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External suction versus simple water-seal on chest drainage following pulmonary surgery: an updated meta-analysis

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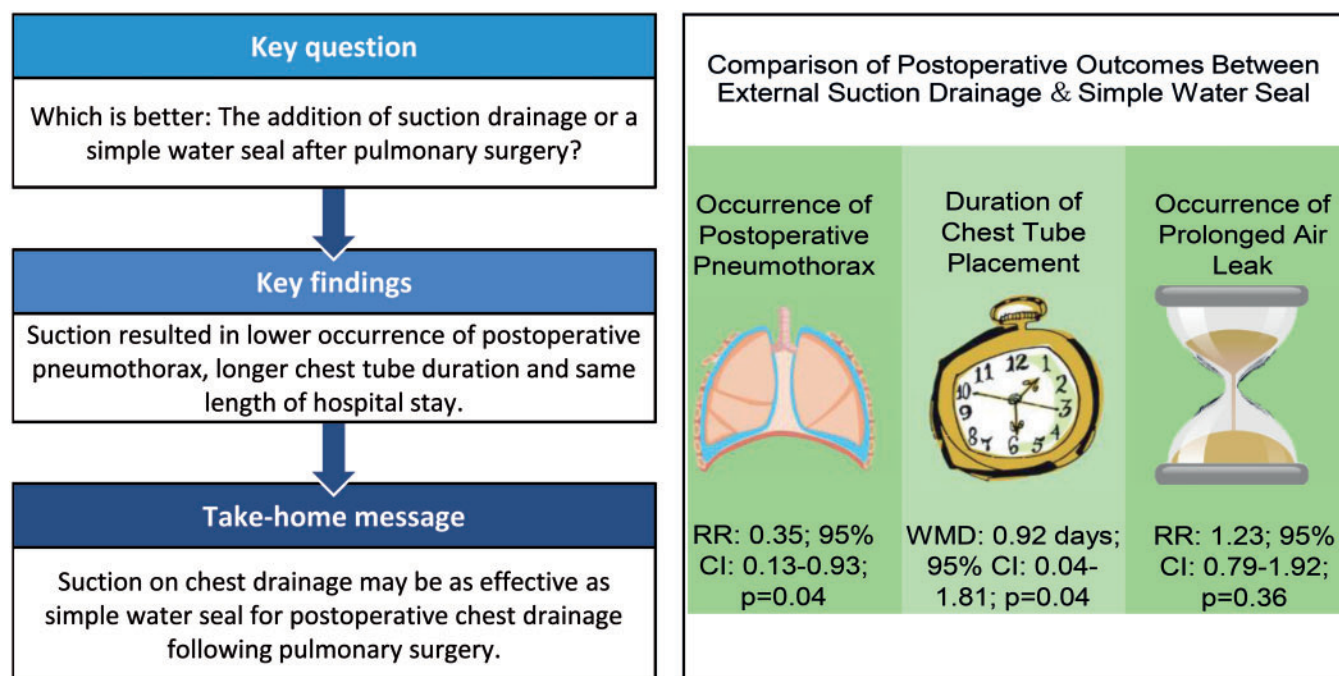
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Abstract

OBJECTIVES: The decision to apply simple water-seal drainage or the addition of an external suction to the simple water-seal drainage following pulmonary surgery is made based on the surgeon's experience or preference and has remained controversial. This meta-analysis aimed to assess the effects of the addition of suction to simple water-seal on the postoperative outcomes.

METHODS: PubMed, EMBASE and Web of Science were searched from their inception to 30 August 2017. The risk ratio and the weight mean difference were calculated for dichotomous and continuous outcomes, respectively, each with 95% confidence intervals (CIs). The heterogeneity and risk of bias were also assessed.

[†]The first two authors contributed equally to this work.

RESULTS: A total of 10 randomized controlled trials enrolling 1601 patients were included. Overall, compared with simple water-seal, the addition of external suction reduced the occurrence of postoperative pneumothorax (risk ratio 0.35, 95% CI 0.13–0.93; $P=0.04$) and other cardiopulmonary complications (risk ratio 0.65, 95% CI 0.48–0.89; $P=0.008$), and increased the duration of chest tube drainage (weight mean difference 0.92 days, 95% CI 0.04–1.81, $P=0.04$). However, the effect difference between the 2 groups was not significant regarding air leak duration, length of hospital stay and the occurrence of prolonged air leak. The stability of these studies was strong. No evidence of publication bias was detected.

CONCLUSIONS: The addition of suction to simple water-seal made no difference to air leak duration, hospital stay or the occurrence of prolonged air leak following pulmonary surgery. In patients where there is concern about a residual or increasing pneumothorax, the addition of suction may be applied selectively.

