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A M E R I C A N C O L L E G E O F



P H Y S I C I A N S



reviews

Treatment of Spontaneous Pneumothorax*

A More Aggressive Approach?

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Key words: chest tube; median sternotomy; pleurodesis; spontaneous pneumothorax; thoracoscopy; thoracotomy; tube thoracostomy

Abbreviations: ELC=emphysema-like changes; PSP=primary spontaneous pneumothorax; SP=spontaneous pneumothorax; SSP=secondary spontaneous pneumothorax; VAT=video-assisted thoracoscopy

Spontaneous pneumothoraces (SPs) occur without an obvious preceding cause and remain a significant problem in the United States.¹ Based on an Olmsted County, Minnesota, resident population

For related material see page 822

review, there are approximately 20,000 new cases of SP per year in the United States.² Applying a Swedish cost analysis study, direct (63%) and indirect (37%) economic impact of SPs may approach \$130 million per year in the United States.³ The evolution of therapeutic interventions such as video-assisted thoracoscopy (VAT), CT scoring of underlying lung disease, and improved efficacy of sclerosing agents since earlier textbook and journal reviews of SP management^{1,4-6} add to management options physicians must consider. The appropriate application of new information could have a significant economic impact and provide improved quality in the care of patients with SP.

A primary spontaneous pneumothorax (PSP) occurs in a person without obvious underlying lung disease. A secondary spontaneous pneumothorax (SSP) occurs as

a complication of underlying lung disease, most often COPD.⁴ Recurrence of an SP continues to be a major consideration in choosing a therapeutic intervention. This clinical commentary will focus on information that may offer refined therapeutic approaches to patients with PSPs or SSPs.

THERAPEUTIC CONSIDERATIONS

Recurrence Rates and Mortality

The goals of pneumothorax therapy are to eliminate the intrapleural air collection, to facilitate pleural healing, and to attempt recurrence prevention. Oxygen supplementation, observation, simple aspiration, and a chest tube without sclerosis do not target the risk of recurrence.

Recurrence rates following an SP vary widely in the literature.^{4,5,7,8} Although the presence of underlying lung disease is a major variable in recurrence rates, differences in observation time and treatments make true rates difficult to assess.⁷ The best data available on risk factors for recurrence in patients without *Pneumocystis carinii* pneumonia come from a Cox regression analysis in 142 patients with SP that found pulmonary fibrosis, age 60 years or older, and increased height/weight ratio to be independent predictors.⁸ Recurrence should be viewed as a time-related event,⁸ with most occurring within the first months following the initial pneumothorax.⁹ A recent estimation of first recurrence rates in the absence of definitive recurrence prevention found recurrence in 28% of PSP and 43% of SSP during a mean 5-year follow-up.⁴ The authors believed that subsequent recurrences are not as likely as thought.⁴

Contralateral occurrence rates after a unilateral SP may be significant,^{1,4,5} but have not been studied adequately. One study of 229 patients cites an approximate rate of 5.2%⁹ and an earlier study notes a rate of 14.6%.¹⁰ Both reports reflect a combined PSP and SSP population. The latter study noted that

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29% of patients with chest radiographic evidence of contralateral bullae developed a contralateral recurrence. Contralateral pneumothoraces arose with greater frequency in teenage patients (41%), particularly if the chest radiograph showed contralateral bullae (60%). Contralateral recurrence rates for comparable patients diminish over subsequent decades of age.¹⁰

PSP has been viewed as a low-mortality “nuisance.”^{4,5} However, death has been reported,¹¹ although it is apparently uncommon. With an evolving emphasis on the economic impact of diseases, an effective method to identify patients with PSP having the greatest recurrence risk might stratify patients into those in whom recurrence prevention therapy would save money and lives.

SSPs can be life threatening in patients with COPD. Age-matched patients with COPD have a 3.5-fold increase in relative mortality with occurrence of an SP.⁷ Mortality percentages in patients with COPD and SSP vary from 1 to 17%,^{9,12-14} with the most recent series reporting mortality as low as 1%.⁹ Concerningly, in one study, 5% of patients with SSP in the setting of COPD died before chest tube placement.¹³

Imaging Developments

CT can detect mild emphysema¹⁵⁻¹⁹ and may play a useful role in the evaluation of patients with pneumothorax. The definition of PSP hinges on the patient having no underlying lung disease. Yet, in a recent study of nonsmoking, non- α_1 -antitrypsin-deficient patients with PSP, Bense and colleagues²⁰ found 81% to have emphysema-like changes (ELC). No ELC were detected in control patients. Such findings not only point to a potential role for CT evaluation of patients with PSP but also to an etiologic role for ELC in development of PSP.

CT studies in patients with PSP have established that ELC are frequently bilateral,²⁰⁻²⁴ occurring in 66%²⁴ and 80%²² in two recent studies. They tend to be in the upper lung zones peripherally^{20,22,24} (Fig 1), and are seldom seen by routine chest radiography.²⁴ The type of CT scanner, thickness of sections, and observer variability can influence accuracy.²¹ High-resolution scanning (thin sections) may overcome many of these limitations, particularly with emphysematous changes >0.5 cm in diameter.²¹

CT may help predict the recurrence of PSP. Warner et al²³ compared patients with first occurrence of PSP, who did not require thoracostomy, to patients with either recurrent PSP or PSP requiring thoracostomy. Using a CT-derived score of ELC, the authors found that the number of blebs and ELC score of the ipsilateral lung were

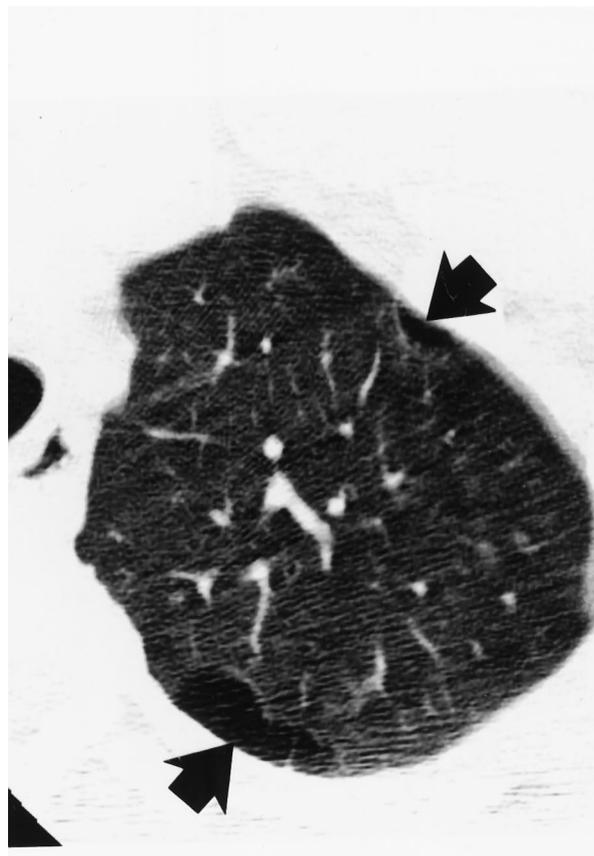


FIGURE 1. High-resolution CT scan of a 27-year-old man with left-sided PSP (resolved) demonstrating subpleural emphysema in the upper lung zone (arrows).

greater in patients with a history of recurrent PSP. Further, the need for thoracostomy was correlated with the ELC score and the number of blebs.²³ However, this study had no control patients (nonsmoking, normal patients without a history of pneumothorax) and the criteria precipitating thoracostomy placement are not defined. Due to a limited number of patients (26), Warner et al²³ could not define with certainty an absolute number of blebs, size of blebs, or ELC score that correlated with an absolute risk of PSP recurrence. Bense et al²⁰ likewise found a correlation between ELC changes and the occurrence of PSP. Earlier analyses have found that bulging bullae, bullae without surrounding fibrosis, and number and size of bullae were also markers of high recurrence risk.^{23,25} Alternately, Mitlehner et al²⁴ found no significant CT differences between 35 PSP patients, with and without recurrence, over a mean 31.7-month follow-up.

