



Comparative Effectiveness of Interventions in Initial Management of Spontaneous Pneumothorax: A Systematic Review and a Bayesian Network Meta-analysis

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Study objective: The best initial strategy for nontension symptomatic spontaneous pneumothorax is unclear. We performed a systematic review and meta-analysis to identify the most efficacious, safe, and efficient initial intervention in adults with nontension spontaneous pneumothorax.

Methods: MEDLINE, Scopus, Web of Science, and [ClinicalTrials.gov](https://www.clinicaltrials.gov) were searched from January 1950 through December 2019 (print and electronic publications). Randomized controlled trials evaluating needle aspiration, narrow-bore chest tube (<14 F) with or without Heimlich valve insertion, and large-bore chest tube (≥ 14 F) insertion in spontaneous pneumothorax were included. Network meta-analyses were performed with a Bayesian random-effects model.

Results: Twelve studies were included in this review (n=781 patients). Analyses of efficacy (n=12 trials) revealed no significant differences between the interventions studied: narrow- versus large-bore chest tubes, odds ratio (OR) 1.05 (95% credible interval [CrI] 0.38 to 2.87); large-bore chest tube versus needle aspiration, OR 1.25 (95% CrI 0.65 to 2.62); and narrow-bore chest tube versus needle aspiration, OR 1.32 (95% CrI 0.54 to 3.42). Analyses of safety (n=10 trials) revealed a significant difference between needle aspiration and large-bore chest tube interventions: OR 0.10 (95% CrI 0.03 to 0.40). No differences were observed in needle aspiration versus narrow-bore chest tube (OR 0.29 [95% CrI 0.05 to 1.82]), and narrow- versus large-bore chest tube comparisons (OR 0.35 [95% CrI 0.07 to 1.67]). Analyses of efficiency were not pursued because of variation in reporting the length of stay (n=12 trials). Narrow-bore chest tube (<14 F) had the highest likelihood of top ranking in terms of immediate success (surface under the cumulative ranking curve=64%). Needle aspiration had the highest likelihood of top ranking in terms of safety (surface under the cumulative ranking curve=95.8%).

Conclusion: In the initial management of nontension spontaneous pneumothorax, the optimal strategy between the choices of a narrow-bore chest tube (<14 F, top ranked in efficacy) and needle aspiration (top ranked in safety) is unclear. Complications were more common in large-bore chest tube (≥ 14 F, including 14-F tube) insertions compared with needle aspiration. [Ann Emerg Med. 2020;76:88-102.]

Please see page 89 for the Editor's Capsule Summary of this article.

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INTRODUCTION

In 2014, spontaneous pneumothorax accounted for \$1.4 billion in inpatient charges in the United States ("national bill," derived from the Healthcare Cost and Utilization Project's analytic tool [HCUPnet]).¹ Spontaneous pneumothorax is increasingly being considered a single entity,² and the traditional classification (primary versus secondary) of spontaneous pneumothorax is being challenged because of the high prevalence of parenchymal disease^{3,4} in patients with primary spontaneous pneumothorax.

Current guidelines recommend needle aspiration,⁵ insertion of a narrow-bore chest tube (<14 F)⁵ with or without a Heimlich valve, and, in some scenarios, insertion of a large-bore chest tube (≥ 14 F)⁶ as strategies for the initial management of symptomatic spontaneous pneumothorax. The British Thoracic Society recommends varied chest tube sizes (8 to 14 F) as the first-line interventions⁵ for secondary spontaneous pneumothorax greater than 2 cm.

Randomized studies (n=2 trials) that included secondary spontaneous pneumothorax cases (n=56) have

Editor's Capsule Summary

What is already known on this topic

A number of alternative strategies are recommended for the initial treatment of spontaneous pneumothorax, but only pairwise comparisons of these have been performed.

What question this study addressed

What are the relative efficacy and safety of needle aspiration, narrow-bore chest tube (<14 F), and large-bore chest tube (\geq 14 F)?

What this study adds to our knowledge

This network meta-analysis of 781 patients in 12 studies found no significant difference in efficacy among the 3 treatment modalities. Complications were greater with large-bore chest tube than needle aspiration.

How this is relevant to clinical practice

These findings support the choice of needle aspiration as first-line treatment, but clinicians should continue to consider pneumothorax size, history, resource availability, and cost when making management decisions.

demonstrated the utility of needle aspiration in the initial management of secondary spontaneous pneumothorax, challenging existing beliefs.^{7,8} A randomized study reported since the publication of the British Thoracic Society guidelines has demonstrated the promise of the narrow-bore chest tube (12 F) with a Heimlich valve in promoting ambulatory management of primary spontaneous pneumothorax.⁹ The best initial strategy for nontension symptomatic spontaneous pneumothorax therefore remains unclear.^{5,6,10,11} Additionally, widespread variation exists in initial approaches to nontension symptomatic spontaneous pneumothorax.¹²⁻¹⁴

A systematic review and a network meta-analysis were therefore undertaken to define the most efficacious, safe, and efficient initial intervention in nontension symptomatic spontaneous pneumothorax. Needle aspiration, narrow-bore chest tube (<14 F), and large-bore chest tube (\geq 14 F) insertion were compared. In this study, we defined a large-bore chest tube as greater than or equal to 14 F (including 14-F pigtail catheters) in keeping with the British Thoracic Society definition of a narrow-bore chest tube (<14 F).⁵ We opted for a network meta-analysis, given that simultaneous comparison of 3 or

more interventions is not possible in a traditional pairwise meta-analysis. Network meta-analysis has the additional advantage of ranking treatments when the ideal choice is unclear.^{15,16}

MATERIALS AND METHODS

A systematic review of studies published in print between January 1, 1950, and September 1, 2019, and electronically published between September 2, 2019, and December 31, 2019, was performed according to searches of MEDLINE, Scopus, Web of Science, and ClinicalTrials.gov databases. The search was last performed on September 1, 2019. Results were not restricted according to language. Approval from the institutional review board was unnecessary because this was a systematic review of published literature and did not involve human subjects.

Selection of Participants

Inclusion and exclusion criteria were framed before the implementation of the search strategy, and the study was registered with the International Prospective Register of Systematic Reviews (PROSPERO).¹⁷ To evaluate the most effective, safe, and efficient initial intervention in symptomatic nontension spontaneous pneumothorax, we included randomized controlled studies based on the following PICO criteria: population included adults (\geq 18 years) presenting with symptomatic nontension spontaneous pneumothorax; intervention/comparator included needle aspiration, narrow-bore chest tube (<14 F),⁵ and large-bore chest tubes, including 14-F pigtail catheters (\geq 14 F); and outcomes included immediate success, length of stay, and complications. Immediate success was used to define effectiveness, length of stay was used to define efficiency, and the risk of complications was used to define safety in our analyses.

Immediate success was defined as the following in each group using both radiologic and patient-centered nonradiologic outcomes:

- a) Resolution of symptoms and complete or near-complete immediate re-expansion (size of residual pneumothorax used to define expansion according to the individual study's authors), with sustained success at 6 to 24 hours postaspiration in the needle aspiration group
- b) Complete or near-complete re-expansion of the lung, absence of air leak, and chest tube removal in less

than 7 days in narrow- and large-bore chest tube groups

- c) The ability to discharge the patient from the emergency department (ED) after narrow-bore chest tube insertion or needle aspiration

Complications were defined as either of the following: infection (exit site, empyema, wound infection, or pneumonia), bleeding, subcutaneous emphysema, hemothorax, re-expansion pulmonary edema, death, tension pneumothorax, tube blockage, and need for reinsertion of a chest tube.

We excluded studies lacking the mention of a randomized design, lacking chest tube size, lacking an appropriate comparator, or having a contradictory description of the study technique.

Outcome Measures

The primary outcome measured in this systematic review was immediate success, and the secondary outcomes were the length of stay and risk of complications (see aforementioned definitions).

Two authors (S.R.M. and J.D.) used the Cochrane Collaboration's tool¹⁸ to characterize the risk of bias as low, high, or unclear.

Data Collection and Processing and Primary Data Analysis

An Internet-based platform (Covidence Systematic Review software; Veritas Health Innovation, Melbourne, Australia) was used for electronic importing and automatic exclusion of duplicate search results. Screening of abstracts and full-text screening phases were subsequently performed. Non-English publications were translated by an academic language translation service.¹⁹ The primary authors were contacted if clarifications were needed in regard to the published data.