Keywords: Suction • Simple water-seal • Chest drains • Pulmonary surgery

INTRODUCTION

The essential principles of a chest drainage system are to permit drainage of fluid and air, to eliminate the residual pleural space, facilitate lung re-expansion and to maintain negative pressure [1].

There are 2 different concepts of chest tube management currently in use: simple water-seal (non-suction drainage) or water seal with the addition of external suction (suction drainage) [2]. The choice is made based on the clinician's preference without much consideration of sound evidence [3]. Some hold the idea that the addition of suction might reduce the air leak and, therefore, accelerate lung rehabilitation, whereas other surgeons assert that simple water-seal could shorten the air leak duration after pulmonary surgery [4–6]. The difference in opinion is related to whether there is an advantage in the addition of external suction to water seal. There can be no doubt that mechanical suction results in more rapid removal of air and fluid and re-expansion of the lung. The question that remains is which provides the better overall outcome for the patient [4]. We conducted this further meta-analysis to answer this question.

MATERIALS AND METHODS

Search strategy

The articles were searched by 2 independent reviewers in the PubMed, EMBASE and Web of Science from their inception to 30 August 2017 with the following terms: 'lung surgery', 'lung resection', 'pulmonary surgery', 'pulmonary resection', 'lobectomy', 'segmentectomy', 'wedge resection' AND 'chest drain', 'chest tube', 'chest drainage', 'air leak', 'air leakage', 'suction'. Both reviewers also manually searched the reference lists of eligible studies to identify potential relevant publications.

Inclusion and exclusion criteria

For inclusion, the studies need to (i) be randomized controlled trials; (ii) focus on patients who had undergone pulmonary surgery and (iii) compare the addition of suction drainage and simple water-seal. The studies were excluded if they met one of the following criteria: (i) essential information was incomplete, (ii) were conference abstracts, letters, review, case reports and animal experiments and (iii) the article was not written in English. Two researchers assessed the suitability of studies independently. Any disagreement was solved by further discussion, and if necessary, a third assessor would arbitrate.

Quality assessment

The risk of bias of each eligible study was evaluated according to the Cochrane Handbook for Systemic Reviews of Interventions. The criteria for evaluating the risk of bias includes sequence generation and concealment of allocation (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessors (detection bias), incomplete outcome data addressed (attrition bias), free of selective reporting (reporting bias) and other bias. Also, this work was independently assessed by 2 reviewers (J.Z. and N.C.). Any disagreement was solved by consensus.

Data extraction and management

The following information was extracted from each eligible study: the first author, publication year, country, disease type, surgery type, grade of air leak, number of subjects, pressure of suction and postoperative outcomes including air leak duration, length of hospital stay, the duration of chest tube drainage, the occurrence of prolonged air leak and postoperative pneumothorax.

Statistical analysis

We summarized dichotomous or continuous outcomes as the risk ratio (RR) or the weight mean difference (WMD), respectively, and each with 95% confidence intervals (CIs). The results were considered statistically significant if P -value was <0.05 . We pooled all the data with the random effects model as the starting point instead of using the fixed-effect model. The fixed-effect model, by requiring that the true effect size not vary from study to study, poses a constraint that is not plausible in this (and most) meta-analysis. Further subgroup analyses were performed to identify the potential heterogeneity, including ethnicity (White or mixed), the drainage volume threshold for removal (200 ml/day or 300 ml/day) and the definition of prolonged air leak (persistent air leak longer than 7 days or 5 days). We also performed sensitivity analysis to identify the robustness of the study by re-meta-analysis with one involved excluded each time. Publication bias was evaluated using the Begg's test and visualization of funnel plots. All statistical analyses were performed by Review Manager V.5.3 (The Cochrane Collaboration, Software Update, Oxford, UK).

