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 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;–:1-15.]

Please see page XX for the Editor’s Capsule Summary of this article.
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 (≥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.

challenging existing beliefs. 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 (≥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). 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 (≥18 years) presenting with symptomatic nontension spontaneous pneumothorax; intervention/comparator included needle aspiration, narrow-bore chest tube (<14 F), and large-bore chest tubes, including 14-F pigtail catheters (≥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 tool 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. 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.

We chose a Bayesian approach with a random-effects prior informative model for these analyses. Bayesian methods are widely used in health outcomes evaluations. Traditional random-effects analyses have the limitation of not considering the uncertainty in the estimate of the between-study variance. This uncertainty is particularly significant when a systematic review results in a small number of included studies. 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.

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).

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

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.

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.

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. We present additional details in regard to search strategy, data extraction, Markov chain Monte Carlo simulation, assessment of
inconsistency, and evaluation of confidence methodology in the supplementary material (available online at http://www.annemergmed.com).

RESULTS

The initial search identified 1,880 possible studies. We included 12 studies7-9,30-38 in the network meta-analysis. Figure 1 describes the sequential process. A summary of excluded randomized studies is provided in Table E3 (available online at http://www.annemergmed.com). Attempts at personal communication resulted in additional information for 3 studies.7,33,39 Two non-English publications34,36 were translated.

Table 1 describes the characteristics of the network. Table 2 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. Exclusion criteria used in the included studies are described in Table E2 (available online at http://www.annemergmed.com). Figure 2A and B 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 (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, Figure E3, 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.

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

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

*Missing data on smoking prevalence (Ma et al,34 Oh et al,36 and Roggla 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 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.51 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 success41,42 in pleural disease research. Additional limitations included a relatively small sample of patients who underwent narrow-bore chest tube
<table>
<thead>
<tr>
<th>Study, Year</th>
<th>Population</th>
<th>Intervention</th>
<th>Comparison</th>
<th>Primary Outcome</th>
<th>Secondary Outcomes</th>
<th>Follow-up Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim, 2019</td>
<td>PSP &gt;25% size presenting to a Korean University hospital. PSP patients accounted for 100% (n=40/40) of the study sample.</td>
<td>16-G* needle aspiration (n=21) followed by at least 12 h inpatient observation. 2 attempts before failure declared.</td>
<td>12-F chest tube insertion (n=19) and connection to an underwater seal. Admitted for observation.</td>
<td>Immediate success rate</td>
<td>1-mo recurrence rate</td>
<td>Hospitalization followed by 1-mo and 1-y follow-up</td>
</tr>
<tr>
<td>Ramouz, 2018</td>
<td>Symptomatic PSP (&gt;18 y) who presented to 2 Iranian university hospitals. PSP patients accounted for 100% (n=70/70) of the sample.</td>
<td>16-G* needle aspiration (n=35) followed by 6-h observation. 2 attempts before failure declared.</td>