Traditional meta-analyses have a significant limitation of allowing only pairwise comparisons (eg, narrow-bore tube versus needle aspiration). In contrast, network meta-analysis allows simultaneous comparison of multiple regularly used treatments (needle aspiration versus narrow-bore chest tube versus large-bore chest tube) and is therefore considered a valuable tool in comparative effectiveness research.^{20,21}

We chose a Bayesian approach with a random-effects prior informative model for these analyses.²² Bayesian methods are widely used in health outcomes evaluations.²² Traditional random-effects analyses have the limitation of

not considering the uncertainty in the estimate of the between-study variance.²³ This uncertainty is particularly significant when a systematic review results in a small number of included studies.²³ Bayesian prior informative approaches account for this uncertainty by using prior distributions for the between-study variance derived from external evidence. Such informative prior distributions relevant to a variety of settings were constructed in accordance with the analyses of 14,886 published meta-analyses from the Cochrane Database of Systematic Reviews and are available for use.²³

For dichotomous outcomes (immediate success and complications), we used WinBUGS (version 1.4.3; Medical Research Council Biostatistics Unit, University of Cambridge, Cambridge, UK) in a Microsoft Excel-based graphic user interface (NetMetaXL, version 1.6.1; Canadian Agency for Drugs and Technologies in Health, Ottawa, Canada).²⁴

For continuous outcomes (length of stay), we planned analysis with JAGS (version 4.3.0; Lyon, France²⁵ in rjags (version 3-10)²⁶ and gemtc packages (version 0.8-2)²⁷ in an R-language-based graphic user interface (GeMTC).²⁷

WinBUGS and JAGS are Bayesian graphic modeling programs that use Markov chain Monte Carlo methods. These methods are simulation based and repeatedly generate random samples that characterize the distribution of parameters of interest, using informative prior distributions.²⁸

Network geometry for each outcome was visualized. Subsequently, Markov chain Monte Carlo simulations were performed. Outcomes were measured as odds ratios (ORs) along with 95% credible intervals (CrIs) for categoric outcomes (immediate success and risk of complications) and mean difference for continuous outcomes (length of stay). Forest plots were generated for graphic comparison of effect sizes. Relative rankings of interventions for the outcomes were presented as their surface under the cumulative ranking curve (SUCRA) values. SUCRA values range from 0% to 100% and represent the likelihood of an intervention's being in the top rank for the respective outcomes.^{21,29} For this study's outcomes, higher SUCRA scores (closer to 100%) represent higher associated immediate success rates, and lower length of stay and lower risk of complications. Such ranking analyses can potentially assist clinicians in offering patients choices among multiple treatment options.²¹ We present additional details in regard to search strategy, data extraction, Markov chain Monte Carlo simulation, assessment of

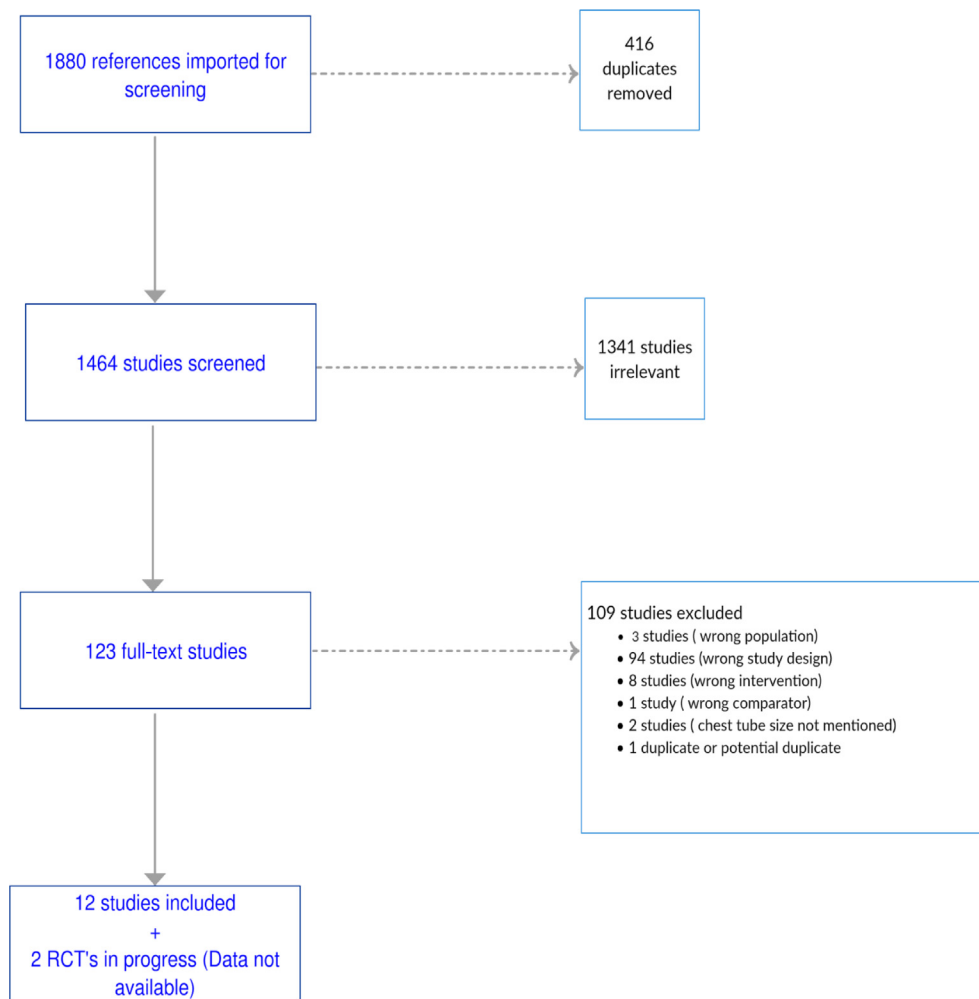


Figure 1. Flow of the study selection process. RCT, Randomized controlled trial.

inconsistency, and evaluation of confidence methodology in the [supplementary material](http://www.annemergmed.com) (available online at <http://www.annemergmed.com>).

RESULTS

The initial search identified 1,880 possible studies. We included 12 studies^{7-9,30-38} in the network meta-analysis. [Figure 1](http://www.annemergmed.com) describes the sequential process. A summary of excluded randomized studies is provided in [Table E3](http://www.annemergmed.com) (available online at <http://www.annemergmed.com>). Attempts at personal communication resulted in additional information for 3 studies.^{7,33,39} Two non-English publications^{34,36} were translated.

[Table 1](http://www.annemergmed.com) describes the characteristics of the network. [Table 2](http://www.annemergmed.com) summarizes the key characteristics of the included studies. Additional data (rates of success, response to failure, rates, and descriptions of complications in each arm of the included studies) are presented in [Table 3](http://www.annemergmed.com). Exclusion criteria used in the included studies are described in

[Table E2](http://www.annemergmed.com) (available online at <http://www.annemergmed.com>). [Figure 2A](http://www.annemergmed.com) and [B](http://www.annemergmed.com) display the network geometry of trials (ie, a single closed loop consisting of 3 nodes, representing the 3 interventions studied). Assessments of risk of bias of the included studies are listed in [Table E1](http://www.annemergmed.com) (available online at <http://www.annemergmed.com>). Most studies varied in terms of risk of bias in the random-sequence generation and allocation concealment domains.

All 12 included studies reported the outcome of immediate success and were analyzed ([Figure 2A](http://www.annemergmed.com), [Figure E3](http://www.annemergmed.com), available online at <http://www.annemergmed.com>). When compared with needle aspiration (n=4 trials, 190 patients), a narrow-bore chest tube had an OR of 1.32 (95% CrI 0.54 to 3.42). In comparison with needle aspiration (n=6 trials, 512 patients), large-bore chest tube had an OR of 1.25 (95% CrI 0.65 to 2.62). Compared with a large-bore chest tube (n=2 trials, 79 patients), a narrow-bore chest tube had an OR of 1.05 (95% CrI 0.38 to 2.87). None of these comparisons revealed a significant

Table 1. Characteristics of the network.

| Attribute | N (%) |
|--|----------|
| Patients, n | 781 |
| Men | 661 (85) |
| Primary spontaneous pneumothorax | 660 (85) |
| Smoking (current or history)* | 369 (57) |
| Right-sided pneumothorax* | 403 (56) |
| Intervention | |
| Needle aspiration | 346 (44) |
| Narrow-bore chest tube with Heimlich/suction | 137 (18) |
| Large-bore chest tube | 298 (38) |

Data are expressed as No. (%) unless otherwise specified.

