Original Article

Early versus late chest tube removal after surgery for primary spontaneous pneumothorax—a systematic review and meta-analysis

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Background: The optimal timing of postoperative chest tube removal remains disputable. Traditionally, chest tubes are left in place for several days for adequate pleurodesis and recurrence prevention after surgery for primary spontaneous pneumothorax (PSP). Currently, early tube removal, defined as immediate removal upon cessation of air leakage, is increasingly practiced. This study aimed to evaluate the safety of early chest tube removal in terms of recurrence in these patients.

Methods: MEDLINE (PubMed), EMBASE and Cochrane databases were searched until January 2024. Inclusion criteria encompassed patients undergoing pleurodesis through video-assisted thoracoscopic surgery (VATS) for PSP if chest tube management was clearly described to discriminate between early and late tube removal protocols, and recurrence rate with a postoperative follow-up period of at least six months was reported. The primary outcome was recurrence rate, with secondary outcomes including postoperative length of stay (LOS), prolonged air leakage (PAL) and chest tube duration. Subgroup analysis contained type of pleurodesis. The quality of evidence was evaluated with the Grading of Recommendations Assessment, Development and Evaluation method.

Results: Thirty-six studies comprising 6,166 patients were included, lacking direct comparative studies on early versus late chest tube removal. Due to loss to follow-up, 6,063 patients were analysed regarding recurrence rate, resulting in 4.49% [95% confidence interval (CI): 3.33–6.03%; I^2=65.6%] after late removal and 7.61% (95% CI: 5.44–10.57%; I^2=8.2%) after early removal (P=0.02). Among the secondary outcomes only chest tube duration was significantly different between early and late removal [2.50 (95% CI: 2.31–2.71) versus 3.42 (95% CI: 3.08–3.81) days, P<0.001]. Subgroup analysis revealed the most pronounced difference in recurrence following pleurectomy as type of pleurodesis (P=0.003). The quality of evidence was considered low.

Conclusions: Although no direct comparative studies were retrieved, the best available evidence suggests that early chest tube removal may be associated with a slightly higher recurrence rate after surgical pleurodesis for pneumothorax. High-quality evidence is needed before implementing early removal.

Keywords: Primary spontaneous pneumothorax (PSP); chest tube duration; recurrence rate

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Submitted Oct 22, 2024. Accepted for publication Feb 19, 2025. Published online Apr 25, 2025.
doi: 10.21037/jtd-24-1802
View this article at: https://dx.doi.org/10.21037/jtd-24-1802

Introduction

Surgical intervention is recommended in patients with recurrent or persistent primary spontaneous pneumothorax (PSP) (1). The preferred surgical strategy is bullectomy (i.e. treating the underlying cause) followed by pleurodesis (i.e., preventing further recurrence) through video-assisted thoracoscopic surgery (VATS) (1,2). Pleurodesis can be achieved chemically and mechanically by pleurectomy or pleural abrasion (1,3,4).

Unfortunately, recommendations regarding postoperative chest tube management are lacking, resulting in practice variation, especially concerning chest tube duration (1,5). This variability may impact recurrence rate, postoperative length of stay (LOS), postoperative pain and patient satisfaction (6,7). Traditionally, postoperative chest tubes are left in place for a fixed period, irrespective of the amount of air leakage or fluid production. A previous review investigated the timing of chest tube removal and highlighted significant discrepancies in chest tube management protocols among studies with LOS directly influenced by chest tube duration (8).

Recent studies showed that chest tube removal on the same day of surgery is safe with a mean postoperative LOS of one day in patients operated for PSP (9,10). In view of a growing interest in early chest tube removal and enhanced recovery after thoracic surgery (ERATS) protocols, in which chest tube management is an important factor (11), a systematic evaluation of the timing of postoperative chest tube removal is warranted. Therefore, the aim of this systematic review and meta-analysis is to evaluate the recurrence rate as safety outcome of early (i.e., direct removal upon cessation of air leakage) versus late (after a fixed number of days) chest tube removal. We present this article in accordance with the PRISMA reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1802/rc).

Highlight box

Key findings

- This systematic review and meta-analysis of 36 articles including 6,166 patients demonstrated slightly higher postoperative recurrence rates after early postoperative chest tube removal in patients with primary spontaneous pneumothorax (PSP).
- Thus far, there are no direct comparative studies about early and late postoperative chest tube removal in patients undergoing video-assisted thoracoscopic surgery (VATS) pleurodesis for PSP resulting in a low level of evidence regarding timing of postoperative chest tube removal.

What is known and what is new?

- With increased attention to enhanced recovery after thoracic surgery protocols, shortening postoperative chest tube duration is increasingly utilized. However, scientific evidence regarding the safety of early chest tube removal after VATS pleurodesis for PSP is scarce.
- This meta-analysis is the first to provide the best available evidence on this topic to guide clinicians for optimal postoperative care.

What is the implication, and what should change now?

- Based on the results of this meta-analysis, early chest tube removal may be associated with increased postoperative recurrences. Although the overall level of evidence was considered low, this meta-analysis provides the best available evidence suggesting clinicians to be precautious with applying early chest tube removal outside a research setting.
- Studies with high level of evidence are needed before implementing early chest tube removal.

Methods

This study was registered in PROSPERO (ID: CRD42022324988) on 1 March, 2022. The research question guiding this review is: 'What is the recurrence rate of pneumothorax in patients undergoing VATS for PSP with early versus late chest tube removal?'

