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REVIEW

Post-Biopsy Manoeuvres to Reduce Pneumothorax Incidence in CT-Guided Transthoracic Lung Biopsies: A Systematic Review and Meta-analysis

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Abstract This systematic review and meta-analysis investigated post-biopsy manoeuvres to reduce pneumothorax following computed tomography-guided percutaneous transthoracic lung biopsy. Twenty-one articles were included with 7080 patients. Chest drain insertion rates were significantly reduced by ninefold with the normal saline tract sealant compared to controls (OR 0.11, 95% CI 0.02–0.48), threefold with the rapid rollover manoeuvre to puncture site down (OR 0.34, 95% CI 0.18–0.63), threefold with the tract plug (OR 0.33, 95% CI 0.22–0.48) and threefold with the blood patch (OR 0.39, 95% CI 0.26–0.58). The absolute chest drain insertion rates were the lowest in the normal saline tract sealant (0.8% vs 7.3% for controls), rapid rollover (1.9% vs 5.2%), deep expiration and breath-hold on needle extraction (0.9% vs 1.8%) and standard rollover versus no rollover (2.6% vs 5.2%). These findings highlight post-biopsy manoeuvres which could help reduce pneumothorax and chest drain insertions following lung biopsies.

Level of Evidence Level 1/no level of evidence, systematic review.

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Introduction

A pneumothorax is the most common complication of computed tomography-guided percutaneous transthoracic needle biopsy (CT-PTNB). The incidence of pneumothorax ranges from 12 to 45%, with 2–15% being significant enough to require a chest drain [1, 2]. Development of a pneumothorax increases costs as well as the need of hospitalisation to manage the patient's symptoms such as chest pain, shortness of breath and hypoxia [2].

Multiple manoeuvres have been trialled to reduce the incidence of pneumothoraxes in lung biopsies including rapid roll over [3, 4], deep expiration and breath-hold technique [5], autologous blood patch [6, 7], tract plug [8, 9] and normal saline tract sealant [10, 11]. There is no consensus on which of these techniques are most effective.

The purpose of this study is to systematically review and meta-analyse the manoeuvres to assess which ones have the most evidence and greatest benefit in reducing pneumothorax rates in lung biopsies. To our knowledge, attempts to synthesise and pool existing data about these techniques have not been performed.

Methods

This systematic review and meta-analysis were conducted in accordance with the preferred reporting items for systematic reviews and meta-analysis (PRISMA) checklist and recommendations made by the cochrane collaboration [12, 13]. Electronic search was performed using EMBASE, MEDLINE, Google Scholar, Cochrane Methodology Register, Cochrane Central Register of Controlled Trials and ACP Journal Club, for pertinent articles from inception to November 2018. The search strategy combined the terms 'biopsy' and 'pneumothorax' and ('lung' or 'lung neoplasms') and ('saline' or 'tract plug' or 'blood patch' or 'rollover' or 'breath hold' or 'comparison') inclusive of relevant truncations, MeSH terms and keywords. Reference lists of included studies were screened to identify potentially relevant studies.

Selection of Studies

The title and abstracts were independently assessed by two investigators (ARH and IL) using the inclusion and exclusion criteria. Inclusion criteria for full texts to be extracted were studies which suggested: (a) lung biopsies were performed using CT or fluoroscopic guidance, (b) pneumothorax considered as an outcome, (c) investigating post-biopsy manoeuvres and techniques to reduce pneumothorax rates, (d) had both an intervention and control group, (e) human subjects and (f) English language. Exclusion criteria included conference presentations, case reports, reviews, editorial and expert opinions. The two investigators cross-matched their initial screen and extracted the full articles. The full articles were then further assessed to ensure they fulfilled the inclusion criteria and had evidence that the study was approved by a relevant institutional ethics committee and patients gave informed consent where appropriate. The reference lists of studies were further assessed for potential possible studies. The final selection of studies was confirmed with all authors.

Data Extraction and Critical Appraisal

Two investigators (ARH and IL) independently extracted data from each retrieved full-text article and compared for accuracy. One author (YRH) further cross-matched and rechecked all extracted data. Discordance was resolved by a senior investigator (MVC). Study characteristics collected included year of publication, study design, number of radiologists, biopsy technique, intervention methodology and number of participants in the intervention and control groups. Outcomes extracted included pneumothorax and pneumothorax requiring chest drain insertion rates in the intervention group and control group.

Quality Assessment

Critical appraisal of RCTs was conducted with the Cochrane's collaboration format using a grading scheme for: randomisation, allocation concealment, outcome data, selective outcome reporting and other sources of bias. The overall quality of studies was classified into three groups: low, high or unclear [13]. Critical appraisal of non-randomised studies was conducted with the Newcastle–Ottawa scale (NOS) using a grading scheme for selection, comparability and outcome bias [14]. Total scores range from zero to nine, with higher scores allocated to studies of greater quality in selection, comparability and outcome.

Statistical Analysis

A random effects model was used to pool odds ratios (OR) for control and intervention groups for the risk of pneumothorax overall and chest drain insertion. Heterogeneity analysis was performed using the I^2 index. I^2 values of 25%, 50% and 75% correlated to low, moderate and high degrees of heterogeneity. The p value for significance was $p < 0.05$. Computations were performed using Review Manager (Version 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014).

Results

Study Selection

A total of 684 unique articles were identified in our initial search (Fig. 1). A large number of studies were excluded because they were abstracts, animal studies, laboratory projects, case studies or did not provide pneumothorax data. After carefully reading the abstracts, 53 articles were selected for full-text review. Following reading the full text, 21 studies met our inclusion criteria [3–11, 15–26]. There were in total 7080 patients, 3692 in the intervention group and 3388 in the control group. There were 12 randomised controlled trials (RCTs) [5, 8–10, 15, 16, 18–20, 22, 23, 26], seven retrospective studies [4, 6, 7, 17, 21, 24, 25] and two prospective studies [10, 11] (Table 1). The manoeuvres which were assessed include the normal saline tract sealant, tract plug, blood patch, rapid rollover (vs slow/none), standard rollover (vs none), and deep expiration and breath-hold during needle withdrawal.