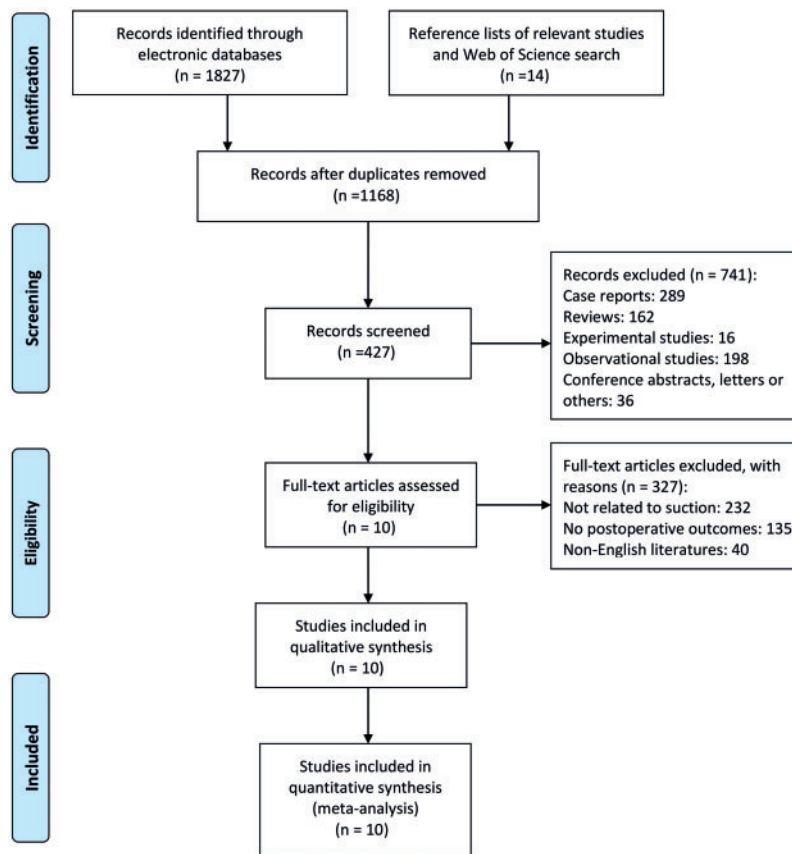


Figure 1: The PRISMA flow diagram of literature retrieval.

Table 1: Main characteristics of the included randomized controlled trials

Study	Sample size	Ethnicity	Participant	Disease	Number of tubes	Initial suction	Suction pressure (cmH ₂ O)	Drainage system	Definition of PAL (days)	Drainage threshold of removal (ml/day)
Alphonso <i>et al.</i> [7]	239	White	Lung surgery	Lung disease	1–2	No	-20	Regular	>6	<200
Ayed <i>et al.</i> [8]	100	White	VATS	PSP	1	No	-20	Regular	>5	<100
Brunelli <i>et al.</i> [5]	145	White	Lobectomy	Lung cancer	2	Yes	-20	Regular	>7	<200
Brunelli <i>et al.</i> [9]	100	White	Lobectomy	Lung cancer	1	NA	-11 to -20	Digital	>7	NA
Cerfolio <i>et al.</i> [10]	33	Mixed	Lung surgery	Lung cancer	NA	NA	-20	Regular	>5	NA
Gocyk <i>et al.</i> [6]	294	White	Lung surgery	Lung disease	1–2	Yes	-20	Regular	>7	<150
Kakhki <i>et al.</i> [11]	31	White	Lung surgery	Lung disease	1	Yes	-10 to -18	Regular	>7	NA
Leo <i>et al.</i> [12]	500	White	Lung resection	Lung disease	1–2	Yes	-15	Digital	>6	<300
Marshall <i>et al.</i> [13]	68	Mixed	Lung resection	Lung disease	NA	Yes	-20	Regular	>8	<300
Prokakis <i>et al.</i> [14]	91	White	Lobectomy	Lung cancer	2	No	-15 to -20	Regular	>7	<200

PAL: prolonged air leak; PSP: primary spontaneous pneumothorax; VATS: video-assisted thoracic surgery.

RESULTS

Characteristics of studies

A total of 1827 references were found from the initial search. After 2 independent researchers screened the titles and abstracts, and if necessary, found full text to confirm, only 10 randomized controlled trials [5–14] recruiting 1568 patients were included. Included articles were published between 2001 and 2016. The sample size of these studies ranged from 31 to 500. Most researchers recruited participants who underwent lung resection

for lung disease, whereas Ayed *et al.* [8] enrolled patients who underwent video-assisted thoracic surgery for primary spontaneous pneumothorax (PSP). The drainage systems used were conventional water-seal chest drainage systems except Leo *et al.* [12] and Brunelli *et al.* [9] who applied an electronic drainage system, which could record air leaks digitally. The postoperative outcome parameters included the occurrence of prolonged air leak and postoperative pneumothorax, the duration of chest tube drainage, air leak duration and length of hospital stay. The PRISMA flow diagram of literature retrieval is shown in Fig. 1. The main characteristics of the included studies are presented in Table 1.