Despite this evidence, routine CT in patients with PSP is not currently recommended. Until further investigation has better defined the correlates of

pneumothorax recurrence and tested those risks prospectively in a validation cohort, CT in all patients with PSP should not be routine. The needed investigations should include rigorous control of the scanning techniques and smoking and nonsmoking normal control subjects. In the meantime, CT for patients with PSP will remain an interesting adjunct whose current use must be individualized.

An SSP, by definition, occurs as a complication of an underlying lung disease.⁴ Older and more recent series of patients with SSP note COPD as the most frequent lung abnormality.^{9,12,26} Other etiologies include tuberculosis, Pneumocystis, sarcoidosis, cystic fibrosis, and lung carcinoma.^{12,26} To our knowledge, there has been no evaluation of differences in the course or outcome of SSP among diseases. The sensitivity of detecting ELC is accentuated in SSP. No studies of recurrence risk assessment by CT scoring of lung abnormalities in COPD are available (to our knowledge). However, as a preinterventional assessment, CT may offer valuable information about the extent and nature of underlying lung disease.

Quantitation of Pneumothorax Size

Some authors have recommended the use of pneumothorax size as a guide to treatment.^{1,4} However, one investigation²⁷ indicates that the chest radiograph is a poor tool to accurately assess pneumothorax size. The accuracy of the CT scan in determining pneumothorax size was first confirmed ($r=0.99$) utilizing a pneumothorax model consisting of a water-filled plastic bag (lung) fitted into a plastic chamber (hemithorax) designed to simulate the human hemithorax. Subsequently, 16 consecutive SP patients had pneumothorax size determined by CT scan compared to that calculated by two methods based on chest radiographs. A poor correlation ($r=0.71$) was found,²⁷ suggesting asymmetric collapse of the lung in most patients.²⁷ Emphasis should be placed on the clinical status of the patient, not on the radiographic size of the pneumothorax, when making therapeutic choices.

THERAPEUTIC OPTIONS

The presented therapeutic algorithms (Figs 2 and 3) are grounded in the following discussions and must be individualized to each patient's unique situation. Open discussion, where possible, with the patient regarding various treatment options is strongly encouraged.

Oxygen

A potentially overlooked and valuable therapeutic modality in the management of SP is the application

of supplemental oxygen. The rate of pleural air absorption, in the absence of supplemental oxygen, appears to be about 1.25%/d of the involved hemithorax.²⁸ For example, if a patient suffers from a 25% pneumothorax, approximately 20 days will be required for reabsorption of the pleural air. Oxygen supplementation can increase this basal resolution room air rate by threefold to fourfold, with the greatest increases noted in patients with the larger pneumothoraces.^{29,30} The application of oxygen creates a gas pressure gradient between the pleural space and the tissue capillaries surrounding the pleural space, thereby enhancing the absorption of pleural nitrogen first and in time any other gases within the space.^{29,30} Oxygen delivery in these reports varied from nasal cannula oxygen at 3 L/min to high-flow masks, including partial rebreathing masks.

Pneumothoraces change arterial PO_2 and alveolar-arterial oxygen difference due to alterations in ventilation-perfusion relationships, anatomic shunt, and dead space.^{31,32} Ventilation-perfusion relationships may become more uneven (worsen) with an increase in anatomic shunt after pleural air drainage with improvement delayed for at least 30 to 90 min,³¹ further emphasizing the potential benefits of supplemental oxygen.

Simple Observation

Simple observation has been used as a treatment option, particularly in patients who are not dyspneic with pneumothoraces <15% in size.^{1,4,5} A more cautious utilization of this option may be warranted except in very select cases.

One series of patients undergoing simple observation highlights the concern.¹¹ Forty patients with PSP or SSP were admitted to the hospital for observation. Pneumothorax size was estimated to be <15% in 80% of patients. Nine of the 40 patients (23%) required tube thoracostomy for progression of symptoms of pneumothorax. Seven of these nine patients had underlying COPD. Two deaths were recorded in a previously healthy 32-year-old woman and in a 73-year-old man with COPD. Unrecognized tension pneumothorax appears to have played a role in the development of sudden cardiopulmonary arrest.¹¹ The recurrence rate, during an unspecified period of follow-up, was 33%.¹¹

By comparison, an earlier retrospective series, including 73 episodes of SP (type and size not defined), and a later prospective series, including 38 episodes (29 PSP, 9 SSP; size <20%), monitored in hospital, reported no deaths but had similar overall recurrence rates of 49% and 36%, respectively.^{33,34} Twenty-nine of the 73 episodes (40%) in the retro-