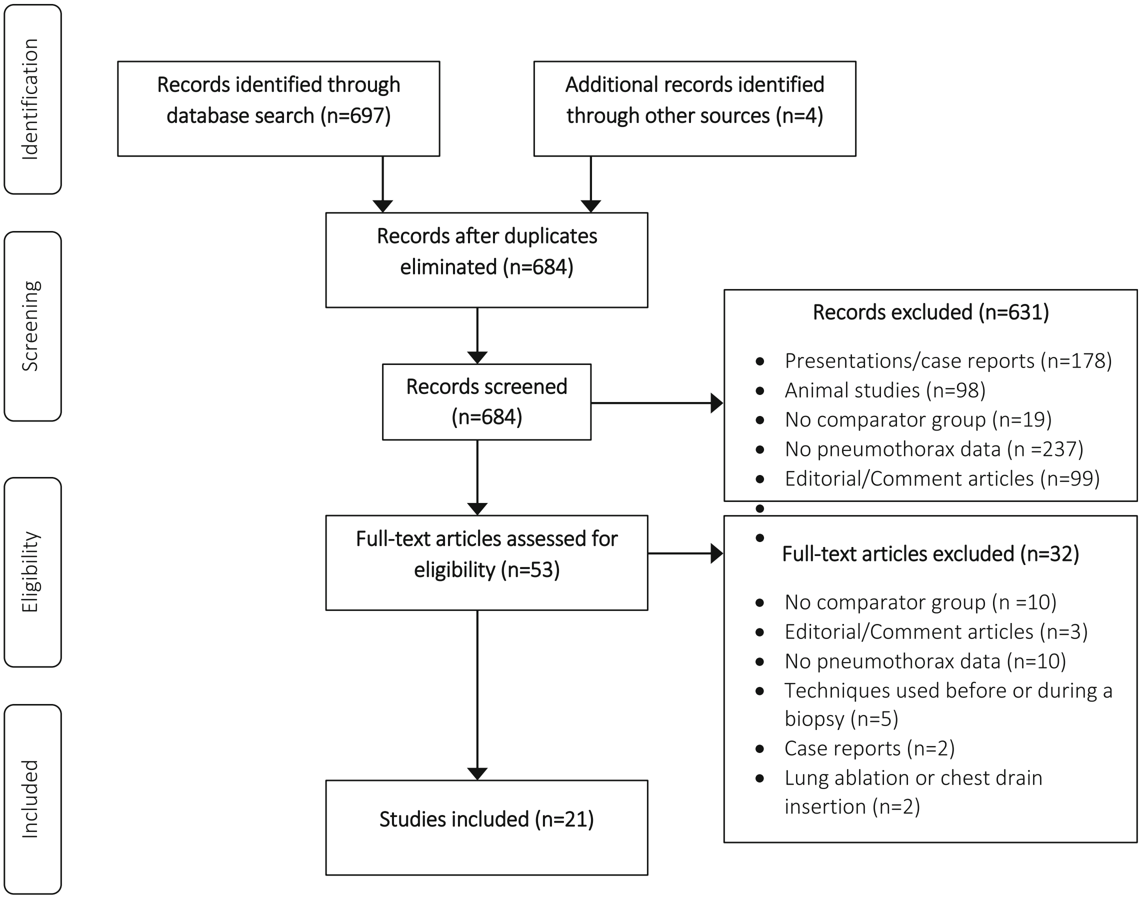

Fig. 1 PRISMA flowchart for study selection

Methodological Quality of Included Studies

In terms of quality, two RCTs received a low bias score [15, 18], six RCTs received an unclear bias score [5, 8–10, 19, 26] and four of 12 RCTS has a high bias score [16, 20, 22, 23] (Table 2). Only three RCTS [10, 15, 18] described adequate randomisation techniques such as using a random-number generator. Only two RCTs clearly described adequate allocation concealment whereby the radiologist was blinded to the study group until after adequate tissue sample had been obtained and an envelop was opened [15, 18]. The remaining studies did not adequately describe how randomisation was done or done by non-random methods, as defined by the Cochrane guidelines [13], such as using odd or even hospital unit number to determine study group [16]. For the non-randomised studies, eight studies received a good quality score and NOS score from 7 to 9 [3, 4, 6, 7, 11, 21, 24, 25]. One study received a poor quality score and NOS score of 5 [17] (Table 2).

Meta-analysis and Systematic Review Outcomes

Normal Saline Tract Sealant

Two studies compared normal saline tract sealant technique to controls, one prospective study [11] and one RCT [10] (Fig. 2A). The overall risk of pneumothorax was reduced by sixfold in the normal saline tract sealant compared to controls (OR 0.18, 95% CI 0.10–0.33, $p < 0.001$, incidence: 6.9% vs. 28.6%) (Fig. 2A). The risk of a chest drain insertion was reduced by ninefold (OR 0.11, 95% CI 0.02–0.48, incidence: 0.8% vs 7.3%) (Fig. 3A, Table 3).

Billich and colleagues used co-axial technique with a 16-gauge (G) introducer and 18G needle. After biopsy, 2–4 mL of normal saline at room temperature was instilled into the introducer needle as it was extracted as the patient did a breath-hold. The control patients had the introducer needle withdrawn at the same speed under breath-hold without instillation of normal saline [11]. Similarly, Li and colleagues [10] a coaxial technique with a 19G introducer and 20G needle and injected 1–3 mL of normal saline, whilst the introducer needle was withdrawn.