*Missing data on smoking prevalence (Ma et al,³⁴ Oh et al,³⁶ and Roggia et al³⁸) and laterality of pneumothorax (Andrivet et al⁸). These studies were excluded from the prevalence calculation of these characteristics.

difference in point estimates (ie, 95% CrI included the value of 1) (Figure 3A).

When treatments were ranked, a narrow-bore chest tube had the highest likelihood of being top ranked for immediate success (SUCRA=64.0%), followed by a large-bore chest tube (SUCRA=60.7%) and needle aspiration (SUCRA=25.2%) (Figure 4, Figure E4, available online at <http://www.annemergmed.com>).

Visualization of the inconsistency plot (Figure E6, available online at <http://www.annemergmed.com>) did not reveal points in the bottom right of the plot, indicating the absence of potential inconsistency. Confidence in point estimates for large- versus narrow-bore chest tube and needle aspiration versus narrow-bore tube comparisons was high and downgraded to moderate for large-bore chest tube versus needle aspiration comparisons (because of major concerns about within-study bias) (Table E4, available online at <http://www.annemergmed.com>). We rated overall confidence in our ranking as high.

Ten studies^{7,9,30-33,35-38} reported complications and were analyzed accordingly (Figure 2B, Figure E3, available online at <http://www.annemergmed.com>). Compared with narrow-bore chest tube (n=3 trials, 144 patients), needle aspiration had an OR of 0.29 (95% CrI 0.05 to 1.82). Compared with a large-bore chest tube (n=5 trials, 450 patients), needle aspiration had an OR of 0.10 (95% CrI 0.03 to 0.40). Compared with a large-bore chest tube (n=2 trials, 79 patients), a narrow-bore chest tube had an OR of 0.35 (95% CrI 0.07 to 1.67). Our analyses suggested the odds of complications were 90% less in the needle aspiration group compared with the large-bore chest tube group (Figure 3B). There were no significant differences in point estimates of needle aspiration versus narrow-bore

chest tube and narrow- versus large-bore chest tube comparisons (Figure 3B).

When treatments were ranked, needle aspiration had the highest likelihood of being top ranked in terms of safety (SUCRA=95.8%), followed by narrow-bore chest tube (SUCRA=49.7%) and large-bore chest tube (SUCRA=4.4%) (Figure 4, Figure E5, available online at <http://www.annemergmed.com>).

Visualization of the inconsistency plot (Figure E7, available online at <http://www.annemergmed.com>) did not reveal points in the bottom right of the plot, indicating the absence of potential inconsistency. Confidence in point estimates for large- versus narrow-bore chest tube and needle aspiration versus narrow-bore chest tube comparisons was high (Table E5, available online at <http://www.annemergmed.com>). For the large-bore chest tube versus needle aspiration comparison, we downgraded confidence to low (concerns in regard to within-study bias and heterogeneity) (Table E5, available online at <http://www.annemergmed.com>). We rated our overall confidence in the ranking of safety as moderate.

The 12 included studies reported the measures of the central tendency of the outcome (length of stay). Because of the nonnormal distribution of this outcome, there was wide variation in reporting of the measures of the central tendency and dispersion. Studies variably reported the central tendency and its dispersion as median (interquartile range),^{7,9,32} mean±SD,^{8,30,35,37,38} mean only,³⁴ or mean±standard error,³¹ or in an unclear fashion.^{33,36} Two studies required having hospitalization before or after successful minimally invasive interventions.^{8,32} Because of these significant limitations, we did not pursue further analyses of length of stay.

LIMITATIONS

One limitation of our analytic model is that it did not include watchful waiting because no randomized studies were reported that used this strategy (one study is currently in progress).⁴⁰ Additionally, analyses of efficiency were not possible owing to wide variation in reporting of length of stay. Authors used various definitions of immediate success, leading to risk of heterogeneity in describing outcomes. For example, patient-centered outcomes, such as the ability to be discharged from the ED or hospital, were used as an additional definition of success by some authors. We do not consider this a significant limitation to the analyses because patient-centered nonradiologic outcomes are increasingly used to define success^{41,42} in pleural disease research. Additional limitations included a relatively small sample of patients who underwent narrow-bore chest tube

Table 2. Characteristics of included studies.

| Study, Year | Population | Intervention | Comparison | Primary Outcome | Secondary Outcomes | Follow-up Duration |
|------------------|---|---|--|--|---|--|
| Kim, 2019 | PSP >25% size presenting to a Korean University hospital. PSP patients accounted for 100% (n=40/40) of the study sample. | 16-G* needle aspiration (n=21) followed by at least 12 h inpatient observation. 2 attempts before failure declared. | 12-F chest tube insertion (n=19) and connection to an underwater seal. Admitted for observation. | Immediate success rate | 1-mo recurrence rate 1-y recurrence rate Length of stay | Hospitalization followed by 1-mo and 1-y follow-up |
| Ramouz, 2018 | Symptomatic PSP (≥18 y) who presented to 2 Iranian university hospitals. PSP patients accounted for 100% (n=70/70) of the sample. | 16-G* aspiration (n=35) followed by 6-h observation. 2 attempts before failure declared. | 16-F/20-F chest tube insertion (n=35) and inpatient observation | Immediate success rate | Pain intensity Length of stay 1-y recurrence rate Complications | Hospitalization followed by 1-y follow-up |
| Thelle, 2017 | Symptomatic (OR) >20% size SSP (OR) >30% size PSP patients presenting to 3 Norwegian teaching hospitals. PSP patients accounted for 62% (n=79/127) of the study sample. | 16-G* needle aspiration (n=64) and inpatient observation. 2 attempts before failure declared. | Large-bore chest tube insertion (n=63) [†] and inpatient observation (14–20 F were the most common sizes) | Duration of hospital stay | Rates of immediate success, 1-wk success, and complications | Hospitalization and short-term outpatient follow-up (7–10 days) postdischarge |
| Korczyński, 2015 | First/second episode of PSP or SSP with symptoms and an intrapleural distance of 2 cm on chest radiograph presenting to a Polish teaching hospital. PSP patients accounted for 69% (n=34/49) of the study sample. | 8-F chest tube drainage (n=22) and if needed a Heimlich valve was inserted. Inpatient observation ensued. | 20- to 24-F chest tube drainage (n=27) and admitted to the hospital for observation | Rate of success, duration of chest tube drainage, and need for surgery | Length of stay, procedure safety, and rate of success of second-line treatment for initial treatment failures | Hospitalization. No outpatient follow-up mentioned. |
| Parlak, 2012 | First episode of PSP/TP evaluated in the ED (OR) Asymptomatic ≥20% size in patients aged 18–85 y presenting to a Dutch hospital. PSP patients accounted for 61% (n=34/56) of the study sample. | 3.9-F (1.3-mm) needle aspiration (n=25) and inpatient observation for 24 h. No further attempts if initial aspiration unsuccessful. | 8-F [‡] chest tube insertion (n=31) with connection to a drainage system. Inpatient observation ensued. | Duration of hospital stay | Rates of immediate success | Hospitalization followed by short-term outpatient follow-up (7 days). Long-term follow-up 1 y after discharge. |

Table 2. Continued.