PRIMARY SPONTANEOUS PNEUMOTHORAX †

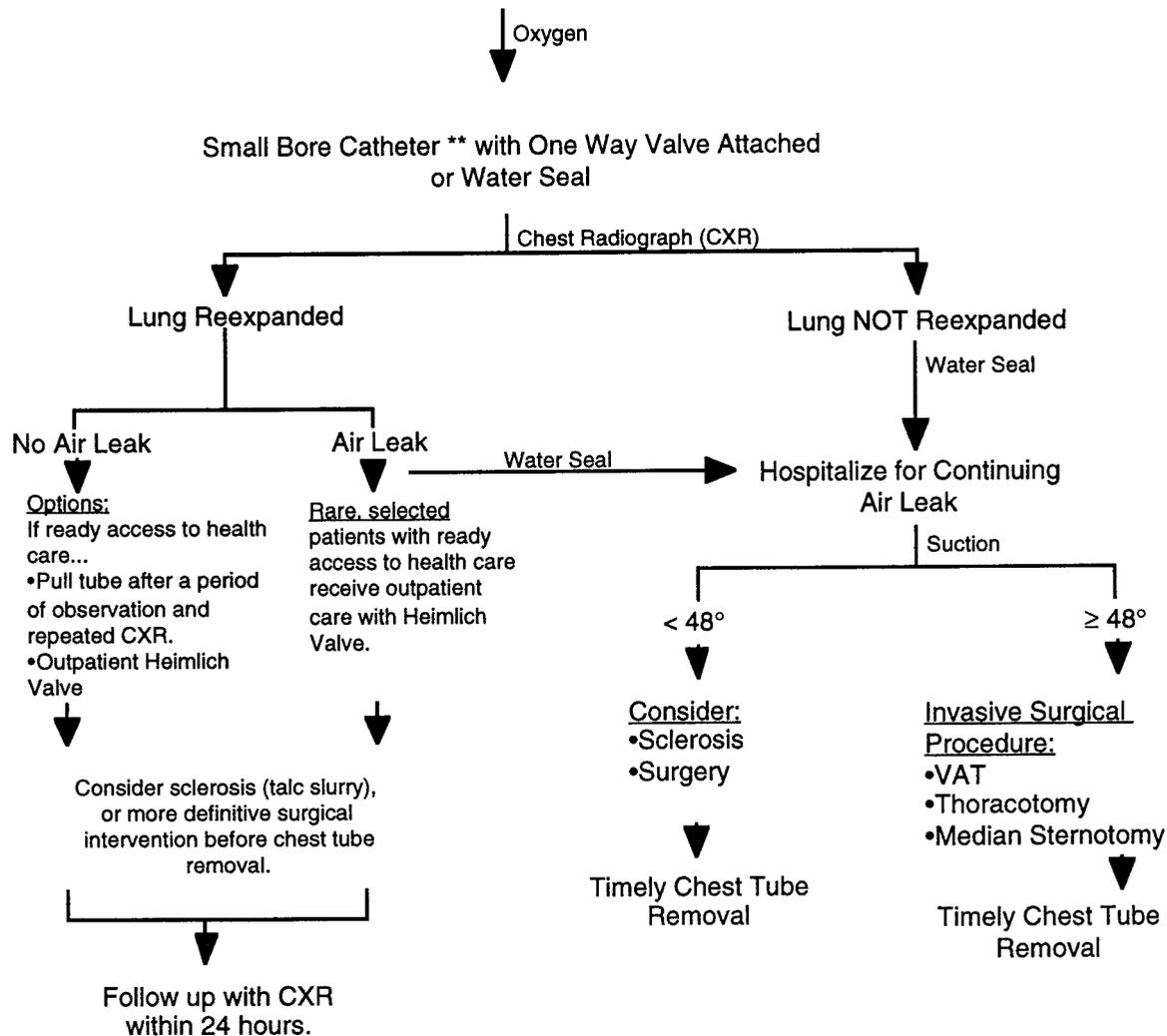


FIGURE 2. PSP treatment summary. See text for details. Dagger=if recurrent, greater consideration for recurrence prevention needs to be given. Two asterisks=large-bore chest tube, $\geq 28F$, if mechanically ventilated or large air leak anticipated.

spective series required tube thoracostomy for reasons not defined.³³ None of the 38 prospective episodes required additional treatment while monitored.³⁴

Although simple observation offers many patients the least invasive treatment for pneumothorax, the critical issue becomes the efficiency of monitoring pneumothorax size. To our knowledge, no studies are available to answer the questions of optimal radiograph timing and whether surrogate markers of pneumothorax progression, such as oximetry or respiratory rate, are helpful. Since observation also does not offer recurrence prevention, it may best be reserved for patients who have contraindications to more definitive approaches. Such contraindications should be determined individually and might include

profound coagulopathy, significant immunocompromise, and imminently terminal conditions. If outpatient observation is embraced, the patient should be in close proximity to a health-care facility, have ready access to transportation, and possess a clear understanding of signs and symptoms signifying the need for prompt reevaluation.

Simple Aspiration

The technique of simple aspiration has been summarized in multiple publications.^{1,4,5,35-40} The only goal of this technique is the evacuation of pleural air and reexpansion of a collapsed lung. Simple aspiration entails placement of a small catheter (often an IV catheter) between the fourth or fifth intercostal

SECONDARY SPONTANEOUS PNEUMOTHORAX †

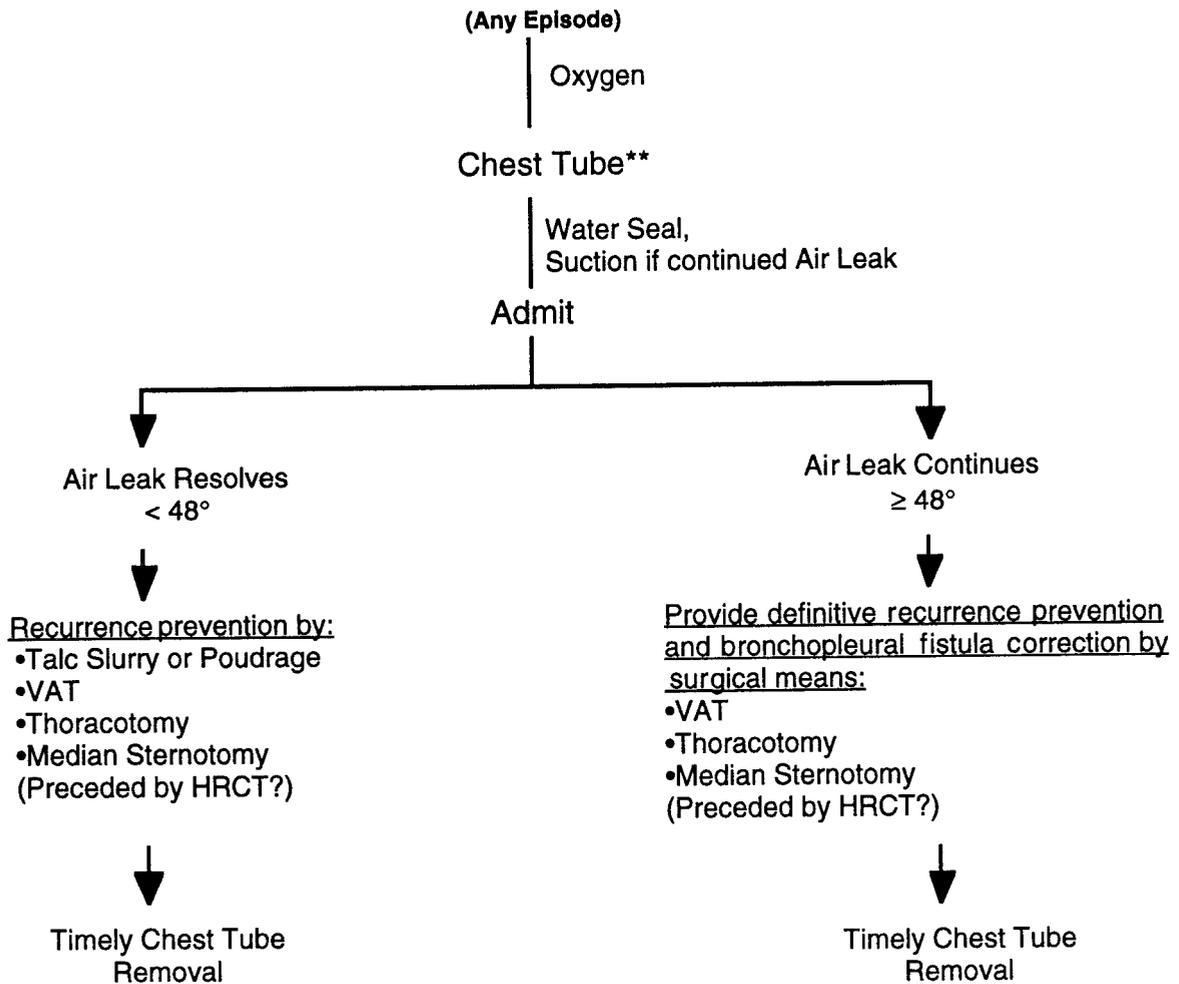


FIGURE 3. SSP treatment summary. See text for details. Dagger=if recurrent, greater consideration for recurrence prevention needs to be given. Two asterisks=large-bore chest tube, $\geq 28F$, if mechanically ventilated or large air leak anticipated.

space over the superior rib margin in the anterior axillary line using the Seldinger or trocar technique after appropriate sterile preparation and anesthesia. A three-way stopcock and a large syringe are used to aspirate intrathoracic air with full lung expansion heralded by the inability to aspirate further air or by sudden cough. The catheter is then removed.