Table 1 Study characteristics

Manoeuvre	Study	Year	Study design	Manoeuvre number	Control number	Mean age	Number of radiologists	Guide and biopsy needle gauge
Normal saline tract sealant								
	Billich	2008	P	70	70	63	3	16G Guide, 18G Biopsy
	Li	2015	RCT	161	161	58	2	19G Guide, 20G Biopsy
Tract plug								
Collagen foam	Engeler	1992	RCT	25	25	–	–	18G Guide,19G Biopsy
Fibrin glue	Petsas	1995	RCT	26	32	68	–	19G Guide, 22G Biopsy
Hydrogel plug	Zaetta	2010	RCT	170	169	67	> 15 centres	19G Guide, - Biopsy
Gelatin powder	Baadh	2016	R	125	124	76	3	17/19G Guide, 18/20G Biopsy
Hydrogel plug	Grage	2017	R	100	100	65	1	19G Guide, 20G Biopsy
Hydrogel plug	Ahrar	2017	R	317	317	63	12 (± trainee)	19 Guide, 20/22G Biopsy
Blood patch:								
Clotted	Bourgouin	1988	RCT	46	83	–	4	19G Guide, 22G Biopsy
	Herman	1990	RCT	46	47	63	1	19G Guide, 22G Biopsy
	Lang	2000	RCT	50	50	51	6	19G Guide, 20/22G Biopsy
	Malone	2013	RCT	123	119	65	6 (± trainee)	17/19G Guide, 18/20G Biopsy
Non-clotted	Clayton	2016	R	245	189	67	6 (± trainee)	19G Guide, 20/22/23G Biopsy
	Graffy	2017	R	482	352	65	6 (± trainee)	19G Guide, 20G Biopsy
Rapid rollover (vs slow)	O'Neill	2012	P	120	81	68	1	19G Guide, 20G Biopsy
Rollover (vs No rollover)	Kim	2015	R	610	617	63	1 (± trainee)	17G Guide, 18G Biopsy
	Moore	1990	R	262	143	64	4 (± trainee)	19G Guide, 21/22G Biopsy (Coaxial: 223 biopsies); 21/22G Biopsy (Non-coaxial: 182 biopsies)
	Collings	1999	RCT	210	213	–	2	19G Guide, - Biopsy (Coaxial: 10 biopsies);
	Tanisaro	2003	RCT	59	48	58	1	19G Guide, 20G Biopsy
								20/22G Biopsy (Non-coaxial: 413 biopsies)
Deep expiration & breath-hold	Min	2013	RCT	219	221	61	–	19G Guide, 20G Biopsy
Blood patch versus hydrogel plug	Maybody	2018	RCT	226	227	67	18	19G Guide, - Biopsy
POOLED				3692	3388			

RCT Randomised control trial, *R* Retrospective, *P* Prospective, *G* Gauge, - not stated

Tract Plug

Six studies assessed tract plug devices (Table 1, Figs. 2, 3) [8, 9, 15, 21, 24, 25]. The overall risk of pneumothorax was halved using a tract plug device compared to controls (OR 0.47, 95% CI 0.33–0.66, incidence: 19.8% vs. 33.9%) (Fig. 2B). The risk of a chest drain insertion was reduced by threefold (OR 0.33, 95% CI 0.22–0.48, incidence: 5.4% vs 14.8%) (Fig. 3B, Table 3).

Three studies assessed a hydrogel plug [15, 21, 25], and three studies investigated different tract plugs: compressed collagen foam plugs [9], fibrin glue [8] and absorbable haemostat gelatin power [24]. Subgroup analysis demonstrated the hydrogel plug [15, 21, 25] reduced the risk of pneumothorax (OR 0.53, 95% CI 0.32–0.88, incidence: 22.7% vs. 36.5%) and chest drain insertion (OR 0.23, 95% CI 0.21–0.48, incidence: 5.8% vs. 16.0%).

All studies demonstrated the tract plug reduced the risk of pneumothorax; however, the three smallest studies did not reach statistical significance, likely due to their small study sample of 200 [21], 50 [9] and 58 patients [8]. The three studies with the highest patient numbers all reached

Table 2 Summary of critical appraisal of included studies

Study	Year	Study design	Critical appraisal of RCTs with Cochrane's Collaboration Tool						
			Adequate randomisation/ sequence generation	Adequate allocation concealment	Blinding of participants, personnel and outcome assessors	Adequate outcome data	Free of selective outcome reporting	Free of other sources of bias	Bias score
Maybody	2018	RCT	Unclear	Unclear	Yes	Yes	Yes	Yes	Unclear
Li	2015	RCT	Yes	Unclear	Yes	Yes	Yes	Yes	Unclear
Malone	2013	RCT	Yes	Yes	Yes	Yes	Yes	Yes	Low
Min	2013	RCT	Unclear	Unclear	Yes	Yes	Yes	Yes	Unclear
Zaetta	2010	RCT	Yes	Yes	Yes	Yes	Yes	Yes	Low
Tanisaro	2003	RCT	No	No	Yes	Yes	Yes	Yes	High
Lang	2000	RCT	Unclear	Unclear	Yes	Yes	Yes	Yes	Unclear
Collings	1999	RCT	No	Unclear	Yes	Yes	Yes	No	High
Petsas	1995	RCT	Unclear	Unclear	Yes	Yes	Yes	Yes	Unclear
Engeler	1992	RCT	Unclear	Unclear	Yes	Yes	Yes	Yes	Unclear
Herman	1990	RCT	No	No	Yes	Yes	Yes	Unclear	High
Bourgouin	1988	RCT	No	No	Yes	Yes	Yes	Yes	High

Critical appraisal of non-randomised studies with Newcastle–Ottawa scale

			Selection (****)	Comparability (**)	Outcome (***)	Total	Quality
O'Neill	2012	P	****	**	***	9	Good
Billich	2008	P	****	*	***	8	Good
Ahrar	2017	R	****	**	**	8	Good
Grage	2017	R	***	*	***	7	Good
Graffy	2017	R	***	*	**	6	Good
Baadh	2016	R	***	*	**	6	Good
Clayton	2016	R	***	*	**	6	Good
Kim	2015	R	***	*	***	7	Good
Moore	1990	R	**		***	5	Poor

RCT randomised control trial, *R* retrospective, *P* prospective

statistical significance in terms of the reduction in pneumothorax which examined the hydrogel plug [15, 25] and absorbable haemostat gelatin powder [24].