| Study, Year | Population | Intervention | Comparison | Primary Outcome | Secondary Outcomes | Follow-up Duration |
|--------------|--|---|--|---|--|---|
| Ho, 2011 | PSP patients (size >3 cm from the apex) presenting to an acute tertiary care hospital in Singapore serving as a national referral center. PSP patients accounted for 100% (n=48/48) of the study sample. | 16-G needle aspiration (n=23) and if successful at 6-h time frame, patient was discharged for outpatient follow-up. 1-2 attempts before failure declared. | 12-F chest tube with Heimlich valve drainage (n=25) and if successful at 6-h time frame, patient was discharged for outpatient follow-up. | Rates of failure and inpatient admission | Rates of complications and full recovery, length of stay, and satisfaction scores | Hospitalization and 3 days' follow-up after discharge from the ED |
| Ma, 2007 | First-episode PSP or SSP patients presenting to a Chinese teaching hospital. PSP patients accounted for 80% of the study sample (n=37/46). | Needle aspiration (n=23) and admitted to the hospital. 5 attempts permitted until failure declared. | 6.3-F chest tube inserted (n=23) and initial aspiration followed by aspiration every 12 h until no more air could be aspirated. Continuous drainage during aspiration intervals. Admitted to the hospital. | Rates of success | Length of stay and costs | Hospitalization and then at 1 wk |
| Ayed, 2006 | Symptomatic (OR) >20% size PSP patients with their first presentation to a tertiary care chest hospital in Kuwait. PSP patients accounted for 100% (n=137/137) of the study sample. | 16-G* needle aspiration (n=65) until the cessation of air leak and, if successful, patient was discharged. 2-needle aspirations before failure declared. | 20-F chest tube inserted (n=72) for 24 h and further evaluation in the hospital | Rate of immediate success | Rates of 1-wk success, hospitalization, complications, inability to work, and length of stay | 1 wk and 3, 6, 12, and 24 mo postdischarge. Earlier if indicated. |
| Oh, 2003 | First-episode PSP patients with 25%-80% pneumothorax size and unstable vital signs who sought care in the ED of a South Korean teaching hospital. PSP patients accounted for 100% of the study sample (n=57/57). | 18-G ^S needle aspiration (n=30) and admitted to the hospital. 2 attempts before failure declared. | 28-F chest tube inserted (n=27) and admitted to the hospital | Rate of success | Length of stay, rates of 3-mo recurrence, urgent readmission, and complications | Hospitalization and then at 1 wk and 1 and 3 mo postdischarge. Earlier when symptoms emerged. |
| Noppen, 2002 | First-episode symptomatic (OR) >20% size PSP patients presenting to a tertiary care teaching hospital and 4 regional hospitals in Belgium. PSP patients accounted for 100% (n=60/60) of the study sample. | 16-G* needle aspiration (n=27) and, if successful, patient was discharged for outpatient follow-up. 2 attempts before failure declared. | 16-F/20-F chest tube inserted (n=33) and further evaluation in the hospital | Rates of immediate, 1-wk, and 1-y success | Rates of hospitalization, length of stay, and safety | Hospitalization and at 48 h, 1 wk, and 2, 6, and 12 mo postdischarge. Earlier when indicated. |

| | | | | | | |
|----------------|---|---|--|--|--|---|
| Roggla, 1996 | Symptomatic patients presenting to the ED of a university hospital in Vienna, Austria. PSP patients accounted for 36% (n=11/30) of the study sample. | 13-F chest tube insertion (n=17) followed by immediate chest radiograph. Offered outpatient management if lung expanded. | 14-F chest tube insertion (n=13) and connected to an underwater seal. All patients hospitalized. Removed if lung stayed expanded for 24 h. | Rates of success at immediate postinsertion and 24- and 48-h postinsertion periods | Duration of drainage, No. of outpatient management events, and duration of hospitalization | Hospitalization |
| Andrivet, 1995 | Adults with the first episode or first recurrence of spontaneous pneumothorax presenting to 4 teaching hospitals in France. PSP patients accounted for 87% (n=53/61) of the study sample. | 16-G*/18-G [§] needle aspiration (n=33) immediately for patients with symptoms and signs of poor tolerance and after 3 days in patients with good tolerance. 2 attempts before failure declared. | 20-F chest tube inserted (n=28) and further evaluation in the hospital | Rates of success and 3-mo recurrence rate | Length of stay, pain and dyspnea scores | Hospitalization and in the clinic and by mail |

PSP, Primary spontaneous pneumothorax; SSP, secondary spontaneous pneumothorax; TP, traumatic pneumothorax.

Definitions of success are as follows:

- Kim, 2019: Residual pneumothorax less than or equal to 25% on chest radiograph obtained immediately after needle aspiration and no signs of worsening on a follow-up on chest radiograph 12 hours later. Two attempts allowed in accordance with study protocol. Complete expansion on chest radiograph, absence of air leak, and removal of chest tube within 5 days of chest tube insertion.
- Ramouz, 2018: Resolution of symptoms and pneumothorax (<20%) on a follow-up 6-h chest radiograph obtained after needle aspiration. Absent air leak with symptom resolution or residual pneumothorax less than 10% within 24 hours of insertion of chest tube.
- Thelle, 2017: Resolution of symptoms and complete/near-complete re-expansion (<20% residual pneumothorax) of the lung immediately and at 6 hours postaspiration (maximum of 2 needle aspirations) in needle aspiration group. Complete/near complete re-expansion of the lung (<10% residual pneumothorax), absence of air leak, and chest tube removal within 3 days in the chest tube group.
- Korczyński, 2015: Complete/near complete re-expansion of the lung and absent air leak within 5 days in the narrow-bore chest tube group. Complete/near complete re-expansion of the lung and absent air leak within 7 days in the chest tube group.
- Parlak, 2012: Complete expansion after the first attempt with discharge after 24 hours in the needle aspiration group. Complete expansion of the lung, absent air leak, chest tube removal, and ability to discharge the patient within 72 hours.
- Ho, 2011: Complete/near complete re-expansion of the lung (up to 10% residual pneumothorax) demonstrated immediately and at 6 hours after needle aspiration. Complete/near complete re-expansion of the lung (up to 10% residual pneumothorax) or no worsening of the pneumothorax on a chest radiograph performed immediately and at 6 hours after 12-F chest tube and Heimlich valve insertion.
- Ma, 2007: Complete/near complete re-expansion of the lung (<30% residual pneumothorax) or inability to aspirate air through the chest tube 24 hours after the last aspiration through the chest tube. Complete/near complete re-expansion of lung (<30% residual pneumothorax) on the chest radiograph 24 hours after the last needle aspiration.
- Ayed, 2006: Complete/near complete re-expansion of the lung in the needle aspiration group. Complete re-expansion of the lung, an absence of air leak, and chest tube removal within 3 days in the chest tube group.
- Oh, 2003: Able to discharge patients without any further procedures (chest tube insertion in the needle aspiration group; thoracotomy in the chest tube drainage group). Additional criteria of success in the chest tube group required re-expansion of the lung within 72 hours and absent large volume air leak.
- Noppen, 2002: Complete/near complete persistent lung re-expansion immediately after needle aspiration. Complete re-expansion, an absence of air leakage, and removal of the chest tube within 3 days of insertion in the chest tube group.
- Roggla, 1996: Complete or near-complete re-expansion of the lung immediately and at 24 and 48 hours postinsertion. For the purpose of this study, a 48-hour time was selected.
- Andrivet, 1995: Complete or near-complete re-expansion of the lung (<20% residual pneumothorax) or absent recurrent pneumothorax within 24 hours of the last procedure in the needle aspiration group. Lack of persistent air leak after 10 days or absent short-term recurrence requiring a second chest tube in the chest tube group was used to define success in the chest tube group.

*16 G Is equivalent to 5.5 F.

†In one case, a 12-F chest tube was used in accordance with a personal communication with the corresponding author.

‡A 2.7-mm chest tube (equivalent to 8 F) was used in the study in accordance with a personal communication with the study author.

§18 G Is equivalent to 3.8 F.