Refinements to this simple aspiration technique have created confusion in terminology. Many commercially available kits contain aspiration catheters and a one-way valve (*eg*, Heimlich valve) that can be left in place until the lung expands or be converted to small-bore chest tubes should an air leak persist. These refinements allow for the continued residence of the catheter after completion of the aspiration. One-way valves can be left in place for as short a time as needed to effect lung reexpansion and then the catheter and valve are pulled. These alterations

to the simple aspiration technique transfigure it to placement of a small chest tube. The term simple aspiration utilized below will encompass only the technique incorporating immediate catheter removal after aspiration.

Aspiration has been recommended as “the initial treatment for most patients with a primary spontaneous pneumothorax greater than 15% of the volume of the hemithorax.”³⁵ Advantages to this approach include its relative simplicity and lack of invasiveness. Low cost has also been suggested to be an advantage.^{37,38}

However, this procedure has several disadvantages. Foremost, simple aspiration offers no definitive recurrence prevention in patients with either a primary or secondary pneumothorax. Also, success rates vary in the literature and depend on whether the patient has a PSP or SSP. Overall success in two

prospective studies, in which a differentiation of PSP and SSP was not provided, was 19 of 36 (53%) and 11 of 19 (58%) episodes.^{37,38} Two additional studies,^{35,36,39} in which numbers of PSP and SSP are defined, note success in 75% (36 of 48 occurrences) for PSP and 37% (11 of 30 occurrences) for SSP (references 36 and 39 represent a pilot and subsequently completed study, respectively). Patients in these studies were admitted to the hospital for close monitoring and serial chest radiographs. Serial aspirations were at times necessary in patients with both successful and unsuccessful outcomes.^{36,39} Patients failing simple aspiration required placement of a tube thoracostomy.

Most recently, a prospective randomized analysis of delayed (72 h) simple aspiration (at times multiple) compared to immediate chest tube placement in hospitalized patients with SP ($\geq 86\%$ PSP) recommended simple aspiration as “first-line” treatment of SP.⁴⁰ This recommendation may be optimistic. The immediate success rate, defined as no air leak by 10 days, was significantly higher for chest tube placement (93%) than aspiration (67%).⁴⁰ Approximately one quarter of patients treated with either a chest tube or simple aspiration had a recurrence within 3 months, again confirming the suboptimal recurrence prevention by either technique.⁴⁰

Some have argued that the absence of an inhaled marker gas within aspirated pleural air predicts sealing and a successful manual aspiration.⁴¹ Subsequent discussions have criticized this technique as expensive and cumbersome.⁴² Noting resistance to aspiration and obtaining a chest radiograph to confirm lung reexpansion predict aspiration success.^{36,38,39}

Economy, simplicity, universal availability, and lack of invasiveness may not be adequate counters to the disadvantages of simple aspiration. Recurrence with its inherent costs and risks is not addressed with simple aspiration and is further compounded by an initial failure rate of 25% in PSP and 63% in SSP.^{35,36,39} Inability to easily predict in whom aspiration will be successful further complicates its use. Finally, the premise that the patient can be safely sent home if aspiration achieves a normal chest radiograph needs to be scrutinized in a carefully controlled trial. These considerations argue an alternate choice to simple aspiration in both PSP and SSP.

Chest Tube (Tube Thoracostomy)

The limitations of simple observation and simple aspiration have led many physicians to consider a more aggressive approach to SPs. Chest tubes have

been advocated for patients with PSP failing simple aspiration and for most patients with a SSP.^{1,4,5}

However, several questions need to be addressed when choosing chest tube treatment of an SP. What is the success rate? How long should the tube be left in place? When is it appropriate to proceed to a more aggressive intervention when a chest tube fails? What steps should be taken in removing a chest tube? Does a chest tube alone prevent future recurrences of an SP? What tube size is optimal? What drainage device, if any, should be attached to the chest tube? Should suction be applied to the chest tube? What are the risks for developing reexpansion pulmonary edema by using a chest tube?

How successful is a chest tube and how long should a chest tube be left in place before proceeding to a more definitive procedure?

Recent articles by Schoenenberger et al^{43,44} address many of these questions for PSP, SSP, and iatrogenic pneumothoraces. One hundred fifteen patients with an SP radiographically $>20\%$ were reviewed retrospectively.⁴³ Patients with a first occurrence or first ipsilateral recurrence of a PSP or first event of SSP due to COPD received treatment by protocol of a 20 to 24F chest tube attached to a closed two-bottle drainage system. Suction, up to 25 cm H₂O, was applied gradually after 20 to 30 min. The tube was left in place for up to 10 days with careful recording of the presence or absence of an air leak. If the leak stopped, suction was discontinued for 24 h and the tube was clamped for another day. Unless the radiograph or initiation of suction noted the presence of pneumothorax, the tube was removed and the patient discharged from the hospital 24 h later. If after 10 days of chest tube and suction a leak persisted, surgical pleurectomy or thoracoscopy with talc insufflation was performed.

Ninety-five patients suffered a PSP (72 first occurrence, 23 first recurrence) and 20 a first occurrence SSP. Air leaks stopped within 5 h in 52% and 48 h in 82% of patients with PSP. Patients with SSP had 5-h and 48-h air leak termination rates of 25% and 60%, respectively. Importantly, if an air leak persisted for >48 h, continued chest tube and suction for up to a total of 10 days yielded few additional pleural closures in patients with either PSP or SSP.⁴³ Separately studied iatrogenic pneumothoraces had spontaneous healing by 72 h in 100% of patients without underlying lung disease and in 71% of patients with lung disease.⁴⁴ Compared to historical recommendations of 5 to 7 days of continued suction in the setting of a continued air leak or lung that would not reexpand,^{1,4,5} the studies of Schoenenberger et al^{43,44} would suggest a 48- to 72-h move to more aggressive care.

Earlier detection of air leak cessation may also

lead to earlier chest tube removal and patient discharge from the hospital. A suction pump device (Pleupump) capable of detecting volumes as low as 0.01 L reduced mean suction time from 8.1 days to 4.8 days and hospital days from 10 to 6.5 in patients with SP.⁴⁵ The authors suggest that the benefits were obtained by having a very accurate gauge of air leakage. Patients were not subjected to premature chest tube clamping while an air leak persisted and were not continued with a chest tube long after discontinuance of an air leak.⁴⁵ Caution should be exercised in use of this device with high-volume air leaks as it is capable of only a 4 L/min capacity.⁴⁵

*How should a chest tube be removed?*⁹

Different approaches are taken to removing a chest tube once an air leak subsides. The conservative approach is to leave the chest tube in place for 24 h after the air leak subsides and the lung reexpands.⁴³ Then the tube may be clamped for an additional 24 h and removed if recollapse does not occur.^{5,7,8,40,43,44,46} However, clamping times as short as 4 h have been used with success in patients with spontaneous and iatrogenic pneumothoraces.^{47,48} Regardless of the pneumothorax etiology, the shorter clamp time of 4 h did not appear to adversely affect outcomes and could significantly reduce hospital time and cost.

Two studies investigating issues of chest tube withdrawal provide tentative clues to appropriate removal techniques.^{49,50} Trauma patients suffering pneumothorax were all initially placed on chest tube suction and at the time of air leak termination were randomized to continued suction or placement on a regimen of water seal.⁴⁹ Patients randomized to a water seal regimen had chest radiographs performed at 6 and 24 h after institution of water seal and the chest tube was removed at 24 h if no recurrence of the pneumothorax was noted radiographically. Patients placed on a regimen of suction had no further radiographs performed with chest tube removal occurring 24 h after air leak resolution. Both the water seal group and suction group had a similar incidence of recurrent pneumothorax (2.5%) after chest tube removal. However, total chest tube time and the time between air leak cessation and tube removal were both significantly shorter in the suction group.⁴⁹ The authors surmise that subclinical air leaks, likely present in both groups, seal better under the influence of suction.⁴⁹ Furthermore, suction may aid in the visual determination of air leak cessation.