Autologous Blood Patch

Six studies assessed autologous blood patches [6, 7, 18–20, 23]. The overall risk of pneumothorax was halved with a blood patch compared to controls (OR 0.57, 95% CI 0.46–0.70), incidence: 27.9% vs 40.1%) (Fig. 2C). The risk of a chest drain insertion was reduced by almost threefold (OR 0.39, 95% CI 0.26–0.58, incidence: 4.8% vs 11.1%) (Fig. 3C, Table 3).

There were variations in the blood patch technique between the studies. The two more recent studies used non-clotted blood [6, 7] and the four earlier studies used clotted blood [18–20, 23]. Graffy [6] and colleagues used non-clotted blood and injected a 2–3 mL bolus in the immediate subpleural lung. Afterwards, patients were instructed to resist coughing and position biopsy site down. In the four studies which used clotted blood, one study fragmented the clotted blood by injection back and forth from one syringe to other several times [18]. Two studies did not state whether the clotted blood was fragmented and we presumed they used non-fragmented clotted blood [20, 23]. All studies injected 3–10 mL of clotted blood through the introducing needle as it was withdrawn. Lang and colleagues had a different clotted blood technique where the supernatant of blood was separated and primarily deployed at the level of biopsied nodule, whilst the solid clot elements were deployed in the peripheral tract and at the point of exit from the visceral pleura [19].

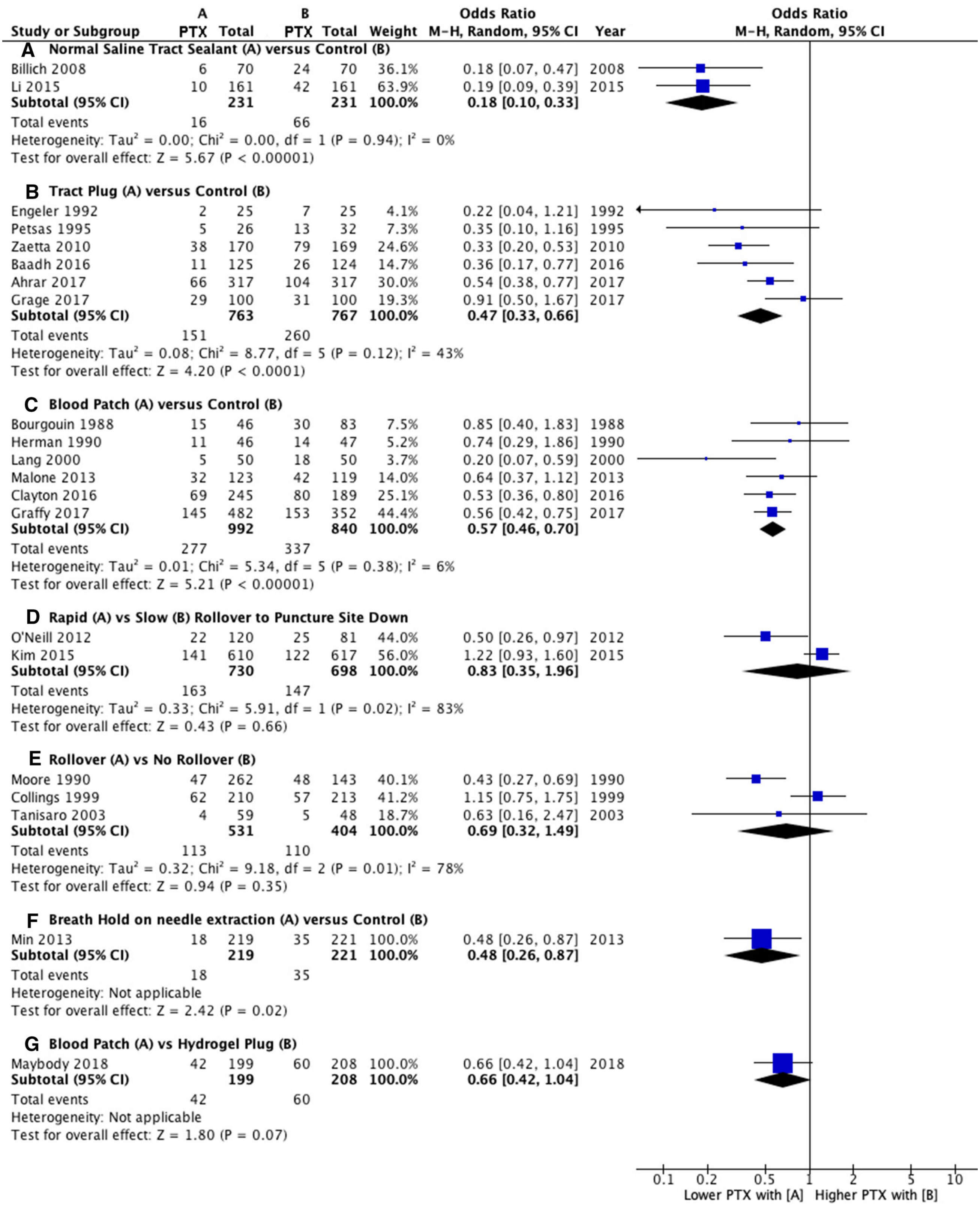

Fig. 2 Forest plot of the association between pneumothorax and interventions: **A** normal saline tract, **B** tract plug, **C** blood patch, **D** rapid roll over, **E** puncture site down, **F** deep expiration & breath-hold during needle extraction, **G** blood patch versus hydrogel plug