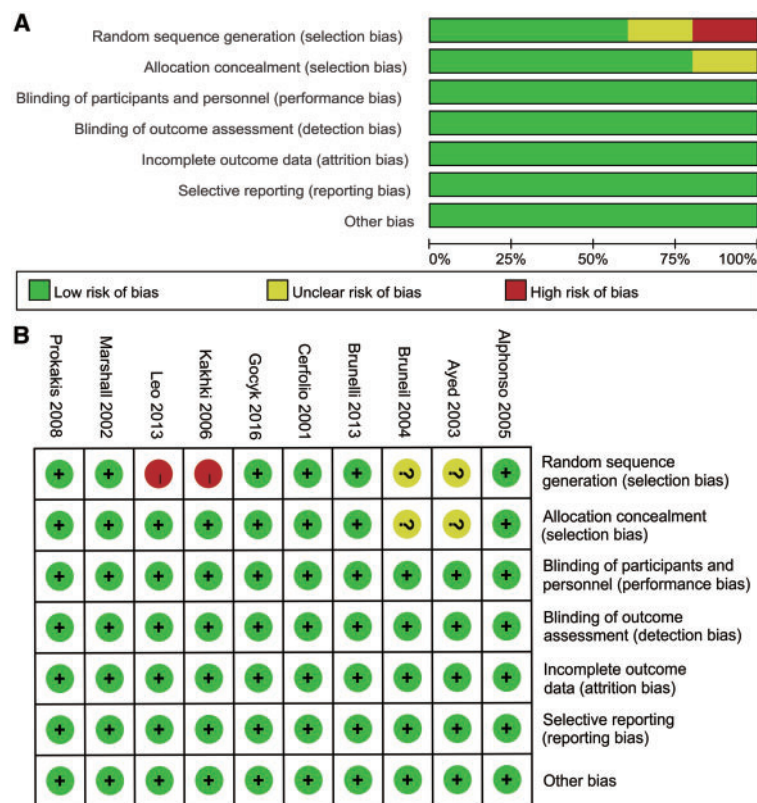


Figure 2: Assessment of risk of bias. (A) Graph of the risk of bias for the included studies and (B) graph of the risk of bias summary for the included studies.

Table 2: Risk of bias assessment

Study	Sequence generation	Concealment of allocation	Blinding of participants and personnel	Blinding of outcome assessors	Incomplete outcome data addressed	Free of selective reporting	Other bias
Alphonso <i>et al.</i> [7]	Low	Low	Low	Low	Low	Low	Low
Ayed <i>et al.</i> [8]	Unclear	Unclear	Low	Low	Low	Low	Low
Brunelli <i>et al.</i> [5]	Unclear	Unclear	Low	Low	Low	Low	Low
Brunelli <i>et al.</i> [9]	Low	Low	Low	Low	Low	Low	Low
Cerfolio <i>et al.</i> [10]	Low	Low	Low	Low	Low	Low	Low
Gocyk <i>et al.</i> [6]	Low	Low	Low	Low	Low	Low	Low
Kakhki <i>et al.</i> [11]	High	Low	Low	Low	Low	Low	Low
Leo <i>et al.</i> [12]	High	Low	Low	Low	Low	Low	Low
Marshall <i>et al.</i> [13]	High	Low	Low	Low	Low	Low	Low
Prokakis <i>et al.</i> [14]	Low	Low	Low	Low	Low	Low	Low

Risk of bias across studies

Two independent researchers assessed the risk of bias of the included studies. Ayed *et al.* [8] and Brunelli *et al.* [9] did not report enough details of sequence generation and concealment of allocation, whereas Kakhki *et al.* [11], Leo *et al.* [12] and Marshall *et al.* [13] performed randomization-based clinical decision, which indicates a potential of high risk of bias. The graph of the risk of bias for the included studies is shown in Table 2 and Fig. 2.

Occurrence of prolonged air leak

Ten studies assessed the occurrence of prolonged air leak: 795 individuals received the simple water-seal in addition to suction,

whereas 806 received simple water-seal on chest drains. There was no significant difference between the 2 groups concerning the occurrence of prolonged air leak (Fig. 3A) (RR 1.23, 95% CI 0.79–1.92; $P=0.36$). No significant difference was revealed in subgroup analysis.

Occurrence of postoperative pneumothorax

From 5 studies comprising 262 patients with suction and 269 with simple water-seal, we concluded that the patients in the suction group had a lower occurrence of postoperative pneumothorax compared with the simple water-seal group (RR 0.35, 95% CI 0.13–0.93; $P=0.04$) (Fig. 3B). No significant difference was found in subgroup analysis.