The definition of early chest tube removal was direct tube removal upon cessation of air leakage. The criteria for the late removal group were chest tube removal after a fixed minimal time period and/or the provision of pleural fluid production <200 mL/24 hours.

Approval by the institutional board and individual consent was waived due to the nature of the study as a Systematic Review and Meta-analysis.

Eligibility criteria

Clinical (non-)randomized trials and observational studies describing chest tube management in patients undergoing VATS for PSP were considered eligible. Articles referring to chest tube management were only eligible if they provided a clear description of the chest tube protocol, surgical technique and if the recurrence rate was reported with either a minimum follow-up per patient of six months or a mean follow-up of 12 months.

Search strategy

Studies were identified in MEDLINE (PubMed), EMBASE and Cochrane. There was no time limit used in the search. The search strategy contained a combination of index terms and free text words related to pneumothorax and surgical treatment for pneumothorax to find all relevant articles regarding postoperative chest tube management. The complete search strategy is detailed in Table S1. The final search was conducted on January 29, 2024.

Study selection

Two reviewers (Q.C.A.v.S. and L.N.S.) independently screened the titles, abstracts and full-text of all identified studies. Discrepancies were resolved by consulting the senior author (F.J.C.v.d.B.). Studies were excluded in case of ineligible study population (e.g., >5% secondary spontaneous pneumothorax), surgery by thoracotomy, sample size <20 (considered as small case series with bias), ineligible outcome measures, inadequate study design (e.g., case series, reviews and editorials), not written in English or insufficient data presentation, also after scrutinizing supplemental material. The description of chest tube management should at least involve criteria on air leakage. Articles should also use the same surgical treatment per intervention or control group (in case of comparison). If more information was needed from an article, the corresponding authors were contacted by email. In case of no response, the article was excluded from analysis. If articles reported on several intervention and control groups from which only a selection was eligible according to our criteria, only the eligible study groups were included in our analysis.

Outcome measures

Recurrence rate

The primary outcome measure was the percentage of pneumothorax recurrence. Recurrence was defined as an ipsilateral recurrent pneumothorax, also when this occurred early after chest tube removal, requiring intervention and/or hospital admission. The minimum required follow-up period per patient was six months. When studies mentioned patients lost to follow-up, those patients were not included in the analysis.

Length of hospital stay

The LOS was defined as the number of days the patient remained in the hospital after surgery, with the date of surgery being day 0.

Postoperative prolonged air leakage (PAL)

PAL was defined as persistent air leakage >5 days after surgery. Studies using a different definition for PAL or lacking a definition were excluded from analysis regarding this outcome. PAL was only considered absent if this was specifically mentioned in the article.

Postoperative chest tube duration

Chest tube duration was defined as the number of days the chest tube was *in situ* with the date of surgery being day 0.

Data collection

Data collection included study design, chest tube management, patient characteristics (age and sex), type of surgery and outcome measures of interest (recurrence rate, LOS, PAL and chest tube duration).

Statistical analysis

All included studies were divided into two groups for comparison, early and late chest tube removal, based on the reported criteria of chest tube management. Continuous data were reported as means with standard deviation (SD) (parametric data) or medians with interquartile range (IQR) (non-parametric data) and categorical data as numbers with percentages. A meta-analysis was performed for the following predetermined outcome measures: recurrence rate, LOS, PAL and chest tube duration. We logit-transformed the outcome and performed univariate random effects meta-analysis using the meta proportion and mean package in R (version 4.3.3). This analysis provided summary estimates which were reported as percentages with 95% confidence intervals (95% CIs) and means with 95% CI. Also, the I^2 statistics were calculated, presenting the percentage of variability that is attributable to between-study heterogeneity. Significant heterogeneity between studies was indicated when I^2 was >50% (12). Subgroup differences were tested using the z-test. $P<0.05$ was considered statistically significant.

Risk of bias (RoB) analysis

The methodological quality of all included studies was independently assessed by two reviewers (Q.C.A.v.S. and L.N.S.) and any disagreement was resolved by discussion with the senior author (F.J.C.v.d.B.). The RoB was evaluated with the Risk of Bias tool (RoB2) for randomized controlled trials (RCTs) and the risk of bias for non-randomized studies for interventions tool (ROBINS-I) for non-RCTs (13,14). The intervention for the evaluation of the RoB concerned early versus late chest tube removal with recurrence rate as outcome measure. (Non-)RCTs with no direct comparison between early and late chest tube removal were assessed as single-arm cohort studies to evaluate RoB precluding the evaluation of bias in the confounding and randomization domain for non-RCTs and RCTs, respectively (Table S2). The Grading Recommendations of Assessment, Development and Evaluation (GRADE) method was used for evaluation of the certainty of the evidence (Tables S3,S4).

Subgroup analysis

Subgroup analysis for recurrence rate was performed for type of surgical pleural intervention (e.g., pleurectomy, abrasion, chemical pleurodesis).