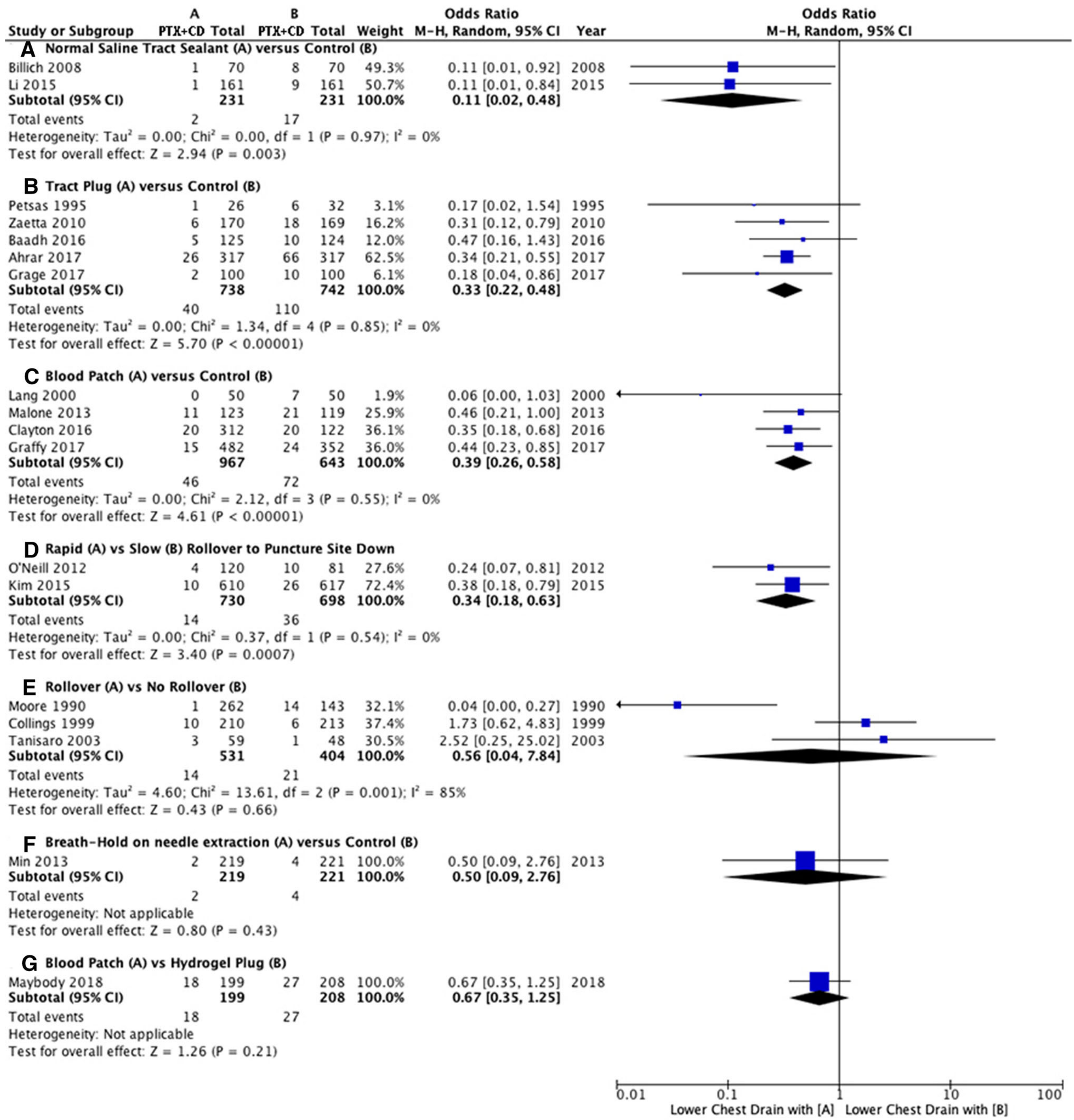

Fig. 3 Forest plot of the association between chest drain insertion for pneumothorax and interventions: **A** normal saline tract, **B** tract plug, **C** blood patch, **D** rapid roll over, **E** puncture site down, **F** deep expiration & breath-hold during needle extraction, **G** blood patch vs hydrogel plug

Subgroup analysis demonstrated the blood patch technique by Lang and colleagues had the best reduction in pneumothorax rates (OR 0.20, 95% CI 0.07–0.59, incidence: 10% vs 36%) [19], followed by the non-clotted blood (OR 0.55, 95% CI 0.44–0.77, incidence: 29% vs 43%) [6, 7], fragmented clotted blood (OR 0.64, 95% CI 0.37–1.12, incidence: 26% vs 35.3%) [18] and finally, non-fragmented clotted blood (OR 0.81, 95% CI 0.45–1.45, incidence: 28% vs 34%) [20, 23].

Rapid Rollover (Puncture Site Down) vs Slow/None

Two studies assessed the benefit of rapid rollover versus slow or no rollover to puncture site down after a lung

Table 3 Intervention versus control group: pooled incidence of pneumothorax overall and pneumothorax requiring chest drain insertion, odds radio

Post-biopsy manoeuvres	Number of studies	Intervention group incidence (%)	Control group incidence (%)	OR (95% CI)
Pneumothorax				
Normal saline tract sealant	2	6.9	28.6	0.18 (0.10–0.33)***
Tract plug	6	19.8	33.9	0.47 (0.33–0.66)***
Blood patch	6	27.9	40.1	0.57 (0.46–0.70)***
Rollover (puncture site down): fast vs slow	2	22.3	21.1	0.83 (0.35–1.96)
Rollover (puncture site down): standard vs none	3	21.3	27.2	0.69 (0.32–1.49)
Deep expiration & breath-hold on needle extraction	1	8.2	15.8	0.48 (0.26–0.87)*
Blood patch (intervention) vs hydrogel plug	1	21.1	28.8	0.66 (0.42–1.04)
Pneumothorax + chest drain				
Normal saline tract sealant	2	0.8	7.3	0.11 (0.02–0.48)***
Tract plug	5	5.4	14.8	0.33 (0.22–0.48)***
Blood patch	4	4.8	11.1	0.39 (0.26–0.58)***
Rollover (puncture site down): fast vs slow	2	1.9	5.1	0.34 (0.18–0.63)***
Rollover (puncture site down): standard vs none	3	2.6	5.2	0.56 (0.04–7.84)
Deep expiration & breath-hold on needle extraction	1	0.9	1.8	0.50 (0.09–2.76)
Blood patch (intervention) vs hydrogel plug	1	9.0	13.0	0.67 (0.35–1.25)