Table 3. Additional extracted data from included studies.

| Study Name/Year | Treatment | Rates of Success (n/N) | Response to Failure | Complications (n/N) | Description of Complications (n) |
|------------------|------------------------|------------------------|--|---------------------|--|
| Kim, 2019 | Needle aspiration | 17/21 | Second attempt and, if failure, then large-bore chest tube drainage | 0/21 | |
| Kim, 2019 | Narrow-bore chest tube | 12/19 | PAL after 5 days resulted in surgery referral | 0/19 | |
| Ramouz, 2018 | Large-bore chest tube | 24/35 | VATS chemical pleurodesis | 6/35 | Wound infection (1), bleeding (3), SQ emphysema (2) |
| Ramouz, 2018 | Needle aspiration | 19/35 | Second needle aspiration attempt, large-bore chest tube drainage, VATS chemical pleurodesis carried out in applicable sequence | 1/35 | Bleeding (1) |
| Thelle, 2017 | Large-bore chest tube | 20/63 | Large-bore chest tube drainage for 7 days. PAL after this period resulted in surgical referral. | 32/63 | Wound infection (4), bleeding (2), pneumonia (1), empyema (1), death (1), reinsertion (16), SQ emphysema (7) |
| Thelle, 2017 | Needle aspiration | 44/64 | Second needle aspiration attempt followed by large-bore chest tube drainage if needed | 0/64 | |
| Korczyński, 2015 | Large-bore chest tube | 22/27 | PAL after 7 days resulted in surgical referral | 0/27 | |
| Korczyński, 2015 | Narrow-bore chest tube | 14/22 | Insertion of large-bore chest tube for days 6–7 and PAL >7 days resulted in surgery referral | 0/22 | |
| Parlak, 2012 | Narrow-bore chest tube | 25/31 | N/A | 0/31 | |
| Parlak, 2012 | Needle aspiration | 17/25 | Narrow-bore chest tube drainage after initial needle aspiration failure | 0/25 | |
| Ho, 2011 | Needle aspiration | 11/23 | Large-bore chest tube drainage | 2/23 | SQ emphysema (2) |
| Ho, 2011 | Narrow-bore chest tube | 18/25 | Large-bore chest tube drainage | 1/25 | Tension pneumothorax (1) |
| Ma, 2007 | Needle aspiration | 21/23 | Referral to surgery | N/A | |
| Ma, 2007 | Narrow-bore chest tube | 23/23 | Referral to surgery | N/A | |
| Ayed, 2006 | Large-bore chest tube | 49/72 | VATS if PAL >7 days | 5/72 | Tube blockage (2), exit-site infection (1), SQ emphysema (2) |
| Ayed, 2006 | Needle aspiration | 40/65 | Large-bore chest tube drainage after 2 unsuccessful needle aspiration attempts | 1/65 | SQ emphysema (1) |

| | | | | | |
|----------------|------------------------|-------|---|------|--|
| Oh, 2003 | Needle aspiration | 24/30 | Large-bore chest tube drainage after 2 needle aspiration attempts | 0/30 | |
| Oh, 2003 | Large-bore chest tube | 22/27 | Thoracotomy after PAL >72 h | 0/27 | |
| Noppen, 2002 | Needle aspiration | 16/27 | Large-bore chest tube drainage (n=9), immediate pleurodesis (n=2) | 0/27 | |
| Noppen, 2002 | Large-bore chest tube | 21/33 | Thoracoscopy/thoracotomy for PAL >7 days | 0/33 | |
| Roggia, 1996 | Large-bore chest tube | 11/13 | N/A | 4/13 | SQ emphysema (3), need for second reinserion (1) |
| Roggia, 1996 | Narrow-bore chest tube | 15/17 | N/A | 6/17 | SQ emphysema (3), need for second reinserion (3) |
| Andrivet, 1995 | Needle aspiration | 22/33 | Large-bore chest tube drainage | N/A | |
| Andrivet, 1995 | Large-bore chest tube | 26/28 | Thoracoscopy | N/A | |

PAL, Persistent air leak; VATS, video-assisted thoracoscopic surgery; SQ, subcutaneous; N/A, not available.

insertion (Table 1), high risk of bias in the domain of allocation concealment (Tables E1, E4, and E5, available online at <http://www.annemergmed.com>), and lack of data from gray literature, potentially introducing publication bias.⁴³

DISCUSSION

Our analysis found no significant differences in estimates of immediate success when comparing narrow-bore chest tube (<14 F), needle aspiration, and large-bore chest tube (≥14 F) strategies for initial management of symptomatic spontaneous pneumothorax. Needle aspiration was associated with significantly lower odds of complications compared with a large-bore chest tube (≥14 F). There were no significant differences in complications when needle aspiration was compared with a narrow-bore chest tube (<14 F). Our analyses yielded an equivocal interpretation in regard to needle aspiration versus narrow-bore chest tube interventions. Although a narrow-bore chest tube had the highest likelihood (SUCRA of 64%) of being the most efficacious, needle aspiration had the highest likelihood (SUCRA of 95.8%) of being the safest. Our systematic review also confirmed the view of existing guidelines⁵ that large-bore chest tubes offer no clear advantage over minimally invasive interventions.

This review adds to the scant existing comparisons⁴⁴ of more than 2 intervention strategies for spontaneous pneumothorax. Previous systematic reviews were restricted to traditional pairwise analyses (ie, needle aspiration versus chest tube and narrow-versus large-bore chest tubes),^{45,46} lacked newer randomized controlled data,^{44,45,47,48} lacked formal distinction between narrow- and large-bore definitions,^{47,48} and did not include non-English publications.⁴⁸ In a significant departure from earlier studies, we included the 14-F chest tube in the large-bore category. Another distinction was our use of a Bayesian analytic approach, an increasingly preferred method for evaluating health outcomes.

Our results reveal valuable insights and raise crucial questions about initial management of symptomatic spontaneous pneumothorax. First, as evidenced by this review and earlier reports, there is widespread variation in immediate care strategies.^{13,14} Such variation can be explained in part by differing guidelines⁴⁹ and definitions of key attributes (eg, pneumothorax size,⁵⁰ chest tube size). However, it is possible that lack of research comparing the effectiveness of competing interventions (watchful waiting,^{11,51,52} needle

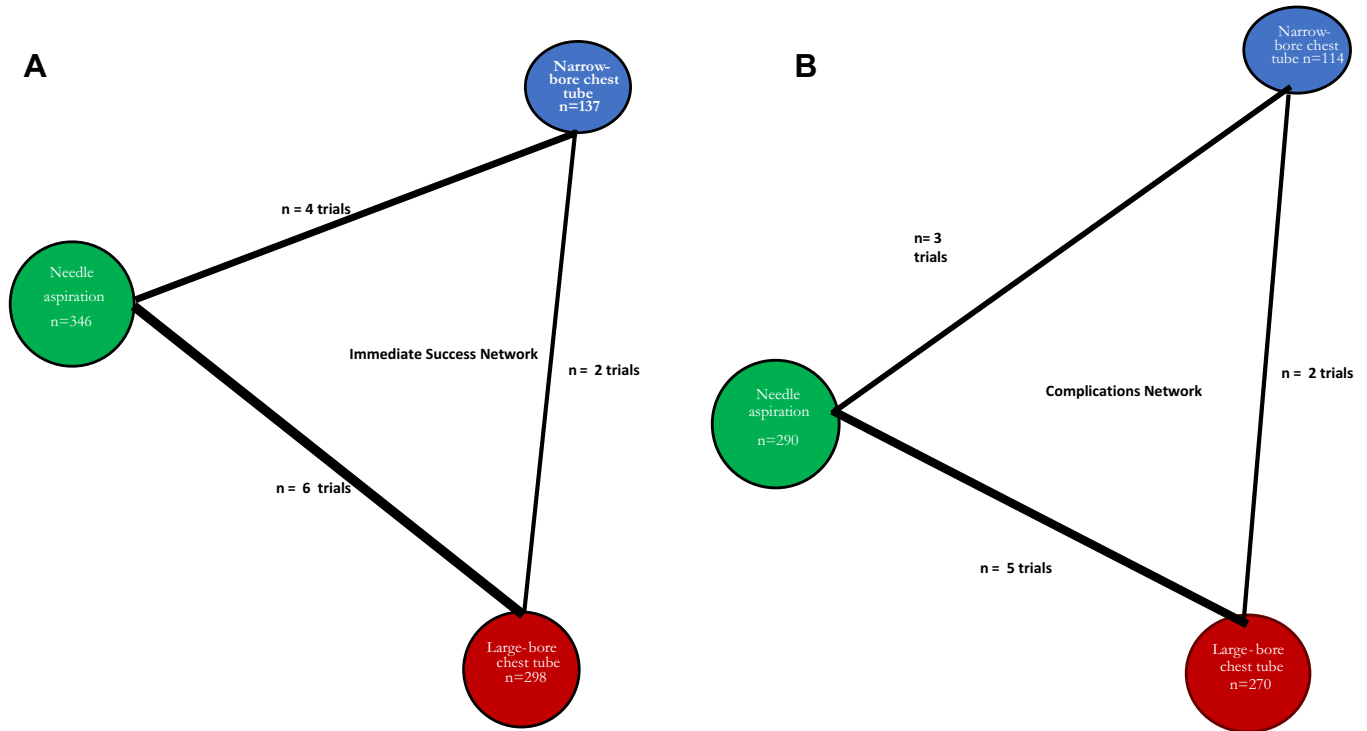


Figure 2. Network plots of intervention comparisons for the outcomes of immediate success and complications. Each circular node corresponds to an intervention, and the node size is proportional to the number of patients assigned to that intervention. Each line represents a direct comparison between interventions, and the thickness of the line is proportional to the number of randomized controlled trials providing data for the comparison.