Chest tubes may be removed too soon despite lung reexpansion and air leak cessation.⁵⁰ Sharma et al⁵⁰ prospectively randomized 40 patients with SP (PSP and SSP not defined) to immediate (within 6 h of lung reexpansion) and late (after 48 h of lung reexpansion) chest tube removal. Regardless of the

presence or absence of suction, patients were found to have a 25% chance of lung recollapse if the tube was removed within 6 h of lung reexpansion and air leak cessation.⁵⁰ No lung recollapse occurred if removal occurred ≥ 48 h after lung reexpansion and air leak cessation.⁵⁰ Prospective analysis of various chest tube removal algorithms is needed to determine safe and timely chest tube termination sequences.

*Do chest tubes alone provide SP recurrence prevention?*⁹

A chest tube alone does not substantially prevent SP recurrence. During the 7-year study period of Schoenenberger et al,⁴³ a recurrence occurred in 34% of PSP patients and in 30% of SSP patients when treated with a chest tube alone. These percentages are similar to those of a Veterans Administration cooperative study in which patients with PSP and SSP treated with a chest tube alone had recurrences of 32% and 43%, respectively.⁹ A similar failure was noted in an earlier study in which proportions of PSP and SSP were not defined.³³ Recurrence rates were found to be 49% for patients treated with bed rest alone, 40% for those treated with bed rest and subsequent chest tube, and 38% for those treated with a chest tube alone.³³

*What size chest tube is appropriate?*⁹

The decision to use small-bore or large-bore chest tubes is dependent on many variables. Variables determining success include the probability of a continued air leak, the magnitude of such a leak, and whether mechanical ventilation is present or planned.

Pneumothoraces often enlarge following mechanical ventilation. Patients with occult pneumothoraces detected incidentally by abdominal CT have a significant progression of their pneumothorax with the application of mechanical ventilation.⁵¹ Eight of 21 ventilated patients with occult pneumothorax had progression with three developing a tension pneumothorax.⁵¹

Flow through a chest tube is governed by the Fanning equation ($v = \pi^2 r^5 P / fl$; v = flow, r = radius, l = length)⁵²⁻⁵⁵ where p = pressure and f = friction factor. Thus the radius (r) is the most important determinant to maximal air flow. Patients with bronchopleural fistulas arising in the setting of chest trauma, thoracotomy, and ARDS have been noted to have air leaks ranging from <1 to 16 L/min.⁵³ The smallest internal diameter accommodating a maximum flow of 15.1 L/min at -10 cm H₂O suction is 6 mm.^{53,54} One US supplier of chest tube devices (Argyle; Sherwood Medical; St. Louis) provides a 28F chest tube having an internal diameter of 6.88 mm (32F chest tube, 7.95 mm; 36F, 9.09 mm) (personal communication; Robert Walsh, RN, RRT;

Sherwood Medical; St. Louis; March and April, 1996). Chest tubes in the 20F to 24F range (internal diameter range=4.72 to 5.87 mm) may be inadequate.

Multiple studies are available addressing the use of small-bore catheters in the setting of a pneumothorax.^{38,47,48,56-60} The problems with small-bore catheters have included occluded three-way stop cocks,⁵⁶ dislodged catheters,⁵⁶ air leaks exceeding the capacity of the catheter,^{47,56,59} and pleural fluid occlusion.⁴⁷ Further complicating the issue of small-bore catheters is the definition of "small bore." While not universally accepted, the term has been used with catheters up to 14F, which will be used in this report.

One series of patients with PSP and SSP exclusively used small-bore catheters (5.5 or 7.0F) attached to a Heimlich valve.⁶⁰ Success was defined as absence of air leak and lung reexpansion. Sixty of 71 episodes (84.5%) were deemed successes, with full reexpansion in 55 of 71 episodes (77.5%) and partial reexpansion (residual pneumothorax <3 mm) in 5 of 71 episodes (7%). The use of a small catheter was not successful in 11 of 71 episodes (15.5%) and required large-tube thoracostomy in 10 of the 11 and eventual thoracotomy without intervening large tube placement in the remaining one.⁶⁰ A large-tube thoracostomy was successful in 6 of the 10, with open thoracotomy required in the remaining 4. No major complications or episodes of small catheter occlusion were noted.⁶⁰ Despite these encouraging results, caution needs to be exercised in applying these results. Would these results be as optimistic if the subpopulation of patients with SSP were separately defined and analyzed?

Therefore, a small-bore catheter (up to 14F) can be safely used as the initial therapy in all patients with an SP, provided the patient is not at significant risk for a large air leak (receiving mechanical ventilation or likely to be given mechanical ventilation) or catheter occlusion (presence of a pleural effusion). A larger-bore chest tube, $\geq 28F$, should be used in a patient at risk for mechanical ventilation or with accompanying pleural fluid.

What drainage device, if any, should be attached to the chest tube?

Once placed, a chest tube is usually connected to a drainage device if the lung fails to reexpand or an air leak persists. The same resistance considerations in choosing chest tube size need to be applied to the connecting tubing and the drainage device.^{52,53,61,62} Four drainage devices in common use were reviewed in 1985 and 1988 regarding their accommodation of various air flows ([Emerson Post-Operative Pump; JH Emerson Co; Cambridge, Mass]; [PleurEvac; DSP Worldwide; Fall River, Mass]; [Sentinel Seal;

Sherwood-Davis & Geck; St. Louis]; and [Thoraklex; Bard, Inc; Murray Hill, NJ]).^{53,62} The maximal air flows (L/min) achieved through these devices utilizing -20 cm H₂O vacuum were 35.5, 34, 19.7, and 2.3, respectively.⁶² Higher flows were attributed to lower intrinsic device resistances. Further, altering the level of suction from -20 to -40 cm H₂O did not significantly vary chest tube air flow.⁵³ Improper alignment of any valve system can also cause increased resistance.⁶³

Should suction be applied to the chest tube?

So and Yu⁴⁶ found no advantage to suction drainage in a group of patients with 53 episodes of SP with success in the suction group being 50% and nonsuction group being 57%. Hospital stays were 5 and 4 days, respectively. Results were similar for patients with PSP and SSP. More recently, Minami et al⁶⁰ found use of a small catheter and Heimlich valve without suction to be successful (complete lung reexpansion) in 77.5% of 71 episodes of spontaneous pneumothorax. Because suction has been demonstrated to be of benefit in the chest tube removal sequence,⁴⁹ we first place the tube to a one-way valve device (provided a large air leak is not present) or water seal without suction but move to suction if an air leak persists.

What are the risks for developing reexpansion pulmonary edema by using a chest tube?