<td>16-F/20-F chest tube insertion (n=35) and inpatient observation</td>
<td>Immediate success rate</td>
<td>Pain intensity</td>
<td>Hospitalization followed by 1-y follow-up</td>
</tr>
<tr>
<td>Thelle, 2017</td>
<td>Symptomatic (OR) &gt;20% size SSP (OR) &gt;30% size PSP patients presenting to 3 Norwegian teaching hospitals. PSP patients accounted for 62% (n=79/127) of the study sample.</td>
<td>16-G* needle aspiration (n=64) and inpatient observation. 2 attempts before failure declared.</td>
<td>Large-bore chest tube insertion (n=63) and inpatient observation (14–20 F were the most common sizes)</td>
<td>Duration of hospital stay</td>
<td>Rates of immediate success, 1-wk success, and complications</td>
<td>Hospitalization and short-term outpatient follow-up (7–10 days) postdischarge</td>
</tr>
<tr>
<td>Korczyński, 2015</td>
<td>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.</td>
<td>8-F chest tube drainage (n=22) and if needed a Heimlich valve was inserted. Inpatient observation ensued.</td>
<td>20- to 24-F chest tube drainage (n=27) and admitted to the hospital for observation</td>
<td>Rate of success, duration of chest tube drainage, and need for surgery</td>
<td>Length of stay, procedure safety, and rate of success of second-line treatment for initial treatment failures</td>
<td>Hospitalization. No outpatient follow-up mentioned.</td>
</tr>
<tr>
<td>Parlak, 2012</td>
<td>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.</td>
<td>3.9-F (1.3-mm) needle aspiration (n=25) and inpatient observation for 24 h. No further attempts if initial aspiration unsuccessful.</td>
<td>8-F chest tube insertion (n=31) with connection to a drainage system. Inpatient observation ensued.</td>
<td>Duration of hospital stay</td>
<td>Rates of immediate success</td>
<td>Hospitalization followed by short-term outpatient follow-up (7 days). Long-term follow-up 1 y after discharge.</td>
</tr>
<tr>
<td>Study</td>
<td>PSP Patients</td>
<td>Initial Management</td>
<td>Success Rates</td>
<td>Complications</td>
<td>Hospitalization</td>
<td>Notes</td>
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<tr>
<td>Ho, 2011</td>
<td>First-episode PSP patients (size &gt;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.</td>
<td>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.</td>
<td>Rates of failure and inpatient admission</td>
<td>Rates of complications and full recovery, length of stay, and satisfaction scores</td>
<td>Hospitalization and 3 days' follow-up after discharge from the ED</td>
<td></td>
</tr>
<tr>
<td>Ma, 2007</td>
<td>First-episode PSP or SSP patients presenting to a Chinese teaching hospital. PSP patients accounted for 80% of the study sample (n=37/46).</td>
<td>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.</td>
<td>Rates of success</td>
<td>Length of stay and costs</td>
<td>Hospitalization and then at 1 wk</td>
<td></td>
</tr>
<tr>
<td>Ayed, 2006</td>
<td>Symptomatic (OR) &gt;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.</td>
<td>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</td>
<td>Rate of immediate success</td>
<td>Rates of 1-wk success, hospitalization, complications, inability to work, and length of stay</td>
<td>1 wk and 3, 6, 12, and 24 mo postdischarge. Earlier if indicated.</td>
<td></td>
</tr>
<tr>
<td>Oh, 2003</td>
<td>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).</td>
<td>18-G§ 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</td>
<td>Rate of success</td>
<td>Length of stay, rates of 3-mo recurrence, urgent readmission, and complications</td>
<td>Hospitalization and then at 1 wk and 1 and 3 mo postdischarge. Earlier when symptoms emerged.</td>
<td></td>
</tr>
<tr>
<td>Noppen, 2002</td>
<td>First-episode symptomatic (OR) &gt;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.</td>
<td>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</td>
<td>Rates of immediate, 1-wk, and 1-y success</td>
<td>Rates of hospitalization, length of stay, and safety</td>
<td>Hospitalization and at 48 h, 1 wk, and 2, 6, and 12 mo postdischarge. Earlier when indicated.</td>
<td></td>
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</tbody>
</table>
## Table 2. Continued.