Results

Description of the studies

The search identified 6,442 unique articles, of which 36 were selected for the meta-analysis comprising 9 RCTs and 27 cohort studies [*Figure 1*, supplementary file (Appendix 1)]. In the included 36 studies, a total of 58 study groups were identified and divided into late (40 groups; 4,837 patients) and early chest tube removal groups (18 groups; 1,329 patients). Study characteristics and RoB assessment are described in *Table 1* and Tables S5,S6. Since there were no comparative randomized studies included, all studies were assessed using the ROBINS-1 tool. Our meta-analysis comprised 6,156 patients with PSP and 10 patients with secondary spontaneous pneumothorax, who underwent bullectomy followed by pleurectomy, pleural abrasion or chemical pleurodesis. The mean age was 23.2 years (SD 4.2) in the early removal group and 26.1 years (SD 3.3) in the late removal group ($P<0.05$). Of all included patients 83% was (5,140/6,166) male with no significant differences between the early and late removal groups. Since 103 of 6,166 patients (1.7%) were lost to follow up, 6,063 patients were analyzed regarding the outcome postoperative recurrence.

Outcome measures

Recurrence rate

The recurrence rate was 4.49% (95% CI: 3.33–6.03%; I^2=65.6%) in the late and 7.61% (95% CI: 5.44–10.57%; I^2=8.2%) in the early chest tube removal group (P=0.02) (*Figure 2*). The postoperative follow-up period ranged from 12–94 months in the late and 6–96 months in the early removal group. The certainty of the evidence was considered low in both groups (Table S3).

Length of hospital stay

The LOS was analyzed in 48 of the 58 study groups (35 of 40 late and 13 of 18 early tube removal groups). The mean was 4.83 days (95% CI: 4.32–5.39; I^2=98.6%) in the late and 4.38 days (95% CI: 4.02–4.78; I^2=98.4%) in the early chest tube removal groups (P=0.18) (*Table 2*; Figure S1). The certainty of the evidence was considered low for the late removal groups and moderate for the early removal groups (Table S3).

PAL

PAL (>5 days) was analyzed in 17 of the 58 study groups (14 of 40 late and 3 of 18 early tube removal groups). The overall incidence of PAL was 6.12% (95% CI: 4.65–8.01%; I^2=48%) in the late and 4.35% (95% CI: 1.82–10.02%; I^2=0%) in the early chest tube removal groups (P=0.45) (*Table 2*; Figure S2). The certainty of the evidence was considered moderate for the late removal groups and low for the early removal groups (Table S3).

Chest tube duration

The postoperative chest tube duration was analyzed in 40 of the 58 study groups (33 of 40 late and 7 of 18 early tube removal groups). The mean was 3.42 days (95% CI: 3.08–3.81; I^2=98%) in the late and 2.50 days (95% CI: 2.31–2.71; I^2=97.6%) in the early chest tube removal groups ($P<0.001$) (*Table 2*; Figure S3). The certainty of the evidence was considered low in both groups (Table S3).