*P-value < 0.05; **P-value < 0.01, ***p-value < 0.001

OR odds ratio, 95% CI 95% confidence interval

biopsy [3, 4]. The overall risk of pneumothorax did not significantly decrease (OR 0.83, 95% CI 0.35–1.96, incidence: 22.3% vs 21.1%) (Fig. 2D). However, the risk of chest drain insertion significantly decreased by a third (OR 0.34, 95% CI 0.18–0.63, incidence: 1.9% vs 5.2%) (Fig. 3D).

Rollover (Puncture Site Down): Standard vs None

Three studies compared the benefit of rollover to puncture site down compared to no rollover after a lung biopsy [16, 17, 22]. The overall risk of pneumothorax did not significantly decrease (OR 0.69, 95% CI 0.32–1.49, incidence: 21.3% vs 27.2%) (Fig. 2E). Similarly, the risk of chest drain insertion did not significantly decrease (OR 0.56, 95% CI 0.04–7.84, pooled incidence 2.6% vs 5.2%) (Fig. 3E).

Breath-Hold After Expiration During Needle Extraction

One study assessed the benefit of breath-hold after forced expiration before needle extraction compared to controls [5]. They demonstrated a significant reduction in pneumothorax rate compared to controls immediately post-biopsy (OR 0.48, 95% CI 0.26–0.87, incidence: 8.2% vs 15.8%) (Fig. 2F). They demonstrated a lower chest drain insertion rate; however, this did not reach statistical significance (OR 0.50, 95% CI 0.09–2.76, incidence: 0.9% vs 1.8%) (Fig. 3F).

Blood Patch Versus Hydrogel Plug

One study compared blood patch to hydrogel plug [26]. It was unclear whether the blood patch was clotted or unclotted. They demonstrated there was a trend towards lower pneumothorax rates with blood patch compared to hydrogel plug (OR 0.66, 95% CI 0.42–1.04, incidence: 21.1% vs 28.8%); however, this did not reach statistical significance (Fig. 2G). A similar trend was seen for chest drain insertion rates (OR 0.67, 95% CI 0.35–1.25, incidence: 9.0% vs 13.0%) (Fig. 3G).

Heterogeneity

There was no significant heterogeneity between the studies that compared pneumothorax with the normal saline tract sealant, tract plug and blood patch technique. There was heterogeneity present between the studies that examined the association between pneumothorax with rapid rollover and standard rollover (Fig. 2).

In terms of pneumothorax requiring chest drain, there was no heterogeneity between the studies for normal saline tract sealant, tract plug, autologous blood patch and rapid rollover. Heterogeneity was present for standard rollover (Fig. 3).

Discussion

This meta-analysis demonstrates a normal saline tract sealant was the most effective technique to reduce the overall pneumothorax incidence and pneumothoraxes requiring a chest drain. Other techniques which significantly reduced pneumothorax overall and chest tube insertion rates were the tract plug and blood patch. Compared to slow rollover, rapid rollover significantly reduced the rates of pneumothoraxes which required a chest drain, but not pneumothorax rates. The breath-hold during needle extraction significantly reduced the rates of pneumothorax rates, but not chest drain insertion rates. There was no reduction in pneumothorax rates with rollover versus no rollover.

In addition to the risk reduction in relation to the control group, it is also important to consider the absolute pneumothorax and chest drain insertion rates in the intervention and control groups. The society of interventional radiology (SIR) recommend a pneumothorax rate of 45% or less and chest drain insertion of 20% or less [1]. The British Thoracic Society (BTS) has stricter recommendations with a pneumothorax rate of 20.5% or less and chest drain insertion of 3.1% or less [2]. Only one study had pneumothorax and chest drain insertion rates of the control group within the BTS recommendations [5]. The control groups in the other studies were above the BTS recommendations. The manoeuvres which reduced pneumothorax rates within BTS guidelines were the normal saline tract (6.9% down from 28.6%), tract plug technique (19.8% down from 33.9%) and deep expiration and breath-hold during needle extraction (8.2% down from 15.8%). The manoeuvres which reduced the chest drain insertion rates within BTS guidelines were the normal saline tract sealant (0.8%), fast rollover (1.9%), standard rollover (2.6%) and deep expiration and breath-hold during needle extraction (0.9%). The other manoeuvres' pneumothorax and chest drain insertion rates still remained above the BTS recommended thresholds (although were reduced compared to controls). Future studies should seek to have their control group within, or at least comparable, to the BTS recommendations.

The normal saline tract was the most effective technique and reduced the pneumothorax risk by fivefold and chest drain insertion rates by tenfold compared to controls. A possible physiological explanation of the technique is that the normal saline fills the biopsy tract to create a water seal which prevents air travelling from the positive pressure alveoli in the lung, via the needle tract, to the negative pressure zone of the pleural space. A constant negative pressure keeps the parietal and visceral pleura together. The moment this negative pressure is disrupted, the lung recoils which causes further air to enter between the parietal and visceral pleural layers, resulting in a pneumothorax. One study instilled 2–4 mL of normal saline at room temperature during extraction of the trocar needle whilst the patient breath-held [11]. The other study instilled 1–3 mL normal saline, whilst the coaxial sheath was being withdrawn [10]. Both studies demonstrated this technique remained significantly associated with lower pneumothorax risk even after adjustment of localisation, lesion size and puncture angle of the needle by multiple regression analysis [10, 11]. The benefits of normal saline include its low cost, relatively quick set-up, easy to handle, universally accessible and not associated with adverse reactions.