The etiology of and risks for reexpansion pulmonary edema remain incompletely defined and likely multifactorial in nature.^{4,5} Possible causes include oxygen-free radical generation, increased vascular permeability, and mechanical lung injury.⁶⁴⁻⁶⁶ Multiple logistic regression analysis of the patients of Matsuura et al⁶⁷ revealed young age and extent of lung collapse as independent risk factors for reexpansion pulmonary edema. Reexpansion pulmonary edema was particularly prevalent for patients 20 to 39 years old and less so for patients older than 40 years of age.⁶⁷ The authors also noted a trend for the duration of collapse to be a risk for reexpansion pulmonary edema,⁶⁷ an association noted in earlier reports.⁶⁸⁻⁷⁰ Although tending to occur after reexpansion from >3 days of lung collapse, reexpansion pulmonary edema may occur after shorter periods of collapse, and may be related to rapid reexpansion.⁷¹ Finally, data on the risk of suction precipitating reexpansion pulmonary edema remain anecdotal as it may occur in the absence of suction^{71,72} and may occur on the contralateral side as well.⁷¹

The incidence of reexpansion edema and its associated mortality also remain controversial. A recent retrospective clinical analysis by Matsuura et al⁶⁷ of 146 SP patients documented a 14% incidence of reexpansion pulmonary edema with no associated mortality. Earlier reports have noted an incidence as

high as 25%⁷³ and mortality as high as 19% (9 of 47 cases).⁷¹ Matsuura et al⁶⁷ and Bernstein⁷⁴ have noted that reexpansion edema may be more common but less morbid than often perceived.

The best treatment of reexpansion pulmonary edema remains supportive.⁷¹ Early recognition of the problem and prompt application of continuous positive airway pressure by mask⁷⁵ may forestall mechanical ventilation.⁷¹

Pleural Sclerosis (Pleurodesis)

Once a chest tube is placed, the application of a chemical sclerosing agent through the chest tube, including through a small-bore catheter, may prevent future recurrences. The efficacy, route of application, and toxicities of the agent applied are all important in choosing a sclerosing substance. These factors also influence the decision of which patients should receive sclerosis-mediated recurrence prevention. The primary questions to be answered are as follows: (1) What agent should be utilized? (2) Which patients with an SP should undergo pleurodesis?

The parenteral preparation of tetracycline hydrochloride gained widespread acceptance as the sclerosing agent of choice in the United States until its removal from the market in 1991.⁷⁶ Nevertheless, the lessons learned from tetracycline sclerosis remain valuable to guide issues with other sclerosing agents. In a large, randomized, controlled study of tetracycline pleurodesis in the setting of SP (80% SSP), the recurrence rate for the tetracycline-treated group was 25%, a significant reduction compared with the control group rate of 41%, following treatment with tube thoracostomy alone.⁹ Subgroup analysis suggested that most of the benefits were found in the SSP patients and in patients with recurrence. A more recent prospective study documented recurrence rates for the tetracycline arm of 9% (6/66), for observation of 36% (10/28), for chest tube alone of 35% (18/51), and for thoracotomy of 0% (0/26).³⁴ Recurrences in the tetracycline arm were less common in SSP (1/27; 4%) than in PSP (5/39; 13%).³⁴

Other tetracycline studies provide guidance to issues of persistent air leak, lung reexpansion, pain control, and patient positioning. In the presence of persistent air leak⁹ or in the absence of lung reexpansion, sclerosis tends to be ineffective.³⁴ Pain control was problematic in tetracycline sclerosis^{9,34} but appeared directly proportional to sclerosis success⁹ and was decreased with analgesics, including narcotics.^{9,34} Patient rotation appears unnecessary as distribution of radiolabelled tetracycline is rapid in patients with pleural effusions and a normal pleura.^{77,78} Distribution occurs due to the close proximity

of the parietal and visceral pleural surfaces allowing for capillary action to develop.⁷⁸ Rotation may enhance distribution when significant air prevents distribution of the sclerosant by capillary action due to air separating the pleural surfaces.⁷⁷ It should be noted that to our knowledge, no studies have been performed on these issues in pneumothorax.

The tetracycline derivatives, doxycycline and minocycline, appear suitable alternatives based on studies in patients with malignant pleural effusions.⁷⁹⁻⁸¹ Two studies utilizing doxycycline with a total of 33 patients, receiving doses of doxycycline from 250 to 2,000 mg (often in incremental doses of 500 mg), had complete success in 21 patients (64%) and partial success in an additional five patients (15%).^{79,80} More recently, 21 of 27 (78%) patients receiving doxycycline for malignant effusions had no fluid reaccumulation at 1 month.⁸² Each of four patients with a persistent bronchopleural fistula treated with doxycycline had closure of the air leaks.⁸² Eleven of the 12 patients (92%) with postoperative air leaks and six of seven patients (86%) with malignant pleural effusions had satisfactory results using minocycline (300 mg).⁸¹ Subsequent animal studies employing intrapleural minocycline demonstrated the development of pleural fibrosis,^{83,84} with similar histopathologic changes to those of intrapleural tetracycline.⁸⁴ Hence, either doxycycline or minocycline appears to be an effective pleurodesis agent, particularly in the setting of malignant pleural effusions, and could likely be applied with similar success in patients with SPs. With no data indicating a discriminatory clinical advantage to either agent, the choice based on acquisition costs is doxycycline (Table 1).

Although bleomycin has been advocated as more effective in the setting of a malignant pleural effusion than tetracycline, with effusion recurrences within 30 days being 36% for bleomycin and 67% for tetracycline,⁸⁵ its efficacy in pneumothorax remains undocumented. Further, bleomycin costs are pro-

Table 1—Commonly Used Sclerosing Agents*

Generic Name	Trade Name	Dose (Commonly Used)	Cost/Dose
Minocycline	Minocin	300 mg	\$85
Doxycycline	Vibramycin	500 mg	\$30
Bleomycin	Blenoxane	80 U	\$1300
Talc Slurry	Talc	5 g	\$6 [†]
Talc Poudrage	Talc	5 g	\$6+VAT [‡]

*Costs based on University of Mississippi Medical Center Pharmacy information, 1997.

[†]\$0.18 per gram acquisition price +\$5 sterilization.

[‡]Thirty-minute operating room time+Medicare allowable physician fee (\$1,072, Jackson, Miss).

hibitive and its application in areas of nonmalignancy raises issues of unwarranted toxicity.^{76,86}

Talc provides a very reasonable alternative to tetracycline. Animal studies demonstrate that talc produces a similar pleural reaction as tetracycline class agents.^{87,88} A review of intrapleural talc for pneumothorax or pleural effusion indicates an overall success rate for pneumothorax recurrence prevention of 91%.⁸⁹ Talc poudrage appears to be more prevalent than talc slurry worldwide.⁸⁹ Intrapleural talc administration is associated with the development of fever in up to 69% of patients.⁸⁹ Pain may be mild⁸⁹ to severe.⁹⁰ Empyema, specific to the administration of talc by slurry or poudrage, has been noted in up to 11% of slurry cases and 3% of poudrage cases.⁸⁹ Published sterilization protocols for talc⁹¹ may limit this problem. Long-term risks related to talc pleurodesis appear minimal if asbestos-free talc is used.^{89,92}

The most compelling concern in recent reviews forestalling universal use of talc for SP recurrence prevention is the risk of respiratory failure, including ARDS.^{4,5} The review by Kennedy and others^{89,93} and talc slurry pleurodesis case series note respiratory failure as a problem both for poudrage and slurry, but indicate that this may be a dose-related phenomenon. A 5-g maximum talc dose, by slurry or poudrage, is recommended.^{89,93}

Traditionally, pleurodesis has been performed through a large-bore chest tube.⁹⁴ Successful pleurodesis has been achieved using small-bore catheters in the setting of malignant pleural effusions.⁹⁴ A retrospective comparison of pleurodesis utilizing large-bore (11 effusions) or small-bore tubes (13 effusions) for malignant pleural effusions indicates that a small-bore catheter in this setting is at least as successful as a larger-bore tube.⁹⁵ Therefore, small-bore catheters can be used with success for sclerosis in patients with an SP provided no contraindications (discussed earlier) preclude their use.