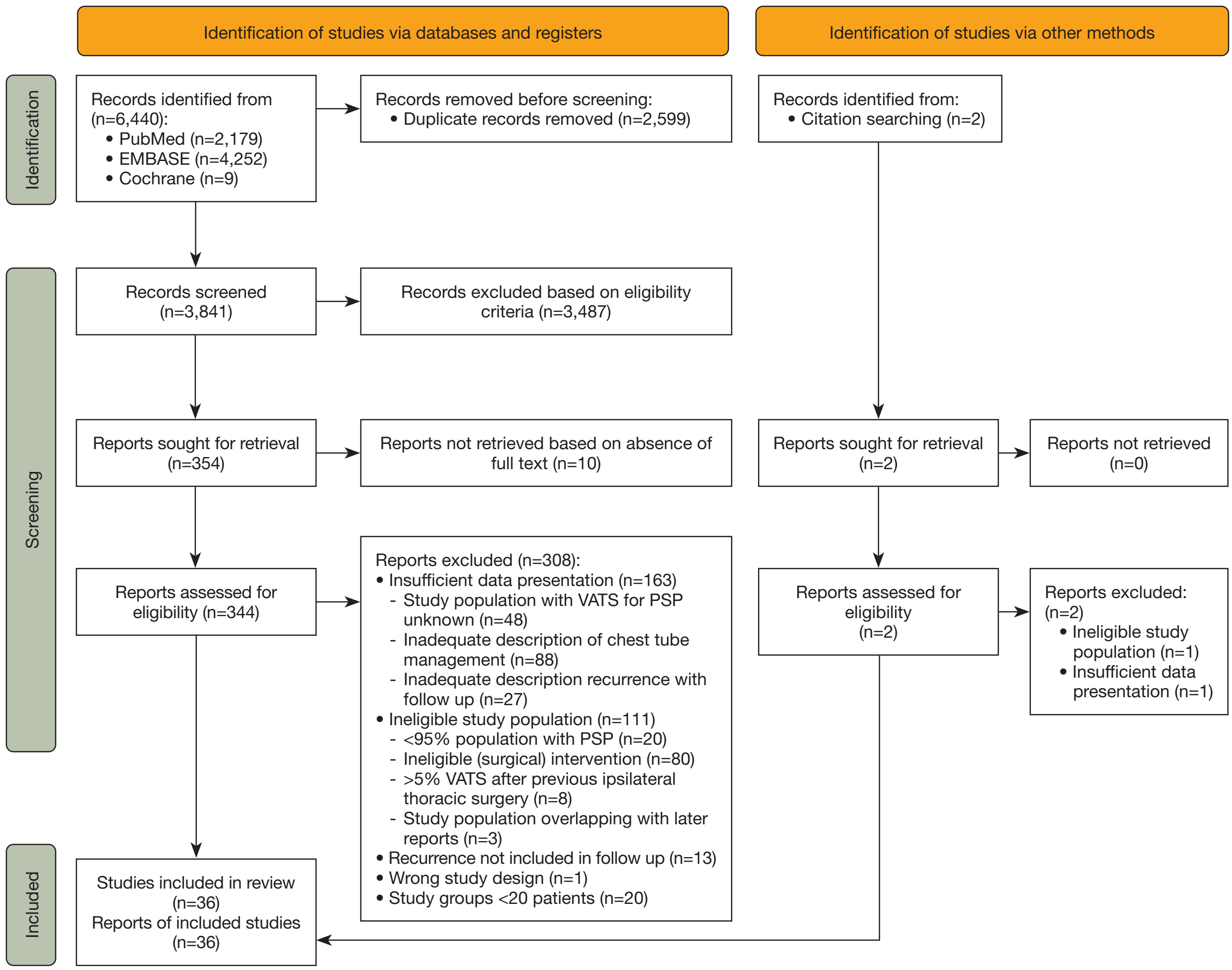

Figure 1 PRISMA 2020 flow diagram of study selection. VATS, video-assisted thoracoscopic surgery; PSP, primary spontaneous pneumothorax.

Subgroup analysis

Surgical pleural intervention

There was only a significant difference in recurrence rate between early and late chest tube removal after pleurectomy (P=0.003) (*Table 3*). No differences in recurrence rates were seen after pleural abrasion and chemical pleurodesis (*Table 3*; Figures S4,S5).

Discussion

Given the growing interest in and clinical impact of early chest tube removal, due to implementation of ERATS strategies, it is important to provide the best available evidence regarding the safety of early chest tube removal in patients surgically treated for PSP. The lack of any study directly comparing early versus late chest tube removal in this patient group precludes the highest level of evidence as assessed by the GRADE method. We attempted to still address this important knowledge gap by including only studies with a very clear description of their chest tube removal criteria and transparent description of recurrence and follow-up. This methodology provides us with the best available evidence, in order to provide surgeons guidance in chest tube management. Although based on low level of evidence, our study indicates that early chest tube removal may be associated with increased postoperative recurrences (P=0.02), underscoring the need for caution when adopting

Table 1 Study characteristics and overall risk of bias per study

Study [study group]§	Gender (% male)	Age (years)†	RCT	N total	Pleurodesis technique	Bullectomy	Recurrence (%)	FU (months)‡	Overall RoB
Late chest tube removal									
Bertrand 1996 [1]	70	30	No	163	Pleural abrasion	Yes	4	25	Moderate risk of bias
Waller 1999 [1]	64	32	No	118	Pleurectomy	Yes	3	≥12	High risk of bias
Ayed 2000 [1]	92	–	No	39	Pleural abrasion	Yes	10	42	Low risk of bias
Ayed 2000 [2]	94	–	No	33	Pleurectomy	Yes	0	42	Low risk of bias
Ayed 2003 [1]	94	23	Yes	50	Pleurectomy	Yes	0	48	Low risk of bias
Ayed 2003 [2]	94	24	Yes	50	Pleurectomy	Yes	4	48	Low risk of bias
Lang-Lazdunski 2003 [1]	93	25	No	182	Pleural abrasion	Yes	10	24	High risk of bias
Gossot 2004 [1]	77	32	No	185	Pleural abrasion	Yes	4	37	Moderate risk of bias
Chen 2004 [1]	78	25	No	313	Pleural abrasion and chemical; minocycline	Yes	3	39	Moderate risk of bias
Chen 2004 [2]	75	26	No	51	Pleural abrasion	Yes	10	39	Moderate risk of bias
Ayed 2006 [1]	86	25	No	94	Pleurectomy	Yes	3	48	Low risk of bias
Ben-Nun 2006 [1]	91	25	No	58	Pleural abrasion	Yes	4	46	Moderate risk of bias
Chang 2006 [1]	90	28	No	30	Pleurectomy	Yes	0	31	Moderate risk of bias
Chang 2006 [2]	94	24	No	35	Pleural abrasion	Yes	9	19	Moderate risk of bias
Chen 2006 [1]	86	24	Yes	103	Pleural abrasion and chemical; minocycline	Yes	2	30	Low risk of bias
Chen 2006 [2]	90	26	Yes	99	Pleural abrasion	Yes	8	28	Low risk of bias
Marcheix 2007 [1]	76	30	No	603	Chemical; silver nitrate	Yes	2	37	Moderate risk of bias
Rena 2008 [1]	79	25	Yes	112	Pleural abrasion	Yes	6	46	Moderate risk of bias
Rena 2008 [2]	83	25	Yes	108	Pleurectomy	Yes	5	46	Moderate risk of bias
Cho 2009 [1]	90	25	No	99	Pleural abrasion	Yes	4	29	Moderate risk of bias
Chen 2012 [1]	86	24	Yes	80	Pleurectomy	Yes	5	26	Low risk of bias
Chen 2012 [2]	90	23	Yes	80	Pleural abrasion and chemical; minocycline	Yes	4	27	Low risk of bias
Lee 2013 [1]	88	24	No	128	Pleural abrasion	Yes	12	24	Moderate risk of bias
Lee 2013 [2]	88	22	No	129	Pleural abrasion	Yes	4	24	Moderate risk of bias
Min 2014 [1]	90	22	Yes	145	Pleural abrasion	Yes	6	18	Moderate risk of bias
Imperatori 2015 [1]	82	25	No	134	Pleurectomy	Yes	7	79 (median)	Low risk of bias
Lin 2016 [1]	100	24	No	112	Pleural abrasion and chemical; iodopovidone	Yes	0	16	Low risk of bias
Dagnegard 2017 [1]	73	30	No	234	Pleurectomy	Yes	13	55	Moderate risk of bias
Zhang 2017 [1]	77	27	Yes	60	Pleural abrasion	Yes	0	16	Moderate risk of bias
Zhang 2017 [2]	72	26	Yes	74	Pleural abrasion	Yes	0	17	Moderate risk of bias