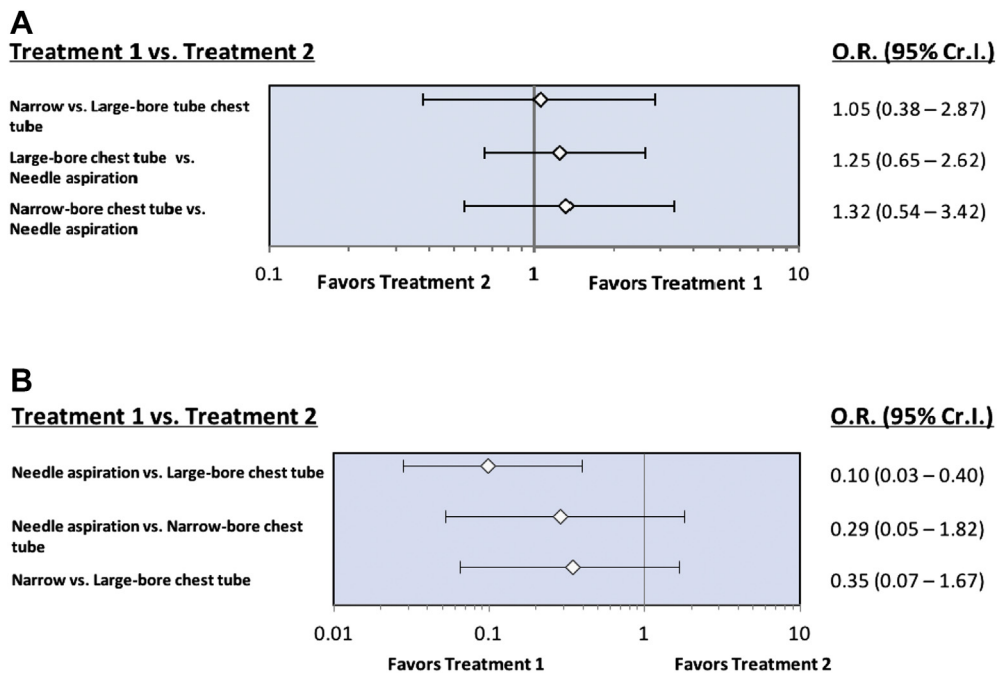


Figure 3. A, Network forest plot showing pairwise estimates of mean ORs (diamonds) and their 95% CrIs (lines) for the outcome of immediate success. B, Network forest plot showing pairwise estimates of mean ORs (diamonds) and their 95% CrIs (lines) for the outcome of major complications.

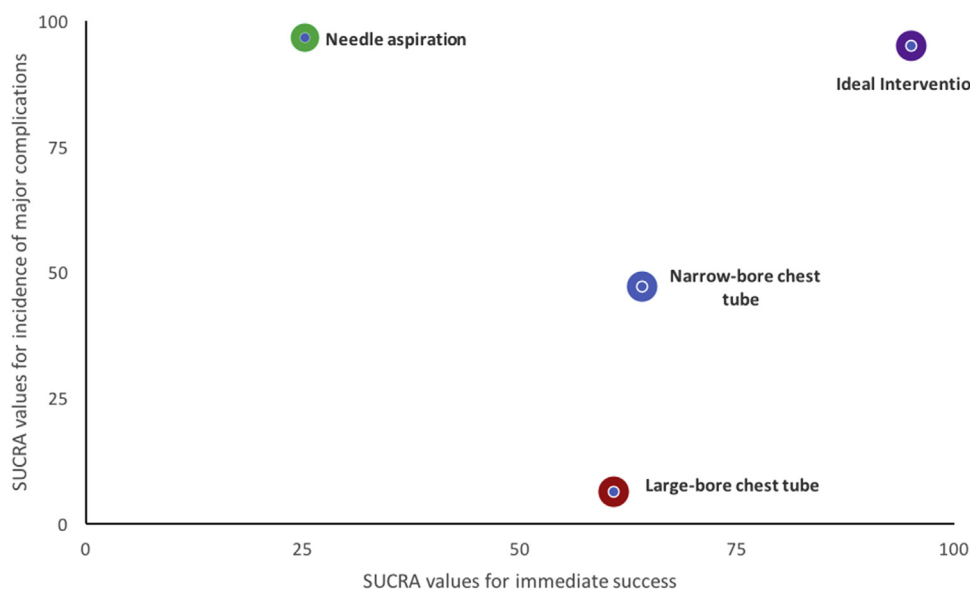


Figure 4. Clustered ranking plot based on cluster analysis of SUCRA (percentage value) for immediate success (efficacy) and risk of complications (safety). A hypothetical ideal intervention (efficacious and safe) is visualized in the upper right corner.

aspiration, and narrow-bore chest tube with Heimlich valve) has contributed to this variation.

Our findings also raised questions about the need for routine intervention (including using minimally invasive interventions, such as needle aspiration) in cases with minimal symptomatic burden. Our network meta-analysis revealed no significant differences in estimates of immediate success between these interventions. It would be worthwhile to compare watchful waiting with needle aspiration and narrow-bore chest tube strategies. In 1966, Stradling and Poole⁵¹ described successful management of spontaneous pneumothorax with watchful waiting. Rates of success were 83% in primary spontaneous pneumothorax (n=68/82) and 55% in secondary spontaneous pneumothorax (n=20/37) in a total of 119 cases.⁵¹ A recent case⁵² has been made for conservative management of large primary spontaneous pneumothorax, based on an Australian center's 15-year experience.¹¹ Fortunately, a large multicenter randomized controlled trial⁴⁰ is under way, examining the role of watchful waiting in cases with minimal symptomatic burden.

In our relative ranking, needle aspiration had the least likelihood of complications and was superior to a large-bore chest tube (≥ 14 F) strategy. This supports the case for needle aspiration as a first-line strategy (including secondary spontaneous pneumothorax) when intervention is indicated (eg, increasing size, high symptom burden). However, needle aspiration requires significant postaspiration observation time. In 2 included studies, patients were observed for 6 to 12 hours before discharge.^{7,31} Given the emphasis on crowding^{53,54}

and care times in the ED, such observation periods are likely impractical and, in some settings, already not permitted.⁵⁵

Furthermore, our findings emphasize the need to study the narrow-bore chest tube strategy in comparison with needle aspiration and watchful waiting. In our relative ranking, the narrow-bore chest tube strategy had the highest likelihood of immediate success (SUCRA 64%). This finding could have been influenced by the use of a composite definition of immediate success. The definition incorporated patient-centered and nonradiologic attributes, such as the ability to be discharged from the ED. Narrow-bore chest tubes with Heimlich valves have the advantage of aiding ambulatory management⁵⁶ and avoid the prolonged observation time needed for needle aspiration,^{57,58} especially in the setting of a well-defined clinical pathway⁵⁹ for pleural disease management.

The risk of complications with narrow-bore chest tubes did not differ significantly from that of large-bore chest tubes in our analysis. We propose 2 likely explanations. Of the 6 included randomized controlled trials^{9,30,32-34,38} that studied narrow-bore chest tube interventions, only 2 discharged patients from the ED after confirming immediate success.^{9,38} The rest of the trials routinely admitted patients, raising the risk of hospitalization-related complications. A second explanation is that current iterations of commercially available stand-alone Heimlich valves (used in 2 trials included in the analyses)^{9,32} have design issues,⁶⁰ which can lead to potentially life-threatening consequences.⁶⁰⁻⁶² We recommend redesign of the stand-alone Heimlich valve before its role is studied.