The rapid rollover to puncture site down manoeuvre had a significantly lower risk of chest drain insertion but similar overall pneumothorax incidence compared to the control group after pooling the results from two studies. Only 8.6% of all pneumothoraxes required a chest drain in the rapid rollover manoeuvre group compared to 24.4% in the control group. This suggests that the rapid rollover manoeuvre reduces the enlargement of an already established pneumothorax. The pathophysiologic basis for this is likely due to the reduction in alveoli size surrounding the needle tract causing airway closure, dependent accumulation of blood within the needle tract, increased resistant to collateral ventilation and a reduction in alveolar-to-pleural pressure gradient at the puncture site [27].

The lack of reduction for pneumothorax rates between the rapid rollover and control group is likely secondary to the slight variation in the methodology between studies. In O'Neill and colleagues, both the rapid rollover group and controls were rolled-over from the CT table onto a stretcher, with the rapid group simply being faster, with a mean of 9.5 s [3]. The diagnosis of a pneumothorax was done by an erect chest radiograph. This study found the rapid rollover intervention group had half the pneumothorax incidence compared to the slow rollover group (18.3% vs 30.9%). In Kim and colleagues, the rollover was done on a narrow cone beam CT (CBCT) table, took a mean duration of 24.6 s and the pneumothorax was diagnosed on the same CBCT table, where the intervention group had just rapidly rolled-over, whilst the control group remained in the same position on the table [4]. They found a higher rate of pneumothorax rates in the rapid rollover group (23.1% vs 19.8%). The authors believe the act of rolling the patient over on a narrow CBCT table may have caused uncontrolled respiration, increased the likelihood of an air leak through the needle tract and resulted in a higher pneumothorax incidence compared to the controls. We hypothesise an additional factor may be an increase in intrathoracic pressure exerted during rollover. These findings highlight the importance of the rollover to occur rapidly and may be most efficient as the patient is transferred from the CT table to the stretcher.

The autologous blood patch approximately halved the risk of any pneumothorax and more than halved the risk of pneumothoraxes requiring a chest drain. The two most recent studies used non-clotted blood [6, 7], and the four earlier studies used clotted blood [18–20, 23]. There was slight variation of how the studies prepared the clotted blood patch: one study fragmented the clotted blood [18] by injection back and forth from one syringe to other several times; two studies did not state whether the clotted blood was fragmented [20, 23]; and the study by Lang and colleagues study separated the supernatant of blood and primarily deployed at the level of biopsied nodule, whilst the solid clot elements were deployed in the peripheral tract and at the point of exit from the visceral pleura [19]. The blood patch technique by Lang and colleagues [19] had the best reduction in pneumothorax rates, followed by the non-clotted blood, fragmented clotted and finally, non-fragmented clotted blood. These outcomes suggest the best substance to attain a water seal is one that is most liquid and consistent. The technique by Lang and colleagues was the most fluid as they injected supernatant at the lesion and the blood clot at the visceral pleural exit site of the tract. Furthermore, due to the dependent position, the supernatant settled towards the visceral pleural entry site of the tract and afford a further seal [19]. However, there have been no other studies confirming this technique. The non-clotted blood patch was the second most effective blood patch as confirmed in two different studies [6, 7]. The progressive reduction in pneumothorax and chest drain insertion rates with more fluid substances also explains why normal saline sealant has the highest reduction in pneumothorax rates. Future RCTs, perhaps comparing autologous blood patch with normal saline sealant are warranted to confirm these findings.

Overall, the tract plug techniques reduced the risk of a pneumothorax and chest drain insertion by half and third, respectively, compared to controls. The hydrogel plug was the most studied and subgroup analysis demonstrated it reduced the risk of a pneumothorax by half and reduced the risk of a chest drain insertion by fourfold. A recent study compared blood patch to hydrogel plug [26]. They demonstrated the blood patch had a trend towards lower pneumothorax rates (21.1% vs 28.8%) and chest drain insertion rates (9% vs 13%) compared to hydrogel plug; however, this did not reach statistical significance. The study did not clarify whether the blood patch was clotted or unclotted.

The deep expiration and breath-hold manoeuvre during needle withdrawal were found to halve the risk of pneumothorax rates. The rate of chest drain insertion was also halved; however, this did not reach statistical significance likely secondary to the small number of patients who required a chest drain (< 7 patients) [5]. The authors hypothesise that increasing the intrathoracic pressure during expiration compresses the pleural space. Previous studies have found that during deep expiration, the intrapleural pressure can rise to 110 mmHg [28] (exceeding atmospheric pressure). This high, positive intrapleural pressure minimises airflow into the needle tract. An additional mechanism may be the edges of the tract becoming more in contact or even overlap during deep expiration, thereby reducing pneumothorax rates [5]. However, this manoeuvre has only been investigated in this one RCT. Future studies are warranted to confirm these benefits in the reduction in pneumothorax rates.

These findings should be interpreted in view of certain limitations. First, of all the studies included, only 12 were RCTs and two were prospective. Seven were retrospective studies which may be subject to selection, performance and measuring bias. Second, the eligibility criteria (e.g. tumour size, emphysema) were not identical between the studies. This leads to between-study heterogeneity. However, all included studies had a control comparator group that had similar baseline characteristics to the intervention group. The control group allows the study to isolate the independent variables' effects on pneumothorax rates and rules out alternative explanation of the study results. This increases the external reliability of the results. Third, there were a variety of different materials used for the tract plug sealant. This meta-analysis cannot recommend one tract sealant material over another as there were no direct comparisons. Fourth, a few included studies were conducted 30 years ago [20, 23] which may reduce the external validity of their results to current practice as there has been significant improvements in equipment. However, recent studies which have assessed the same techniques such as the blood patch technique have demonstrated similar outcomes as the initial studies [7, 18]. A critical appraisal of all studies and their risk for biases are summarised in Table 2. Finally, this study only included fluoroscopy and CT-guided lung biopsies. Importantly, ultrasound-guided biopsy of pleural-based lung lesions has also been shown to have a significantly lower complication rate compared to CT-guided biopsies of pleural lesions (1.1% vs 23.3%) [29].