Table 1 (*continued*)

Table 1 (*continued*)

Study [study group][§]	Gender (% male)	Age (years)[†]	RCT	N total	Pleurodesis technique	Bullectomy	Recurrence (%)	FU (months)[‡]	Overall RoB
Mithiran 2019 [1]	81	28	No	75	Chemical; magnesium silicate	Yes	7	≥12	Low risk of bias
Mithiran 2019 [2]	92	25	No	127	Pleurectomy	Yes	8	≥12	Low risk of bias
Hsu 2021 [1]	87	22	Yes	102	Pleural abrasion	Yes	5	26	Low risk of bias
Hsu 2021 [2]	88	22	Yes	102	Pleural abrasion	Yes	17	26	Low risk of bias
Campisi 2022 [1]	77	24	No	53	Pleural abrasion	No	15	94	Moderate risk of bias
Campisi 2022 [2]	79	–	No	452	Pleural abrasion	Yes	7	94	Moderate risk of bias
Huang 2023 [1]	75	16	No	20	Pleural abrasion and chemical; OK-432	Yes	5	18	Moderate risk of bias
Huang 2023 [2]	89	17	No	28	Pleural abrasion	Yes	29	18	Moderate risk of bias
Kennedy 2023 [1]	73	–	No	114	Chemical; talc	No	1	48 (median)	Moderate risk of bias
Kennedy 2023 [2]	75	–	No	63	Chemical; talc	Yes	0	39 (median)	Moderate risk of bias
Early chest tube removal									
Horio 2002 [1]	91	33	No	53	Pleural abrasion	Yes	2	38	Moderate risk of bias
Casadio 2002 [1]	85	26 (median)	No	133	Pleural abrasion	Yes	4	53	Moderate risk of bias
Chen 2012 [1]	75	29	No	36	Pleural abrasion	Yes	3	16	Moderate risk of bias
Chen 2012 [2]	85	25	No	26	Pleural abrasion	Yes	8	31	Moderate risk of bias
Kutluk 2018 [1]	91	28	Yes	45	Pleurectomy	Yes	9	≥6 (at least)	Moderate risk of bias
Kutluk 2018 [2]	87	27	Yes	45	Pleurectomy	Yes	9	≥6 (at least)	Moderate risk of bias
Kutluk 2018 [3]	80	28	Yes	45	Pleurectomy	Yes	13	≥6 (at least)	Moderate risk of bias
Olesen 2018 [1]	74	26	Yes	38	Pleurectomy	Yes	13	52	Low risk of bias
Olesen 2018 [2]	82	27	Yes	50	Pleurectomy	Yes	12	61	Low risk of bias
Liu 2020 [1]	83	21	No	142	Pleural abrasion	Yes	9	73	Low risk of bias
Liu 2020 [2]	90	22	No	123	Pleural abrasion	Yes	8	77 (median)	Low risk of bias
Liu 2020 [3]	93	21	No	70	Pleural abrasion	Yes	7	79	Low risk of bias
Jeon 2020 [1]	94	19 (median)	No	154	Pleural abrasion	Yes	13	52	Moderate risk of bias
Jung 2021 [1]	97	20 (median)	No	175	Chemical; viscum album extract	Yes	0	38 (median)	Moderate risk of bias
Kao 2021 [1]	100	17	No	32	Pleural abrasion	Yes	9	96	Moderate risk of bias
Kao 2021 [2]	100	17	No	40	Pleural abrasion	Yes	15	59	Moderate risk of bias
Kao 2021 [3]	100	17	No	60	Pleural abrasion	Yes	17	82	Moderate risk of bias
Fung 2022 [1]	77	25	No	62	Pleurectomy	Yes	10	77	Moderate risk of bias

[†], age expressed in mean years or in median years when stated; [‡], FU expressed in mean months or, when specified, in median months, in one study the follow-up was at least 6 months [reported as ≥6 (at least)] and in two studies the mean follow-up was at least 12 months (reported as ≥12); [§], definitions of study groups 1, 2, 3 can be found in Table S5. FU, follow-up; RCT, randomized controlled trial; RoB, risk of bias.