Design iterations should incorporate mistake proofing to prevent errors in attaching the valve to the chest tube, a significant source of error.⁶³ With a redesign, there is potential for narrow-bore chest tubes to move into the upper right corner (improved safety while retaining efficacy) shown in Figure 4. Two such devices with integrated Heimlich valve design^{56,64} are now available, and favorable economic and safety outcomes have been described with one device⁶⁵ in nonrandomized settings. A randomized controlled trial comparing a narrow-bore chest tube (integrated Heimlich valve) with needle aspiration is under way in the United Kingdom.⁶⁴

In this network, 85% of the patients had primary spontaneous pneumothorax, suggesting additional studies are needed for secondary spontaneous pneumothorax. Although needle aspiration is not a traditional first-line intervention in secondary spontaneous pneumothorax, a 2017 study⁷ demonstrated in a randomized fashion that needle aspiration results in a shorter length of stay and higher efficacy in secondary spontaneous pneumothorax compared with a large-bore chest tube. In 2019, Khan et al⁵⁸ described their nonrandomized experience of efficient and successful ambulatory management of secondary spontaneous pneumothorax (rates of success $n=32/65$) with a narrow-bore chest tube with an integrated Heimlich valve.

The strengths of this analysis include a robust search strategy, well-defined population, inclusion of non-English publications, personal communication with study authors, and adherence to a priori inclusion and exclusion criteria, published in a well-known international register of systematic reviews.¹⁷ A seminal randomized study (Harvey and Prescott³⁹) comparing needle aspiration with large-bore chest tube insertion was not included in our model because of absent outcomes for the large-bore chest tube group, as confirmed by our communication with the study author. We based our decision on our a priori published, rigorous inclusion/exclusion criteria.¹⁷ One may question the definition of large-bore chest tubes (≥ 14 F, including 14-F pigtail catheters) and the inclusion of large-bore chest tubes in our analytic model. However, we based this definition on the British Thoracic Society criterion of less than 14 F for defining narrow-bore chest tubes.⁵ In our clinical experience, insertion of a commercially available 14-F chest tube (eg, Wayne pneumothorax catheter) is more invasive (ie, requiring a guidewire and a dilator) than inserting 8- to 11-F chest tubes. A 14-F (4.67-mm) chest tube's diameter is almost twice that of a commercially available 8-F (2.67-mm) narrow-bore chest tube, supporting our decision.

We believe the inclusion of a large-bore chest tube (≥ 14 F) in our model is clinically relevant because it mirrors actual practice, in which it is common to use a 14-F pigtail catheter for symptomatic management. Definitive elective interventions for recurrent disease, such as video-assisted thoracoscopic surgery and chemical pleurodesis, were excluded because they are inherently different (ie, unlikely to be first-line interventions even in recurrent symptomatic spontaneous pneumothorax presenting to the ED). This exclusion contributes to maintaining the assumption of "transitivity" in our analyses, a crucial prerequisite²⁰ in network meta-analyses.

In summary, our systematic review and network meta-analyses of published randomized controlled trials in symptomatic adult spontaneous pneumothorax shows that a narrow-bore chest tube (<14 F) with or without a Heimlich valve has the highest likelihood of being top ranked for the outcome of immediate success, whereas needle aspiration has the highest likelihood of being top ranked for safety. It also confirmed that large-bore chest tubes (including 14-F chest tubes) offer no advantage over narrow-bore chest tubes (<14 F) or needle aspiration in the initial management of symptomatic spontaneous pneumothorax. It remains unclear whether narrow-bore chest tube insertion or needle aspiration is the best (most effective and safest) initial strategy. Future studies evaluating watchful waiting, needle aspiration, and narrow-bore chest tube with a Heimlich valve with improved design (ie, integrated Heimlich valve) are needed.

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REFERENCES

1. HCUPnet. *Healthcare Cost and Utilization Project (HCUP) 2014*. Rockville, MD: Agency for Healthcare Research & Quality; 2014. Available at: <http://hcupnet.ahrq.gov/>. Accessed February 22, 2017.
2. Bintcliffe OJ, Hallifax RJ, Edey A, et al. Spontaneous pneumothorax: time to rethink management? *Lancet Respir Med*. 2015;3:578-588.
3. Cottin V, Streichenberger N, Gamondes JP, et al. Respiratory bronchiolitis in smokers with spontaneous pneumothorax. *Eur Respir J*. 1998;12:702-704.
4. Bintcliffe OJ, Edey AJ, Armstrong L, et al. Lung parenchymal assessment in primary and secondary pneumothorax. *Ann Am Thorac Soc*. 2016;13:350-355.
5. MacDuff A, Arnold A, Harvey J; Group BTS/DPG. Management of spontaneous pneumothorax: British Thoracic Society pleural disease guideline 2010. *Thorax*. 2010;65(Suppl 2):ii18-ii31.
6. De Leyn P, Lisonde M, Ninane V, et al. Guidelines on the management of spontaneous pneumothorax. *Acta Chir Belg*. 2005;105:265-267.
7. Thelle A, Gjerdevik M, SueChu M, et al. Randomised comparison of needle aspiration and chest tube drainage in spontaneous pneumothorax. *Eur Respir J*. 2017;49:1601296.
8. Andrivet P, Djedaini K, Teboul JL, et al. Spontaneous pneumothorax. Comparison of thoracic drainage vs immediate or delayed needle aspiration. *Chest*. 1995;108:335-339.
9. Ho KK, Ong ME, Koh MS, et al. A randomized controlled trial comparing minichest tube and needle aspiration in outpatient management of primary spontaneous pneumothorax. *Am J Emerg Med*. 2011;29:1152-1157.
10. Baumann MH, Strange C, Heffner JE, et al. Management of spontaneous pneumothorax: an American College of Chest Physicians Delphi consensus statement. *Chest*. 2001;119:590-602.
11. Simpson G. Spontaneous pneumothorax: time for some fresh air. *Intern Med J*. 2010;40:231-234.
12. Iepsen UW, Ringbaek T. Management of pneumothorax differs across Denmark. *Dan Med J*. 2014;61:A4803.
13. Kelly AM, Clooney M; Spontaneous Pneumothorax Australia Study G. Deviation from published guidelines in the management of primary spontaneous pneumothorax in Australia. *Intern Med J*. 2008;38:64-67.
14. Contou D, Schlemmer F, Maitre B, et al. Management of primary spontaneous pneumothorax by intensivists: an international survey. *Intensive Care Med*. 2016;42:1508-1510.
15. Dobler CC, Wilson ME, Murad MH. A pulmonologist's guide to understanding network meta-analysis. *Eur Respir J*. 2018;52:1800525.
16. Dias S, Caldwell DM. Network meta-analysis explained. *Arch Dis Child Fetal Neonatal Ed*. 2019;104:F8-F12.
17. de Longpre J, Mummadi S, Hahn P. *Initial Management of Spontaneous Pneumothorax: A Systematic Review & Network Meta-Analysis*. York, UK: Centre for Reviews & Dissemination, University of York; 2017. Available at: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=76856. Accessed June 20, 2018.
18. Higgins JP, Altman DG, Gotzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*. 2011;343:d5928.
19. Academic Language Experts. Academic translation. Available at: <https://www.aclang.com/>. Accessed July 12, 2018.
20. Rouse B, Chaimani A, Li T. Network meta-analysis: an introduction for clinicians. *Intern Emerg Med*. 2017;12:103-111.
21. Mbuagbaw L, Rochweg B, Jaeschke R, et al. Approaches to interpreting and choosing the best treatments in network meta-analyses. *Syst Rev*. 2017;6:79.
22. Lu G, Ades AE. Combination of direct and indirect evidence in mixed treatment comparisons. *Stat Med*. 2004;23:3105-3124.
23. Turner RM, Davey J, Clarke MJ, et al. Predicting the extent of heterogeneity in meta-analysis, using empirical data from the Cochrane Database of Systematic Reviews. *Int J Epidemiol*. 2012;41:818-827.
24. Brown S, Hutton B, Clifford T, et al. A Microsoft-Excel-based tool for running and critically appraising network meta-analyses—an overview and application of NetMetaXL. *Syst Rev*. 2014;3:110.
25. Plummer M. JAGS: a program for analysis of Bayesian graphical models using Gibbs sampling. Paper presented at: Proceedings of the 3rd. Vienna, Austria: International Workshop on Distributed Statistical Computing, March 20-22, 2003.
26. Plummer M, Stukalov A, Denwood M. *rjags: Bayesian graphical models using MCMC*, 2016. Available at: <https://cran.r-project.org/web/packages/rjags/rjags.pdf>. Accessed August 1, 2019.
27. van Valkenhoef G, Lu G, de Brock B, et al. Automating network meta-analysis. *Res Synth Methods*. 2012;3:285-299.
28. Hamra G, MacLhose R, Richardson D. Markov chain Monte Carlo: an introduction for epidemiologists. *Int J Epidemiol*. 2013;42:627-634.
29. Salanti G, Ades AE, Ioannidis JP. Graphical methods and numerical summaries for presenting results from multiple-treatment meta-analysis: an overview and tutorial. *J Clin Epidemiol*. 2011;64:163-171.
30. Kim IH, Kang DK, Min HK, et al. A prospective randomized trial comparing manual needle aspiration to closed thoracostomy as an initial treatment for the first episode of primary spontaneous pneumothorax. *Korean J Thorac Cardiovasc Surg*. 2019;52:85-90.
31. Ramouz A, Lashkari MH, Fakour S, et al. Randomized controlled trial on the comparison of chest tube drainage and needle aspiration in the treatment of primary spontaneous pneumothorax. *Pak J Med Sci*. 2018;34:1369-1374.
32. Korczyński P, Gorska K, Nasilowski J, et al. Comparison of small bore catheter aspiration and chest tube drainage in the management of spontaneous pneumothorax. *Adv Exp Med Biol*. 2015;866:15-23.
33. Parlak M, Uil SM, van den Berg JW. A prospective, randomised trial of pneumothorax therapy: manual aspiration versus conventional chest tube drainage. *Respir Med*. 2012;106:1600-1605.
34. Ma WL, Zhang X, Song R, et al. [Effects of pleural drainage using central venous catheter and simple aspiration in treatment of spontaneous pneumothorax: a clinical comparative study]. *Zhonghua Yi Xue Za Zhi*. 2007;87:1749-1751.
35. Ayed AK, Chandrasekaran C, Sukumar M. Aspiration versus tube drainage in primary spontaneous pneumothorax: a randomised study. *Eur Respir J*. 2006;27:477-482.
36. Oh SW, Hyun SY, Yang HJ, et al. Comparison of simple manual aspiration and chest tube drainage in the first occurrence of a primary spontaneous pneumothorax. *J Korean Soc Emerg Med*. 2003;14:403-408.
37. Noppen M, Alexander P, Driesen P, et al. Manual aspiration versus chest tube drainage in first episodes of primary spontaneous