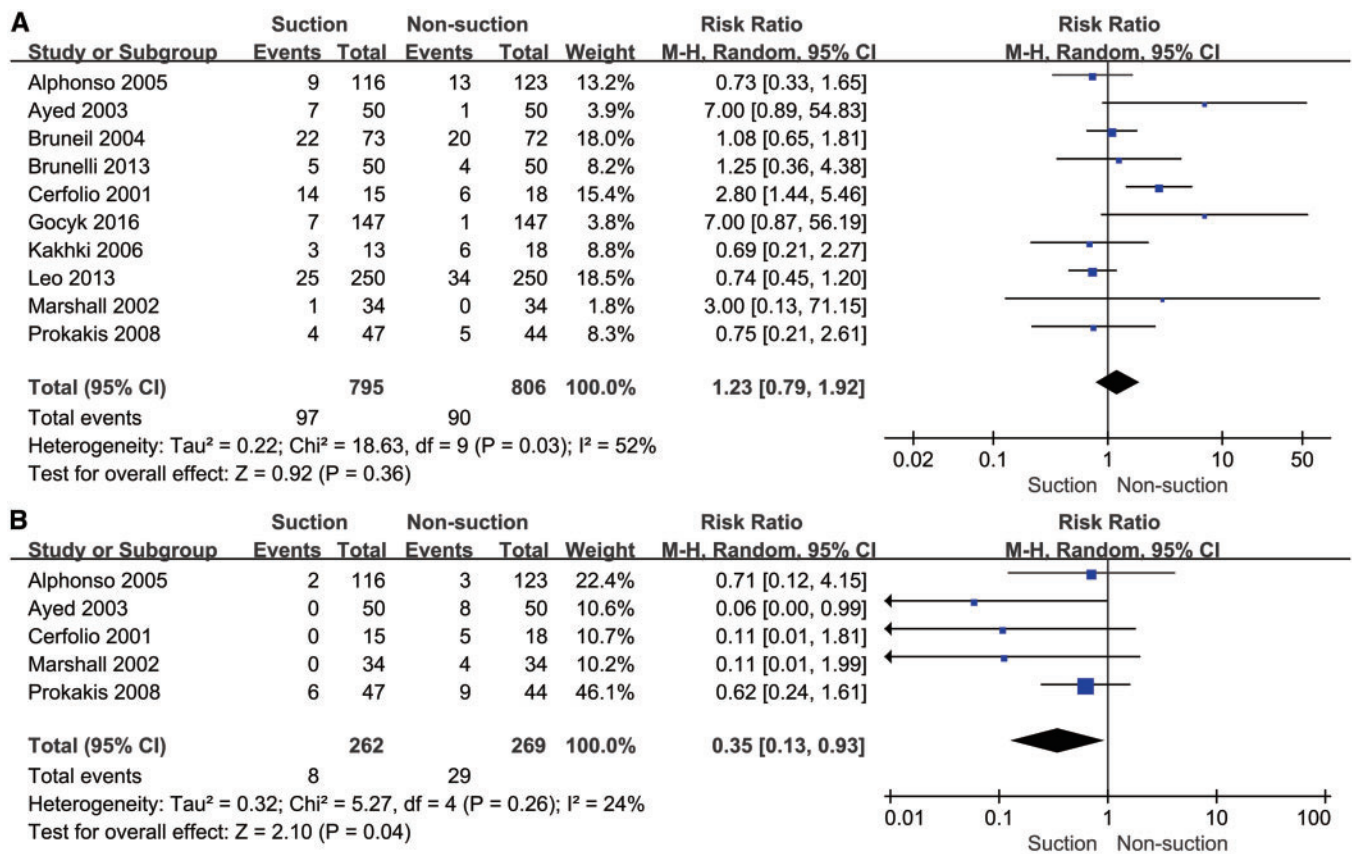


Figure 3: Meta-analysis of the effect of the addition of suction to simple water-seal or simple water-seal on the occurrence of (A) prolonged air leak and (B) postoperative pneumothorax.

Duration of chest tube drainage

A total of 6 studies measured the duration of chest tube drainage. Results indicated that simple water-seal may significantly shorten the duration of chest tube drainage compared with the addition of suction drainage (WMD 0.92 days, 95% CI 0.04–1.81; $P = 0.04$) (Fig. 4A).

Air leak duration

Four studies assessed the duration of air leak, with 304 patients on suction drainage and 303 on simple water-seal drainage. The effect difference between the 2 groups was not significant (WMD 0.81 days, 95% CI -0.21 to 1.82; $P = 0.12$) (Fig. 4B).

Length of hospital stay

Five studies assessed the length of hospital stay, with no statistically significant difference between the suction drainage and simple water-seal (WMD 1.57 days, 95% CI -0.83 to 3.98; $P = 0.20$) (Fig. 4C). Subgroup analyses were conducted based on the drainage volume threshold for removal: 4 studies removed the chest tube when drainage volume was less than 200 ml/day, whereas 1 study removed the chest tube when drainage volume was less than 300 ml/day. Our analysis indicated that a lower drainage volume threshold for removal was significantly associated with an increased hospital stay (I^2 0%, WMD 1.02 days, 95% CI 0.41–1.62, $P = 0.001$).