Study (study group)	Intervention	n Rec	n Total	% Rec (95% CI)
Late chest tube removal				
Waller 1999 (1)	Pleurectomy	3	118	2.54 [0.53; 7.25]
Chen 2004 (1)	Pleural abrasion and chemical pleurodesis	9	313	2.88 [1.32; 5.39]
Chen 2004 (2)	Pleural abrasion	5	51	9.80 [3.26; 21.41]
Ben-Nun 2006 (1)	Pleural abrasion	2	58	3.45 [0.42; 11.91]
Chang 2006 (1)	Pleurectomy	0	30	0.00 [0.00; 11.57]
Chang 2006 (2)	Pleural abrasion	3	35	8.57 [1.80; 23.06]
Chen 2006 (1)	Pleural abrasion and chemical pleurodesis	2	103	1.94 [0.24; 6.84]
Chen 2006 (2)	Pleural abrasion	8	99	8.08 [3.55; 15.30]
Chen 2012 (1)	Pleurectomy	4	80	5.00 [1.38; 12.31]
Chen 2012 (2)	Pleural abrasion and chemical pleurodesis	3	80	3.75 [0.78; 10.57]
Lee 2013 (1)	Pleural abrasion	15	128	11.72 [6.71; 18.59]
Lee 2013 (2)	Pleural abrasion with PGA sheets	5	129	3.88 [1.27; 8.81]
Hsu 2021 (1)	Pleural abrasion with vicryl mesh coverage	5	102	4.90 [1.61; 11.07]
Hsu 2021 (2)	Pleural abrasion	17	102	16.67 [10.02; 25.34]
Huang 2023 (1)	Pleural abrasion and chemical pleurodesis	1	20	5.00 [0.13; 24.87]
Huang 2023 (2)	Pleural abrasion	8	28	28.57 [13.22; 48.67]
Bertrand 1996 (1)	Pleural abrasion	6	149	4.03 [1.49; 8.56]
Ayed 2000 (1)	Pleural abrasion	4	39	10.26 [2.87; 24.22]
Ayed 2000 (2)	Pleurectomy	0	33	0.00 [0.00; 10.58]
Ayed 2003 (1)	Pleurectomy; chest tube on waterseal	0	50	0.00 [0.00; 7.11]
Ayed 2003 (2)	Pleurectomy; chest tube on suction	2	50	4.00 [0.49; 13.71]
Lang-Lazdunski 2003 (1)	Pleural abrasion	20	167	11.98 [7.47; 17.89]
Gossot 2004 (1)	Pleural abrasion	4	111	3.60 [0.99; 8.97]
Ayed 2006 (1)	Pleurectomy; macroscopic and histological findings	3	94	3.19 [0.66; 9.04]
Marcheix 2007 (1)	Chemical pleurodesis	12	603	1.99 [1.03; 3.45]
Rena 2008 (1)	Pleural abrasion	7	112	6.25 [2.55; 12.45]
Rena 2008 (2)	Pleurectomy	5	108	4.63 [1.52; 10.47]
Cho 2009 (1)	Pleural abrasion and covering procedure after wedge resection	4	99	4.04 [1.11; 10.02]
Min 2014 (1)	Pleural abrasion	8	145	5.52 [2.41; 10.58]
Imperatori 2015 (1)	Pleurectomy	9	134	6.72 [3.12; 12.37]
Lin 2016 (1)	Pleural abrasion and chemical pleurodesis; transareolar VATS	0	112	0.00 [0.00; 3.24]
Dagnegard 2017 (1)	Pleurectomy	31	234	13.25 [9.18; 18.27]
Zhang 2017 (1)	Pleural abrasion with polyglycolic acid sleeve	0	60	0.00 [0.00; 5.96]
Zhang 2017 (2)	Pleural abrasion without polyglycolic acid sleeve	0	74	0.00 [0.00; 4.86]
Mithiran 2019 (1)	Chemical pleurodesis	5	75	6.67 [2.20; 14.88]
Mithiran 2019 (2)	Pleurectomy	10	127	7.87 [3.84; 14.00]
Campisi 2022 (1)	Pleural abrasion	8	53	15.09 [6.75; 27.59]
Campisi 2022 (2)	Pleural abrasion with standard apical resection	30	452	6.64 [4.52; 9.34]
Kennedy 2023 (1)	Chemical pleurodesis	1	114	0.88 [0.02; 4.79]
Kennedy 2023 (2)	Chemical pleurodesis	0	63	0.00 [0.00; 5.69]
Random effects model			**4734**	**4.49 [3.33; 6.03]**
Heterogeneity: I^2 = 65.6%, τ^2 = 0.6307, p < 0.0001				
Early chest tube removal				
Casadio 2002 (1)	Pleural abrasion	5	133	3.76 [1.23; 8.56]
Chen 2012 (1)	Pleural abrasion; 1port VATS	1	36	2.78 [0.07; 14.53]
Chen 2012 (2)	Pleural abrasion; 3port VATS	2	26	7.69 [0.95; 25.13]
Kutluk 2018 (1)	Pleurectomy; 1port VATS	4	45	8.89 [2.48; 21.22]
Kutluk 2018 (2)	Pleurectomy; 2port VATS	4	45	8.89 [2.48; 21.22]
Kutluk 2018 (3)	Pleurectomy; 3port VATS	6	45	13.33 [5.05; 26.79]
Liu 2020 (1)	Pleural abrasion; ipsilateral VATS without contralateral bullae	12	142	8.45 [4.44; 14.30]
Liu 2020 (2)	Pleural abrasion; ipsilateral VATS with contralateral bullae	10	123	8.13 [3.97; 14.44]
Liu 2020 (3)	Pleural abrasion; bilateral VATS with contralateral bullae	5	70	7.14 [2.36; 15.89]
Jeon 2020 (1)	Pleural abrasion	20	154	12.99 [8.12; 19.34]
Jung 2021 (1)	Chemical pleurodesis	0	175	0.00 [0.00; 2.09]
Kao 2021 (1)	Pleural abrasion; bilateral VATS with contralateral bullae	3	32	9.38 [1.98; 25.02]
Kao 2021 (2)	Pleural abrasion; unilateral VATS with contralateral bullae	6	40	15.00 [5.71; 29.84]
Kao 2021 (3)	Pleural abrasion; unilateral VATS without contralateral bullae	10	60	16.67 [8.29; 28.52]
Horio 2002 (1)	Pleural abrasion	1	53	1.89 [0.05; 10.07]
Olesen 2018 (1)	Pleurectomy after HRCT blebs < 1cm	5	38	13.16 [4.41; 28.09]
Olesen 2018 (2)	Pleurectomy after HRCT blebs > 1cm	6	50	12.00 [4.53; 24.31]
Fung 2022 (1)	Pleurectomy	6	62	9.68 [3.63; 19.88]
Random effects model			**1329**	**7.61 [5.44; 10.57]**
Heterogeneity: I^2 = 8.2%, τ^2 = 0.3499, p = 0.3568				
Random effects model			**6063**	**5.29 [4.18; 6.67]**
Heterogeneity: I^2 = 59.3%, τ^2 = 0.5909, p < 0.0001				
Test for subgroup differences: χ^2_1 = 5.34, df = 1 (p = 0.0209)				