In summary, much of the available pleurodesis data must be extrapolated from pleural effusion literature but likely can be applied to SP. Talc appears the most efficacious agent for SP recurrence prevention despite certain rare risks that will likely be mitigated by a ≤ 5 -g dose. Doxycycline and minocycline are likely of similar efficacy to one another and to tetracycline (Table 1).

The case against simple observation or aspiration and the adoption of placing a chest tube with subsequent sclerosis in all patients suffering an SP (Figs 2 and 3) assert that some risk of mortality and a recurrence rate in excess of 25% require definitive therapy that prevents recurrence. This therapeutic choice is further based on ever-decreasing economic health-care resources. Additional studies are needed

to prove that immediate sclerosis after air leak cessation can be accomplished successfully without additional hospital days. Central to this approach should be an open discussion of the issues with the patient, including both the health risks and additional cost of a recurrence. Patients should also be apprised that no reliable method to determine who will have a recurrence is currently available.

The adoption of this more aggressive therapeutic method will no doubt create controversy, but less so in patients suffering an SSP than those with a PSP. However, until prospective randomized controlled trials comparing outcome and costs of the various therapeutic options are available, the most acceptable therapy for patients with either PSP or SSP will remain arguable. Until such studies are complete, current literature supports more aggressive management.

Surgical Interventions

Videothoracoscopy vs Thoracotomy: Thoracotomy with various intraoperative interventions has been a mainstay of definitive therapy to prevent recurrence in patients with an SP.^{96,97} Thoracoscopy offers excellent visualization of the pleura and lung and when combined with intraoperative interventions also provides recurrence prevention.⁹⁶ The introduction of video technology (VAT), improved instrumentation, and fiberoptics has further encouraged thoracoscopic utilization. Thoracotomy achieves pneumothorax recurrence prevention by either mechanical abrasion pleurodesis or pleurectomy with recurrence rates of 2 to 5% and $< 1\%$, respectively.⁹⁶ Comparable success may be possible with thoracoscopy, but multi-institutional verification is yet to be reported.⁹⁶

The goals of either procedure are to ablate bullous lung disease and induce pleural symphysis through various intraoperative maneuvers. Accepted indications for surgical intervention include persistent air leak, recurrent pneumothorax, contralateral pneumothorax, simultaneous bilateral pneumothoraces, and a first pneumothorax occurring in a patient with a high-risk occupation such as diving or flying.⁹⁸⁻¹⁰⁰

Numerous reports have described thoracoscopic approaches to the management of SP.⁹⁹⁻¹¹¹ Thoracoscopy allows definitive treatment of an SP through ablation of bullous disease by electrocautery,^{103,107} laser,^{105,108,110} suture ligation techniques,^{101,102,105,106,109-111} or staple devices,^{98-104,109-111} and pleural sclerosis by mechanical means (including pleurectomy),^{98-104,106,109-111} chemical use,¹¹¹ or talc application.^{101,103,104} Potential advantages to a thoracoscopic approach over thoracotomy in patients with SP include more rapid full lung reexpansion and reduced postoperative pulmonary dysfunction and pain that results in a shorter hospital stay.^{96,98,106}

Despite the presumed advantages, to our knowledge, only one report provides a prospective, controlled, randomized comparison of thoracoscopy (VAT) to thoracotomy in the management of SP.¹⁰⁰ Sixty patients with SP received treatment by VAT or posterolateral thoracotomy.¹⁰⁰ Inclusion criteria included a recurrent SP or an air leak persisting for >5 days. With either surgical approach, patients underwent apical pleurectomy, and bullectomy when appropriate, utilizing a stapling device. Patients with SP, regardless of PSP or SSP, undergoing VAT had significantly longer operative times. The thoracotomy group had larger postoperative decrements in FEV₁ and FVC. However, no difference was noted in postoperative morphine use, chest drainage days, length of stay, primary treatment failures (persistent air leak postoperatively), recurrences, or deaths.¹⁰⁰ Primary treatment failures occurred in 4 of 30 (13%) VAT patients and 1 of 30 (3.3%) thoracotomy patients, all with SSP. After a mean follow-up of >15 months, pneumothorax recurrence was 2 of 30 (6.7%) for VAT and 1 of 30 (3.3%) for thoracotomy, all in patients with PSP.¹⁰⁰ The authors conclude from their randomized study that VAT is superior to thoracotomy in the treatment of patients with PSP.¹⁰⁰ This conclusion appears based on trends of lower postoperative analgesic use and length of stay. The authors further conclude that VAT is less reliable in patients with SSP, but may be of benefit to those in whom an open procedure would not be tolerated.¹⁰⁰

Given the data, these conclusions favoring VAT may be inappropriately encouraging. VAT did not statistically lessen length of stay and was associated with increased operating room time, particularly in patients with SSP,¹⁰⁰ theoretically increasing costs.

Until further prospective studies comparing VAT and minithoracotomy are available, the initial enthusiasm for thoracoscopy should be tempered. Although thoracoscopy provides effective management to most patients with SP, to label it the best available operative option for SP seems premature. Since none of the intraoperative options, including pleurodesis agents,⁹⁷ has been shown to be more advantageous over another, randomized controlled analysis of both thoracoscopic and thoracotomy approaches to SP are needed to determine which operative approach and intraoperative interventions are most efficacious.

The benefits of thoracotomy should be stressed lest they be forgotten in the ongoing enthusiasm for VAT. Studies applying thoracotomy (including the axillary approach), mechanical pleurectomy (both apical and full), and bullous lesion removal in the setting of PSP and SSP found recurrences of <1% with a mean follow-up of >4 years.^{26,112} Major

complications were seen in 3.8% of 233 patients of Weeden and Smith²⁶ and included three deaths (1.3%, all of whom underwent full pleurectomies), four episodes of respiratory failure (1.7%), and two episodes (0.8%) of significant hemorrhage. A clear association between these complications and underlying COPD could be defined.²⁶ The series of Deslauriers et al¹¹² of 409 apical (partial) pleurectomies via transaxillary approach and bullous lesion repairs was accompanied by only one incidental death (0.2%) due to an unrecognized brain tumor, hemorrhage in three, and significant air leak in two for a total major complication rate of 1.2%. The total significant complication rate of these two series, including deaths, is 14 of 642 patients (2.2%).^{26,112}

Pleural abrasion of the visceral and/or parietal pleural surface is a less radical alternative to pleurectomy,¹¹³ although it is technically difficult to perform through a cosmetically appealing transaxillary approach.¹¹² Three recent series incorporating thoracotomy with pleural abrasion in 237 mixed patients with PSP and SSP demonstrated posthospitalization recurrences varying from 1 to 3.6% in follow-up of 7 months to 5 years.¹¹⁴⁻¹¹⁶ Complete parietal pleural abrasion was clearly defined in one study,¹¹⁵ but was implied in the remaining two.^{114,116} Postoperative complications consisted of six patients with early, in-hospital, pneumothorax recurrence after chest tube removal (6/237; 2.5%),¹¹⁶ seven patients with postoperative air leaks lasting ≥ 5 days (7/237; 2.9%),^{114,116} and one episode of notable hemorrhage (1/237; 0.4%),¹¹⁵ for a total complication rate of 5.9% (14/237). Long-term postthoracotomy chest discomfort occurred in two patients.¹¹⁶ No deaths were recorded.