Occurrence of other cardiopulmonary complications

We also analysed the incidence of other cardiopulmonary complications including pneumonia, empyema, atelectasis, arrhythmia and bleeding. We found that the addition of suction had a lower incidence of postoperative cardiopulmonary complications compared with simple water-seal (RR 0.65, 95% CI 0.48–0.89; $P = 0.008$). We were unable to draw any significant conclusions regarding specific cardiopulmonary complications.

Other parameters

For other parameters, we looked at effusion and staple line (length of the stapled parenchyma for each patient). However, we found no significant difference in effusion volume within the first 24 h or 48 h. The results from 2 studies recruiting 213 patients indicated that the suction group had bigger 'air leak days/cm of the staple line' compared with the simple water-seal group (WMD 0.07, 95% CI 0.01–0.13, $P = 0.03$), which meant that suction drainage may prolong air leak days per centimetre of staples. No significant difference was found concerning the value 'chest tube days/cm of the staple line'. All the main results of our analysis are listed in Table 3.

Sensitivity analysis and publication bias

From derived forest plots, we found that none of the displayed outcomes were outside of the estimated range. Also, no

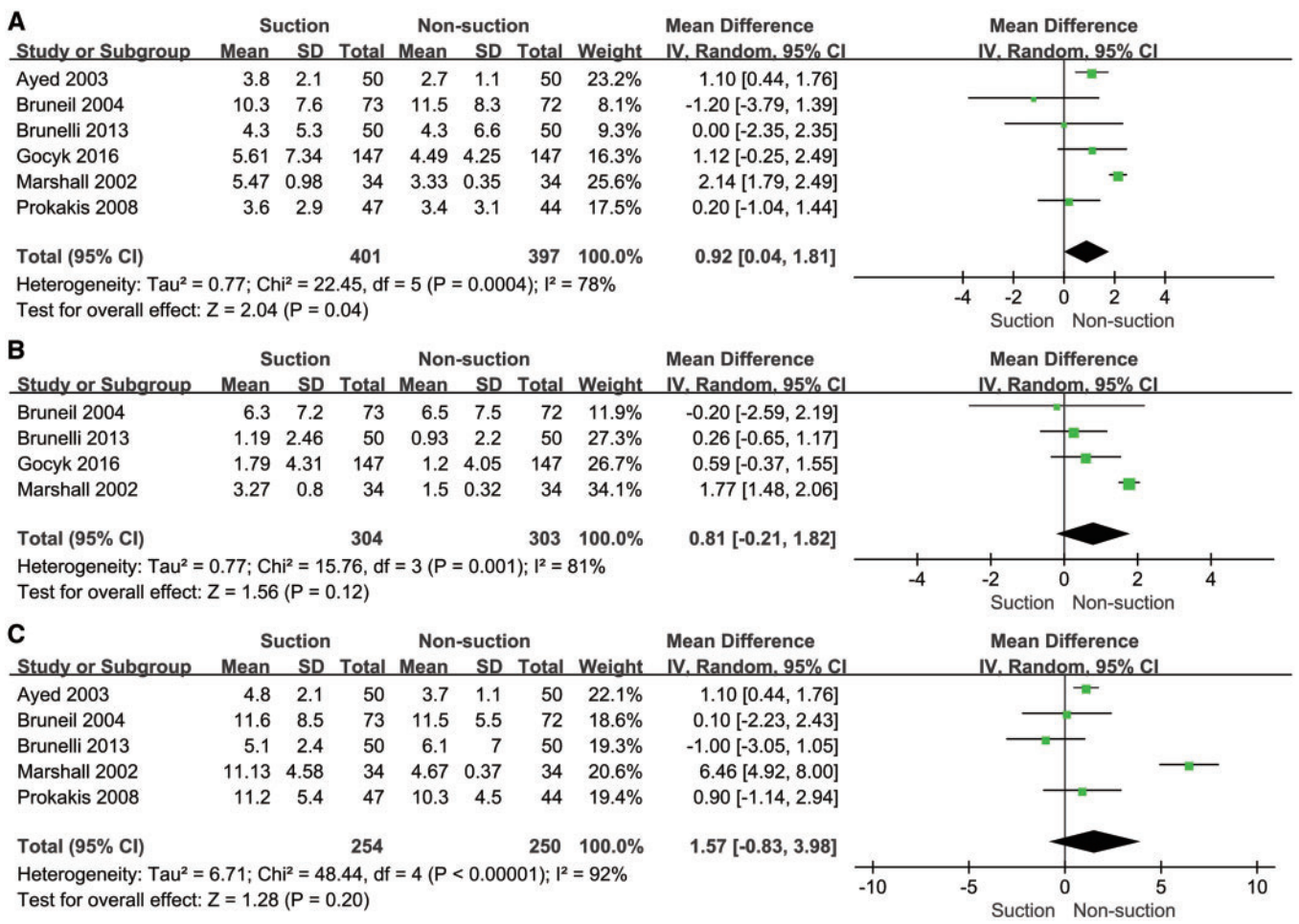


Figure 4: Meta-analysis of the effect of the addition of suction to simple water-seal or simple water-seal on (A) the duration of chest tube drainage, (B) air leak duration and (C) length of hospital stay.

significant discoveries were identified in sensitivity analyses. Furthermore, we found no significant publication bias by visual inspection of the funnel plot and Begg's test ($P = 1.00$).