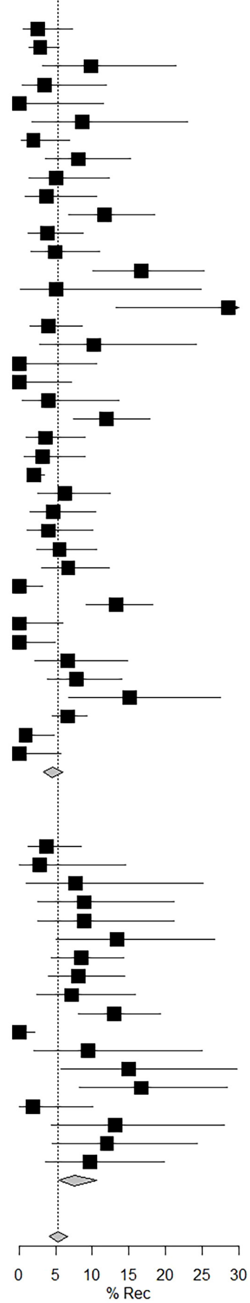

Figure 2 Random effects meta-analysis of the recurrence rate after video-assisted thoracoscopic surgery pleurodesis after early and late chest tube removal. Definitions of study groups 1, 2, 3 can be found in Table S5. CI, confidence interval; I^2, heterogeneity; Intervention, the researched intervention of the included study; n Rec, number of recurrences; n Total, total number of patients with complete follow-up.

this approach. Although in general ERATS guidelines advocate early chest tube removal, our results warrant a prospective trial comparing early and late chest tube removal before widespread implementation.

A previous descriptive review on timing of chest tube removal also manifested different chest tube management

Table 2 Secondary outcomes

Type of chest tube management	Late chest tube removal			Early chest tube removal			P
	Value (95% CI)	N	I^2 (%)	Value (95% CI)	N	I^2 (%)	
LOS (days)†	4.83 (4.32–5.39)	4,196	98.6	4.38 (4.02–4.78)	1,117	98.4	0.18
PAL >5 days‡	6.12 (4.65–8.01)	1,672	48	4.35 (1.82–10.02)	115	0	0.45
Chest tube duration (days)†	3.42 (3.08–3.81)	4,004	98	2.50 (2.31–2.71)	650	97.6	<0.001

†, mean and 95% CI; ‡, incidence in percentage and 95% CI. CI, confidence interval; I^2, heterogeneity; LOS, length of hospital stay; PAL, prolonged air leakage.

Table 3 Recurrence rates between early and late chest tube removal in subgroup analysis

Type of chest tube management	Late chest tube removal			Early chest tube removal			P
	Incidence (95% CI) (%)	N	I^2 (%)	Incidence (95% CI) (%)	N	I^2 (%)	
VATS pleurectomy	4.28 (2.48–7.27)	1,058	48.5	10.88 (7.75–15.05)	285	0	0.003
VATS pleural abrasion	6.65 (4.78–9.18)	2,193	60.6	8.14 (5.83–11.25)	869	41.6	0.40
VATS chemical pleurodesis	1.99 (0.81–4.79)	855	54.6	N/A	N/A	N/A	N/A
VATS pleural abrasion with chemical pleurodesis	2.39 (1.44–3.92)	628	0	N/A	N/A	N/A	N/A

CI, confidence interval; I^2, heterogeneity; N/A, not applicable; VATS, video-assisted thoracoscopic surgery.

protocols (8). They concluded that chest tube removal as early as postoperative day two appears safe since no postoperative complications occurred and chest radiographs were satisfactory. Different from this narrative review, our systematic review focused on early chest tube removal (i.e., upon cessation of air leak) and its effect on postoperative recurrence rate, which is the most important safety outcome in such evaluation. It is worth noting that factors beyond chest tube management, such as type of surgical pleurodesis and patient factors, may also influence recurrence rates, underscoring the complexity of this analysis.