The efficacy of pleural abrasion in SSP has been questioned recently. An earlier report by Videm et al⁷ of 303 patients suggested that pleural abrasion was well tolerated in COPD patients. No recurrences were noted in an unspecified period of follow-up.⁷ A more recent retrospective study in patients undergoing thoracotomy with pleural gauze abrasion and bullous revision noted a significantly higher recurrence rate in patients with SSP (3/24; 12.5%) compared with PSP (3/100; 3%) ($p < 0.05$)¹¹⁷ in a minimum 2-year follow-up. In contrast to the earlier study by Videm et al,⁷ this more recent study with fewer patients¹¹⁷ found perioperative complications were restricted to patients with SSP and included air leaks persisting >5 days, and one episode each of pneumonia and heart failure.

In summary, total pleurectomy with bullous resection remains the gold standard for recurrence prevention. Further studies are needed to document whether limited apical pleurectomy or pleural abrasion, done either through a thoracotomy or VAT,

carries benefits in the postoperative course that balance the slightly lower efficacy rate. In addition, apical pleurectomy may not be adequate in patients with extensive COPD.

Median Sternotomy: Given the bilateral nature of the disease in PSP and SSP, more aggressive surgical approaches to recurrence prevention in patients with SP have been recommended by some. An early citation dating to the late 1950s advocates bilateral thoracotomy with exposure of both hemithoraces.¹¹⁸

Surgical approaches allowing bilateral exposure to the hemithoraces reappeared in the 1970s. Kalnins et al¹¹⁹ reported the use of median sternotomy to approach bilateral parietal pleural abrasion, talc instillation, and bullous ligation. Twenty-six patients, 16 of whom had experienced symptoms of bilateral pneumothorax, underwent median sternotomy with 25 of the 26 found to have evidence of bilateral cysts or blebs. No operative complications or recurrences in 2 years of follow-up were reported despite limited access to the posterior and basal portions of the lung.¹¹⁹ Patients appeared to have more rapid convalescence and less pain than after a lateral thoracotomy.¹¹⁹ Similar reports,^{10,120-126} applying median sternotomy with intraoperative bullous repair and/or pleural symphysis techniques as therapeutic approach(es) to pneumothorax, have appeared and validate the success of Kalnins et al.¹¹⁹

Ikedo et al¹⁰ demonstrated the recovery of lung function after a median sternotomy for SP noting a 1-month postoperative vital capacity of >80% of predicted in 21 of 23 patients. Moreover, a comparative study of median sternotomy and lateral thoracotomy in patients not undergoing pulmonary resection demonstrated that median sternotomy patients had a more prompt recovery of peak flow and vital capacity measurements beginning by postoperative day 4 and persisting by day 7.¹²⁷

Given these advantages of median sternotomy, the criticisms and questions regarding its use in patients with pneumothorax may need to be reconsidered. Perhaps a more helpful question would be to consider why we do not employ this highly successful approach, with less morbidity than thoracotomy, more frequently in patients with SP? Until this question is clearly answered, median sternotomy in the setting of SP should be limited to patients with a contralateral recurrence, with simultaneous bilateral pneumothoraces, or with considerable pneumothorax risk such as divers and aviators having a history of an SP. Other patients likely to benefit would be those suffering a spontaneous pneumothorax with AIDS complicated by *P carinii* pneumonia and patients with a history of familial SP given their high incidences of bilateral involvement.^{124,126} The development of more refined CT scoring systems in

patients with SP may lead to median sternotomy becoming the procedure of choice in patients in whom a high contralateral recurrence could be reliably predicted.

Special Therapeutic Concerns

Therapeutic considerations to this point have been focused on general options in patients with PSP and in patients with SSP due to COPD. The reader is referred to other sources for therapeutic issues related to other secondary causes of spontaneous pneumothorax such as Pneumocystis, tuberculosis, cystic fibrosis, or catamenial pneumothorax.^{4,5}

However, the potential lung transplant patient with pneumothorax should be approached with forethought. Preexisting pleural abnormalities were once considered contraindications to lung transplantation because of the high incidence of pleural hemorrhage during adhesion lysis for native lung removal.¹²⁸ Therefore, optimal pneumothorax prevention in a transplant candidate should afford the greatest degree of prevention with the minimum degree of pleural fibrosis.¹²⁸ The procedure achieving this goal may well be thoracotomy or VAT with apical bullectomy and apical pleural abrasion. The use of chemical pleurodesis or extensive pleurectomy or abrasion should be restricted to those patients failing a limited approach. However, if a more extensive intervention is used, transplant is not absolutely precluded.¹²⁸ Close communication with the potential transplant candidate's coordinating transplantation center is encouraged before embarking on therapy.

The recent repopularization of lung reduction surgery for the treatment of COPD opens potential options to be considered in patients with severe COPD and an SP. Such patients may be ideal candidates for not only a pneumothorax recurrence prevention procedure but also lung reduction. However, given the controversies surrounding the application and implementation of lung reduction sur-

Table 2—Areas in Which Additional Pneumothorax Research Is Needed

1. To determine safety, costs, and outcomes of recurrence prevention in PSP and SSP, including a comparison of chemical sclerosis and surgical options.
2. To determine the optimal sequence of chest tube removal.
3. To determine if chest CT adds meaningfully to the workup and management of SP (with or without surgery).
4. To define the risks of pneumothorax recurrence and apply them prospectively for validation.
5. To determine if symptoms, time of presentation, sex, comorbid disease, duration of pneumothorax, and size of pneumothorax help in predicting patient groups best treated with simple observation.

Table 3—Potential Cost-Limiting Steps to SP Currently Supported by Available Information*

1. Appropriate initial selection of a chest tube and drainage device, *ie*, limit use of small-bore devices to patients not likely to require mechanical ventilation or have significant air leaks. (Could limit need for additional chest tube placement and replacement of inadequate drainage devices.)
Potential cost savings:[†] based on one chest tube, one chest tube tray, one drainage device, and one portable chest radiograph: \$322.
2. Definitive intervention, often surgical, in patients with air leaks persisting ≥ 48 h (time potentially saved: 3 to 5 d).
Potential cost savings:[†] based on 3 to 5 day additional room charges: \$585 to \$975.
3. Timely removal of chest tubes (time potentially saved: ≥ 24 h).
Potential cost savings:[†] based on 1 additional hospital day room charge: \geq \$195.

*See text for further discussion.

[†]Cost savings based on current patient charges at the University of Mississippi Medical Center; costs *do not include physician fees, unless indicated, or other ancillary fees*: chest tube, \$37; chest tube tray, \$32; portable chest radiograph (including reading fee), \$68; drainage device (Thoraklex), \$185; and 1-day room charge (semiprivate), \$195.

gery,¹²⁹⁻¹³² the inclusion of patients with both severe COPD and pneumothorax for lung reduction surgery may only further complicate unresolved issues.

CONCLUSIONS

Therapeutic options in SP are developing at a pace outstripping the available objective information regarding their success. While newer options such as VAT should be considered, investigated, and greeted with cautious enthusiasm, older therapeutic options such as thoracotomy and even median sternotomy should not be overlooked. CT analysis of patients with SP should be further studied with the hope of better risk prediction and patient stratification. Additionally, greater attention and research in areas of chest tube management and other therapeutic interventions may allow more efficient patient care (Table 2). Although some of the therapeutic approaches (Figs 2 and 3) to SP are more aggressive than previous recommendations, they may limit the length of hospital stay, readmissions for recurrences, and ultimately the cost of caring for patients with SP (Table 3).

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