DISCUSSION

Compared with simple water-seal, the addition of external suction increased the duration of chest tube drainage, decreased the occurrence of postoperative pneumothorax and other cardiopulmonary complications and increased 'air leak days/cm of the staple line'. However, between simple water-seal and external suction, no significant differences were found regarding air leak duration, length of hospital stay and the occurrence of prolonged air leak. The differences between the 2 groups, including the criteria for chest tubes removal (especially the drainage volume threshold for chest tube removal), the definition of prolonged air leak, the onset time of suction drainage, the disease type (lung cancer, pneumothorax and other lung disease) and whether discharged home on device, may affect the results. However, the lack of sufficient data prevented us from performing a further analysis of these differences.

The duration of chest tube drainage was an important issue that might affect postoperative success [15]. We found that the addition of suction increased the duration of chest tube drainage compared with simple water-seal, and this was in accordance with the study by Ayed *et al.* [8] and Marshall *et al.* [13]. However,

Brunelli *et al.* [9] found no significant differences between the effects of the 2 groups. The drainage device was digital, which was not the same with other research studies. Miller *et al.* [16] and our previous study [17] showed that the use of a digital drainage system may change the duration of chest tube drainage.

The occurrence of postoperative pneumothorax was associated with the surgical lesions and the quality of the operation [18]. We found that suction drainage was beneficial in reducing the incidence of postoperative pneumothorax compared with simple water-seal. Meanwhile, some previous meta-analyses arrived at the same conclusion [19, 20]. However, Ayed *et al.* [8] drew a different conclusion. They recruited 100 consecutive participants who underwent video-assisted thoracic surgery for PSP, equally assigned into external suction and simple water-seal in a 1:1 ratio and found no significant difference between the 2 groups. Although Ayed *et al.* [8] only included PSP patients, the previous presence of air leak may have influence on the incidence of postoperative pneumothorax [21]. Furthermore, they removed the chest tubes according to the removal criteria 'lung was fully recovered with no air leak and less than 100-ml pleural fluid drainage for 24 h'. This lower drainage volume (compared to other studies) was rational as the PSP patients have less pleural fluid than lung patients in other studies.

There was no widely accepted definition of prolonged air leak in the included studies. Most researchers considered 'prolonged air leak' to be a persistent air leak longer than 7 days, whereas other authors regarded 'prolonged air leak' as a persistent air leak

Table 3: Main results of our analysis

Outcomes	No. of studies	No. of participants	Results				Heterogeneity		
			RR/WMD	95% CI		P-value	I ² (%)	PH	Model
Occurrence of PAL	10	1601	RR 1.23	0.79	1.92	0.36	52	0.03	Random
Ethnicity									
White	8	1500	RR 0.98	0.67	1.43	0.90	27	0.21	Random
Mixed	2	101	RR 2.81	1.46	5.39	0.002	0	0.97	Random
Drainage threshold of removal									
200 ml/day	5	869	RR 1.26	0.64	2.50	0.50	49	0.10	Random
The definition of PAL									
>7 days	6	729	RR 1.10	0.73	1.64	0.65	0	0.47	Random
>6 days or 5 days	4	872	RR 1.42	0.59	3.43	0.43	79	0.002	Random
Occurrence of postoperative pneumothorax	5	531	RR 0.35	0.13	0.93	0.04	24	0.26	Random
Ethnicity									
White	3	430	RR 0.46	0.15	1.47	0.19	33	0.23	Random
Drainage threshold of removal									
<200 ml/day	3	430	RR 0.46	0.15	1.47	0.19	33	0.23	Random
Duration of chest tube	6	798	WMD 0.92	0.04	1.81	0.04	78	0.0004	Random
Ethnicity									
White	5	730	WMD 0.73	0.12	1.34	0.02	14	0.33	Random
Drainage threshold of removal									
<200 ml/day	4	630	WMD 0.73	0.02	1.44	0.04	28	0.24	Random
Duration of air leak	4	607	WMD 0.81	-0.21	1.81	0.12	81	0.001	Random
Ethnicity									
White	3	539	WMD 0.37	-0.26	1.01	0.25	0	0.79	Random
Length of hospital stay	5	504	WMD 1.57	-0.83	3.98	0.2	92	<0.0001	Random
Ethnicity									
White	4	436	WMD 0.62	-0.27	1.51	0.17	27	0.25	Random
Drainage threshold of removal									
200 ml/day	3	336	WMD 1.02	0.41	1.62	0.001	0	0.72	Random
Effusion volume in the first 24 h	2	354	WMD 43.62	-34.47	121.72	0.27	88	0.003	Random
Effusion volume in the first 48 h	3	499	WMD 10.42	-124.77	145.61	0.88	80	0.007	Random
Air leak days/cm of the staple line	2	213	WMD 0.07	0.01	0.13	0.03	85	0.01	Random
Chest tube days/cm of the staple line	2	213	WMD 0.09	-0.02	0.20	0.11	93	<0.0001	Random
Cardiopulmonary complications	3	745	RR 0.65	0.48	0.89	0.008	0	0.68	Random
Pneumonia	3	736	RR 0.64	0.34	1.22	0.17	0	0.58	Random
Empyema	2	591	RR 1.44	0.24	8.74	0.69	0	0.68	Random
Atelectasis	2	591	RR 0.57	0.24	1.35	0.20	0	0.45	Random
Arrhythmia	3	736	RR 0.93	0.47	1.86	0.84	43	0.18	Random
Bleeding	2	591	RR 0.98	0.37	2.57	0.96	0	0.65	Random