Although surgical pleurodesis is a necessary step in recurrence prevention, pleurodesis techniques may vary and therewith exert different risks of recurrence, which has previously been explored by two reviews reporting the lowest recurrence rates after VATS chemical pleurodesis (15,16). Therefore, we performed subgroup analyses regarding pleurodesis technique showing similar recurrence rates in the VATS pleural abrasion and VATS chemical pleurodesis group with or without pleural abrasion. Interestingly, after pleurectomy the recurrence rate was 6% lower in the late chest tube removal group compared to the early removal group (P=0.003), suggesting it may be safer leaving the chest tube in place for a few days in these cases. Although the number of pleurectomy cases in the early group was limited, this pleurodesis technique may be considered less effective, potentially requiring a longer chest tube duration. To our knowledge, the safety of chest tube removal being dependent on the type of pleurodesis has not previously been explored and may be an interesting avenue for future research.

Although early chest tube removal was expected to result in a shortened LOS, this meta-analysis found a non-significant (P=0.18) reduction in LOS of only half a day. Factors that potentially obscured a reduction in LOS by early tube removal are the retrospective nature of most included studies, high heterogeneity, variation in discharge criteria and different study aims. Next to chest tube duration, which was a day shorter in the early group (P<0.001), the ERATS guideline outlines 44 additional crucial items for enhanced recovery, all of which impact LOS (11,17). Since ERATS items are scarcely reported in studies and it was not our aim to correct for all ERATS items in our review, any potential difference in LOS due to early or late chest tube removal could have been missed. Furthermore, some studies specifically evaluating early chest tube removal and its effect on LOS were excluded from our review, since their outcomes did not adhere to our inclusion criteria. Furuya for example investigated early chest tube removal showing a mean LOS of only 1 day (9). In this study, chest tube removal was delayed in only 15% of cases due to persistent air leak or bloody drainage, resulting in a mean LOS of two days, which is still lower than the mean LOS found in our review. Another small prospective study even showed safe chest tube removal in the operating room in case of absence of air leakage, with a mean LOS of 1 day (10). Based on these two studies, a shorter LOS after early chest tube removal was expected, whereas our review could not confirm these findings.

Next to an effect on recurrence and LOS, there may be an interaction between chest tube duration and PAL. Although the presence of a chest tube in itself is not a risk factor for PAL, chest tube duration and/or the level of suction on the drainage system may influence its persistence. We demonstrated a comparable postoperative incidence of 4–6% after early and late chest tube removal (P=0.45). This is in accordance with previous studies with reported incidences of PAL up to 8% (6,8). Between studies the amount of applied suction varied from −5 to −25 cmH_2O based on in-house protocols and incomplete lung expansion or active air leakage (18-20). Interestingly, a retrospective study showed that water seal following VATS pleurodesis was associated with reduced chest tube duration and LOS, suggesting that the use of less or no suction could be beneficial (21). This is in line with results from a RCT in lobectomy cases, demonstrating significantly decreased chest tube duration after suction with −2 cmH_2O compared to −10 cmH_2O (22). The underlying physiology puts forward that excessive suction may maintain the source of air leakage.

Although our findings advocate caution regarding early chest tube removal, we must acknowledge several limitations. First, the absence of studies directly comparing early with late tube removal in patients with PSP necessitated inclusion of studies solely based on the accurate description of our outcome measures of interest and tube management criteria, which does not automatically imply that these criteria were strictly adhered to. For instance, only one study explicitly specified the method and device used to determine the cessation of air leakage (23). Seven additional studies provided clear descriptions or visualizations of the devices employed, of which 2 were digital and 5 analog (20,24-29). While digital drainage systems enable objective assessment of air leakage, the use of analog devices may result in a more subjective appraisal, potentially influencing chest tube duration. Moreover, variations in the reported removal criteria as well as in perioperative care, such as surgical approach and the number of chest tubes used, introduced heterogeneity across studies. These differences cannot be fully accounted for, thereby limiting the robustness of our recommendations. Secondly, the quality of all studies, assessed with the ROBINS-1 tool, was scored in the majority as having moderate RoB. Consequently, owing to the heterogeneous nature across studies and the moderate to high RoB, the overall certainty of the evidence according to the GRADE method was considered low. Finally, potential benefits of early chest tube removal lie within other outcome measures such as improved patient satisfaction and decreased postoperative pain, which are scarcely reported and hence must be confirmed by high-quality research (7,30). These limitations prevent drawing firm conclusions regarding postoperative chest tube management, and therefore a newly designed RCT is established focusing on the safety of postoperative chest tube and pain management in patients operated for PSP; the Pneumotrial (clinicaltrials.gov; NCT06053476).

Conclusions

This meta-analysis indicates that early chest tube removal following VATS pleurodesis for PSP may be associated with a slightly higher recurrence rate, emphasizing the need for caution when considering this approach. Although the quality of evidence is considered low due to lack of direct comparative studies, this review provides the best available evidence to guide clinicians in chest tube decision-making. Our findings furthermore indicate to maintain a conservative approach regarding chest tube removal after VATS pleurodesis by pleurectomy. A prospective RCT should be conducted to obtain reliable and definite insight into the safety and benefits of early chest tube removal.

Acknowledgments

None.

Footnote

Reporting Checklist: The authors have completed the PRISMA reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1802/rc

Peer Review File: Available at https://jtd.amegroups.com/

article/view/10.21037/jtd-24-1802/prf

Funding: None.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1802/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Cite this article as: van Steenwijk QCA, Spaans LN, Braun J, Dijkgraaf MGW, van den Broek FJC. Early versus late chest tube removal after surgery for primary spontaneous pneumothorax—a systematic review and meta-analysis. J Thorac Dis 2025;17(4):2194-2205. doi: 10.21037/jtd-24-1802

