a patch was considered a cause of conversion from the thoracoscopic approach to open procedures, especially for large defects. Criss *et al*.[5] reported no advantages to using patches for small and medium-sized hernias.

When comparing thoracoscopic repair to open surgery, it was found to be associated with a significantly longer operative time, referring to the duration from skin incision to skin closure. While Tyson *et al*.[11] demonstrated in their study that thoracoscopic CDH repair did not result in increased operative time and showed no significant differences in perioperative parameters compared with open repair, nine out of 13 included studies[15,20-27] were reported significantly longer operative times for thoracoscopic repair. In our study, we demonstrated an overall reduction in operative time in the OG compared with the TG ($P = 0.000$). This data did not seem to be a disadvantage in terms of hypercapnia or postoperative ventilation time.[33] Importantly, this longer operative time for technically challenging thoracoscopic repairs is expected to decrease over time.

In our review, we also analyzed the length of stay in both groups of patients. In three out of seven included studies,[5,11,15] the length of stay was significantly shorter in thoracoscopically treated patients. Our meta-analysis confirmed this finding ($P = 0.000$). We believe this discrepancy is multifactorial, possibly due to fewer preoperative risk factors in patients selected for the thoracoscopic approach. This could result in shorter stays in the Neonatal Intensive Care Unit and the use of a minimally invasive technique.

The main limitation of this study is the lack of randomization of patients in all included studies, and it could represent a potential bias in the final conclusion, needing a careful evaluation.

Conclusion

The thoracoscopic approach offers less mortality and a shorter length of stay but a significantly higher intraoperative complications and recurrence rate as compared to open surgery. We believe that, to date, the thoracoscopic approach for CDH cannot be considered a gold standard, but it should be used in selected, low-risk patients. To decrease intraoperative problems and CDH recurrences, open surgery has been demonstrated to be advantageous. Even if open CDH repair could be considered a time-honored procedure, thoracoscopy is a valid tool in the hands of an expert mini-invasive surgery.

Systematic review registration: From the website "What is PROSPERO? - University of York".

Author contributions

Formal analysis, AA; investigation, FC; data curation, RB; writing—review and editing, PI; supervision, SA and CR. All authors have read and agreed to the published version of the manuscript.

Ethical policy and Institutional Review board statement

Not applicable.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Not applicable.

Abbreviations

CDH	Congenital diaphragmatic hernia
ECMO	Extracorporeal membrane oxygenation
FETO	Fetal endoscopic surgery
GRADE	Grading of recommendations, assessment, development and evaluations
I^2	I-squared
LHR	Lung-to-head ratio
MIS	Minimally invasive surgery
MRI	Magnetic resonance imaging
OG	Open group
OR	Odds ratio
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
ROBINS-I	Risk of bias in non-randomized studies of interventions
TG	Thoracoscopic group
χ^2	Chi-squared

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