CI: confidence interval; PAL: prolonged air leak; PH: *P*-value of heterogeneity; RR: risk ratio; WMD: weighted mean difference.

longer than 8, 6 or 5 days. Initially, we thought that the difference in definitions among the included studies may impact the incidence of prolonged air leak. However, no significant difference was identified in subgroup analyses. Based on the recent literature, several authors have recommended defining a prolonged air leak as a postoperative air leak lasting >5 days, and this definition is consistent with the Society of Thoracic Surgeons (STS) database definition for a prolonged air leak as an air leak exceeding the otherwise necessary length of stay [22, 23].

We found patients with chest tubes placed to the addition of suction had a lower incidence of postoperative pneumothorax compared with simple water-seal. Herein, we propose 2 possible reasons for how suction drainage could have decreased the occurrence of postoperative pneumothorax. First, applying chest tubes to suction might accelerate the elimination of excessive air and drainage in the pleural cavity directly. Second, chest tubes connected to suction could be more stable to ensure the drainage function and avoid complications.

Staples are widely used to close stumps during operations such as sleeve gastrectomy and are considered to be a main

cause of staple-line bleeding, staple-line leaks and dehiscence [24]. Some researchers pointed out that buttressing the staple lines could decrease the air leak duration after pulmonary surgery [25, 26]. The length of the staple line reflects the extent of the resection, which, of course, impacts on the incidence of postoperative air leakage. To help control for this, we assessed the ratio of air leak duration and the length of the staple line between the 2 groups. Our results indicated that suction drainage is associated with higher air leak days/cm of the staple line. That meant that in the condition where the length of the staple line is same between the 2 groups, the suction group would have longer air leak days.

In China, thoracic surgeons do not apply suction drainage systems routinely. There are several possible reasons for this. First, the lack of guidelines for when and how to use suction drainage. Second, it may be inconvenient to use. Third, the clinical effect of the addition of suction drainage is not definite. The higher cost of suction drainage (compared to simple water-seal) is also a possible reason. Our meta-analysis may help promote evidence-based medicine in this field in China.

Limitations

Compared with previous published meta-analyses, the strengths of this analysis included (i) updating published articles and recruiting more studies; (ii) further discussion on more postoperative outcome parameters such as the occurrence of cardiopulmonary complications and (iii) clear inclusion and exclusion criteria, careful screening of studies, independent collection of data, complete assessment of studies quality and reliable tests to identify heterogeneity. However, we also had some limitations. (i) Heterogeneity among included studies. We assessed the risk of bias of each eligible studies and found 3 studies that had a high risk of bias due to randomization based on clinical experience. The heterogeneity test for each analysis was well accepted. In addition, we conducted a subgroup analysis and a sensitivity analysis to explain heterogeneity based on some potential source of heterogeneity; (ii) lack of standard procedure for chest tube management. For example, there was still no universally accepted definition of prolonged air leak; (iii) insufficient sample size for some data items. For example, when we analysed the occurrence of arrhythmia and bleeding, only 2 studies were homogeneous and used in the final analysis. The low number of studies for this data item might unfairly affect our results. Therefore, more large-sample randomized controlled trials are needed.

CONCLUSIONS

The addition of suction to simple water-seal made no difference to air leak duration, hospital stay or the occurrence of prolonged air leak following pulmonary surgery. In patients where there is concern about a residual or increasing pneumothorax, the addition of suction may be applied selectively.

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