<table>
<thead>
<tr>
<th>Study, Year</th>
<th>Population</th>
<th>Intervention</th>
<th>Comparison</th>
<th>Primary Outcome</th>
<th>Secondary Outcomes</th>
<th>Follow-up Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roggla, 1996</td>
<td>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.</td>
<td>13-F chest tube insertion (n=17) followed by immediate chest radiograph. Offered outpatient management if lung expanded.</td>
<td>14-F chest tube insertion (n=13) and connected to an underwater seal. All patients hospitalized.</td>
<td>Rates of success at immediate postinsertion and 24- and 48-h postinsertion periods</td>
<td>Duration of drainage, No. of outpatient management events, and duration of hospitalization</td>
<td></td>
</tr>
<tr>
<td>Andrivet, 1995</td>
<td>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.</td>
<td>16-G*/18-G² 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.</td>
<td>20-F chest tube inserted (n=28) and further evaluation in the hospital</td>
<td>Rates of success and 3-mo recurrence rate</td>
<td>Length of stay, pain and dyspnea scores</td>
<td>Hospitalization and in the clinic and by mail</td>
</tr>
</tbody>
</table>

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.
- **Pariak, 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 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) on the chest radiograph 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.
²In one case, a 12-F chest tube was used in accordance with a personal communication with the corresponding author.
²A 2.7-mm chest tube (equivalent to 8 F) was used in the study in accordance with a personal communication with the study author.
²18 G is equivalent to 3.8 F.
<table>
<thead>
<tr>
<th>Study Name/Year</th>
<th>Treatment</th>
<th>Rates of Success (n/N)</th>
<th>Response to Failure</th>
<th>Complications (n/N)</th>
<th>Description of Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim, 2019</td>
<td>Needle aspiration</td>
<td>17/21</td>
<td>Second attempt and, if failure, then large-bore chest tube drainage</td>
<td>0/21</td>
<td></td>
</tr>
<tr>
<td>Kim, 2019</td>
<td>Narrow-bore chest tube</td>
<td>12/19</td>
<td>PAL after 5 days resulted in surgery referral</td>
<td>0/19</td>
<td></td>
</tr>
<tr>
<td>Ramouz, 2018</td>
<td>Large-bore chest tube</td>
<td>24/35</td>
<td>VATS chemical pleurodesis</td>
<td>6/35</td>
<td>Wound infection (1), bleeding (3), SQ emphysema (2)</td>
</tr>
<tr>
<td>Ramouz, 2018</td>
<td>Needle aspiration</td>
<td>19/35</td>
<td>Second needle aspiration attempt, large-bore chest tube drainage, VATS chemical pleurodesis carried out in applicable sequence</td>
<td>1/35</td>
<td>Bleeding (1)</td>
</tr>
<tr>
<td>Thelle, 2017</td>
<td>Large-bore chest tube</td>
<td>20/63</td>
<td>Large-bore chest tube drainage for 7 days. PAL after this period resulted in surgical referral</td>
<td>32/63</td>
<td>Wound infection (4), bleeding (2), pneumonia (1), empyema (1), death (1), reinsertion (16), SQ emphysema (7)</td>
</tr>
<tr>
<td>Thelle, 2017</td>
<td>Needle aspiration</td>
<td>44/64</td>
<td>Second needle aspiration attempt followed by large-bore chest tube drainage if needed</td>
<td>0/64</td>
<td></td>
</tr>
<tr>
<td>Korczyński, 2015</td>
<td>Large-bore chest tube</td>
<td>22/27</td>
<td>PAL after 7 days resulted in surgical referral</td>
<td>0/27</td>
<td></td>
</tr>
<tr>
<td>Korczyński, 2015</td>
<td>Narrow-bore chest tube</td>
<td>14/22</td>
<td>Insertion of large-bore chest tube for days 6–7 and PAL &gt;7 days resulted in surgery referral</td>
<td>0/22</td>
<td></td>
</tr>
<tr>
<td>Parlak, 2012</td>
<td>Narrow-bore chest tube</td>
<td>25/31</td>
<td>N/A</td>
<td>0/31</td>
<td></td>
</tr>
<tr>
<td>Parlak, 2012</td>
<td>Needle aspiration</td>
<td>17/25</td>
<td>Narrow-bore chest tube drainage after initial needle aspiration failure</td>
<td>0/25</td>
<td></td>
</tr>
<tr>
<td>Ho, 2011</td>
<td>Needle aspiration</td>
<td>11/23</td>
<td>Large-bore chest tube drainage</td>
<td>2/23</td>
<td>SQ emphysema (2)</td>
</tr>
<tr>
<td>Ho, 2011</td>
<td>Narrow-bore chest tube</td>
<td>18/25</td>
<td>Large-bore chest tube drainage</td>
<td>1/25</td>
<td>Tension pneumothorax (1)</td>
</tr>
<tr>
<td>Ma, 2007</td>
<td>Needle aspiration</td>
<td>21/23</td>
<td>Referral to surgery</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Ma, 2007</td>
<td>Narrow-bore chest tube</td>
<td>23/23</td>
<td>Referral to surgery</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Ayed, 2006</td>
<td>Large-bore chest tube</td>
<td>49/72</td>
<td>VATS if PAL &gt;7 days</td>
<td>5/72</td>
<td>Tube blockage (2), exit-site infection (1), SQ emphysema (2)</td>
</tr>
<tr>
<td>Ayed, 2006</td>
<td>Needle aspiration</td>
<td>40/65</td>
<td>Large-bore chest tube drainage after 2 unsuccessful needle aspiration attempts</td>
<td>1/65</td>
<td>SQ emphysema (1)</td>
</tr>
</tbody>
</table>
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 guidelines55 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.
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 Poole\(^51\) 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 case\(^52\) 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 trial\(^10\) 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 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 management\(^36\) and avoid the prolonged observation time needed for needle aspiration,\(^57,58\) especially in the setting of a well-defined clinical pathway\(^55\) 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.

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**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.
Design iterations should incorporate mistake proofing to prevent errors in attaching the valve to the chest tube, a significant source of error. 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 are now available, and favorable economic and safety outcomes have been described with one device 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.

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 study 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 al described their nonrandomized experience of efficient and successful ambulatory management of secondary spontaneous pneumothorax (rates of success 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. A seminal randomized study (Harvey and Prescott) 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. 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. 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 prerequisite 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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