Conclusion

This meta-analysis demonstrates normal saline tract sealant, tract plug, blood patch and rapid rollover and deep expiration and breath-hold on needle extraction significantly reduce the risk of pneumothorax and/or chest drain insertion. The normal saline tract and rapid rollover manoeuvre following lung biopsy significantly reduced chest drain insertion rates within the BTS guidelines (0.8% and 1.9%, respectively). Standard rollover and breath-hold in expiration on extraction also had a trend to benefit and a rate of chest drain insertion that was within the BTS guidelines. Future studies are warranted to confirm these findings.

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Compliance with Ethical Standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Gupta S, et al. Quality improvement guidelines for percutaneous needle biopsy. J Vasc Interv Radiol. 2010;21(7):969–75.
2. Manhire A, et al. Guidelines for radiologically guided lung biopsy. Thorax. 2003;58(11):920–36.
3. O'Neill AC, et al. Rapid needle-out patient-rollover time after percutaneous CT-guided transthoracic biopsy of lung nodules: effect on pneumothorax rate. Radiology. 2012;262(1):314–9.
4. Kim J, et al. Rapid needle-out patient-rollover approach after cone beam CT-guided lung biopsy: effect on pneumothorax rate in 1,191 consecutive patients. Eur Radiol. 2015;25(7):1845–53.
5. Min L, et al. Breath-hold after forced expiration before removal of the biopsy needle decreased the rate of pneumothorax in CT-guided transthoracic lung biopsy. Eur J Radiol. 2013;82(1):187–90.
6. Graffy P, et al. Pulmonary intraparenchymal blood patching decreases the rate of pneumothorax-related complications following percutaneous CT–guided needle biopsy. J Vasc Interv Radiol. 2017;28(4):608–13.
7. Clayton JD, et al. Nonclotted blood patch technique reduces pneumothorax and chest tube placement rates after percutaneous lung biopsies. J Thorac Imaging. 2016;31(4):243–6.
8. Petsas T, et al. Fibrin glue for sealing the needle track in fine-needle percutaneous lung biopsy using a coaxial system: part II—clinical study. Cardiovasc Interv Radiol. 1995;18(6):378–82.
9. Engeler C, et al. Pneumothorax after lung biopsy: prevention with transpleural placement of compressed collagen foam plugs. Radiology. 1992;184(3):787–9.
10. Li Y, et al. Usefulness of normal saline for sealing the needle track after CT-guided lung biopsy. Clin Radiol. 2015;70(11):1192–7.
11. Billich C, et al. CT-guided lung biopsy: incidence of pneumothorax after instillation of NaCl into the biopsy track. Eur Radiol. 2008;18(6):1146–52.
12. Moher D, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Intern Med. 2009;151(4):264–9.
13. Higgins JP, et al. The cochrane collaboration's tool for assessing risk of bias in randomised trials. BMJ. 2011;343:d5928.
14. Wells GA, Shea B, O'Connell D, Peterson J, Welch V, Losos M, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality of non randomised studies in meta-analyses. 2011. http://www.ohri.ca/programs/clinical_epidemiology/oxford.htm.
15. Zaetta JM, et al. A lung biopsy tract plug for reduction of post-biopsy pneumothorax and other complications: results of a prospective, multicenter, randomized, controlled clinical study. J Vasc Interv Radiol. 2010;21(8):1235–43.
16. Tanisaro K. Patient positioning after fine needle lung biopsy-effect on pneumothorax rate. Acta Radiol. 2003;44(1):52–5.
17. Moore EH, et al. Positional precautions in needle aspiration lung biopsy. Radiology. 1990;175(3):733–5.
18. Malone LJ, et al. Effect of intraparenchymal blood patch on rates of pneumothorax and pneumothorax requiring chest tube placement after percutaneous lung biopsy. Am J Roentgenol. 2013;200(6):1238–43.
19. Lang EK, et al. Autologous blood clot seal to prevent pneumothorax at CT-guided lung biopsy. Radiology. 2000;216(1):93–6.
20. Herman S, Weisbrod G. Usefulness of the blood patch technique after transthoracic needle aspiration biopsy. Radiology. 1990;176(2):395–7.
21. Grage RA, et al. Efficacy of a dehydrated hydrogel plug to reduce complications associated with computed tomography–guided percutaneous transthoracic needle biopsy. J Thorac Imaging. 2017;32(1):57–62.
22. Collings CL, et al. Pneumothorax and dependent versus nondependent patient position after needle biopsy of the lung. Radiology. 1999;210(1):59–64.
23. Bourgouin P, et al. Transthoracic needle aspiration biopsy: evaluation of the blood patch technique. Radiology. 1988;166(1):93–5.
24. Baadh AS, et al. Utilization of the track embolization technique to improve the safety of percutaneous lung biopsy and/or fiducial marker placement. Clin Imaging. 2016;40(5):1023–8.
25. Ahrar JU, et al. Efficacy of a self-expanding tract sealant device in the reduction of pneumothorax and chest tube placement rates after percutaneous lung biopsy: a matched controlled study using propensity score analysis. Cardiovasc Interv Radiol. 2017;40(2):270–6.
26. Maybody M, et al. Autologous blood patch injection versus hydrogel plug in CT-guided lung biopsy: a prospective randomized trial. Radiology. 2018;290(2):547–54.
27. Zidulka A, et al. Position may stop pneumothorax progression in dogs. Am Rev Respir Disease. 1982;126(1):51–3.
28. Khanorkar S. Mechanics of respiration. In: Khanorkar S, editor. Insights into physiology. London: JP Medical Ltd; 2012.
29. Khosla R, McLean AW, Smith JA. Ultrasound-guided versus computed tomography-scan guided biopsy of pleural-based lung lesions. Lung India Official Organ Indian Chest Soc. 2016;33(5):487.