- pneumothorax: a multicenter, prospective, randomized pilot study. *Am J Respir Crit Care Med.* 2002;165:1240-1244.
38. Roggla M, Wagner A, Brunner C, et al. The management of pneumothorax with the thoracic vent versus conventional intercostal tube drainage. *Wien Klin Wochenschr.* 1996;108:330-333.
 39. Harvey J, Prescott RJ. Simple aspiration versus intercostal tube drainage for spontaneous pneumothorax in patients with normal lungs. British Thoracic Society Research Committee. *BMJ.* 1994;309:1338-1339.
 40. Brown SG, Ball EL, Perrin K, et al. Study protocol for a randomised controlled trial of invasive versus conservative management of primary spontaneous pneumothorax. *BMJ Open.* 2016;6:e011826.
 41. Argento AC, Murphy TE, Pisani MA, et al. *Patient-Centered Outcomes Following Thoracentesis.* Thousand Oaks, CA: Pleura; 2015:2.
 42. Feller-Kopman DJ, Reddy CB, DeCamp MM, et al. Management of malignant pleural effusions. An official ATS/STS/STR clinical practice guideline. *Am J Respir Crit Care Med.* 2018;198:839-849.
 43. Paez A. Grey literature: an important resource in systematic reviews. *J Evid Based Med.* 2017;10:233-240.
 44. Vuong NL, Elshafay A, Thao LP, et al. Efficacy of treatments in primary spontaneous pneumothorax: a systematic review and network meta-analysis of randomized clinical trials. *Respir Med.* 2018;137:152-166.
 45. Aguinagalde B, Zabaleta J, Fuentes M, et al. Percutaneous aspiration versus tube drainage for spontaneous pneumothorax: systematic review and meta-analysis. *Eur J Cardiothorac Surg.* 2010;37:1129-1135.
 46. Chang SH, Kang YN, Chiu HY, et al. A systematic review and meta-analysis comparing pigtail catheter and chest tube as the initial treatment for pneumothorax. *Chest.* 2018;153:1201-1212.
 47. Carson-Chahhoud KV, Wakai A, van Agteren JE, et al. Simple aspiration versus intercostal tube drainage for primary spontaneous pneumothorax in adults. *Cochrane Database Syst Rev.* 2017;9:CD004479.
 48. Kim MJ, Park I, Park JM, et al. Systematic review and meta-analysis of initial management of pneumothorax in adults: intercostal tube drainage versus other invasive methods. *PLoS One.* 2017;12:e0178802.
 49. Yoon J, Sivakumar P, O'Kane K, et al. A need to reconsider guidelines on management of primary spontaneous pneumothorax? *Int J Emerg Med.* 2017;10:9.
 50. Kelly AM, Druda D. Comparison of size classification of primary spontaneous pneumothorax by three international guidelines: a case for international consensus? *Respir Med.* 2008;102:1830-1832.
 51. Stradling P, Poole G. Conservative management of spontaneous pneumothorax. *Thorax.* 1966;21:145-149.
 52. Simpson G. Letter from Australia. *Respirology.* 2018;23:788-789.
 53. Mullins PM, Pines JM. National ED crowding and hospital quality: results from the 2013 Hospital Compare data. *Am J Emerg Med.* 2014;32:634-639.
 54. Kocher KE, Meurer WJ, Desmond JS, et al. Effect of testing and treatment on emergency department length of stay using a national database. *Acad Emerg Med.* 2012;19:525-534.
 55. Ngo H, Forero R, Mountain D, et al. Impact of the four-hour rule in Western Australian hospitals: trend analysis of a large record linkage study 2002-2013. *PLoS One.* 2018;13:e0193902.
 56. Kim YP, Haam SJ, Lee S, et al. Effectiveness of ambulatory Tru-Close thoracic vent for the outpatient management of pneumothorax: a prospective pilot study. *Korean J Radiol.* 2017;18:519-525.
 57. Sano A, Yotsumoto T, Tsuchiya T. Outpatient drainage for patients with spontaneous pneumothorax over 50 years of age. *Lung India.* 2017;34:232-235.
 58. Khan F, Vali Y, Naeem M, et al. Safety and efficacy of ambulatory management of secondary spontaneous pneumothorax: a case series. *BMJ Open Respir Res.* 2019;6:e000373.
 59. Mummadi SR, Hahn PY. Outcomes of a clinical pathway for pleural disease management: "pleural pathway." *Pulm Med.* 2018;2018:2035248.
 60. Broder JS, Fox JW, Milne J, et al. Heimlich valve orientation error leading to radiographic tension pneumothorax: analysis of an error and a call for education, device redesign and regulatory action. *Emerg Med J.* 2016;33:260-267.
 61. Crocker HL, Ruffin RE. Patient-induced complications of a Heimlich flutter valve. *Chest.* 1998;113:838-839.
 62. Mariani PJ, Sharma S. Iatrogenic tension pneumothorax complicating outpatient Heimlich valve chest drainage. *J Emerg Med.* 1994;12:477-479.
 63. Grout JR. Mistake proofing: changing designs to reduce error. *Qual Saf Health Care.* 2006;15(suppl 1):i44-49.
 64. Hallifax R, Laskawiec-Szkonter M, Dobson M, et al. Randomised Ambulatory Management of Primary Pneumothorax (RAMPP): protocol of an open-label, randomised controlled trial. *BMJ Open Respir Res.* 2019;6:e000403.
 65. Tsuchiya T, Sano A. Outpatient treatment of pneumothorax with a thoracic vent: economic benefit. *Respiration.* 2015;90:33-39.