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EXPERT CONSENSUS DOCUMENT

The Society of Thoracic Surgeons Expert Consensus Document on the Management of Pleural Drains After Pulmonary Lobectomy

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The Society of Thoracic Surgeons Workforce on Evidence-Based Surgery provides this document on management of pleural drains after pulmonary lobectomy. The goal of this consensus document is to provide guidance regarding pleural drains in 5 specific areas: (1) choice of drain, including size, type, and number; (2) management, including use of suction vs water seal and criteria for removal; (3) imaging recommendations, including the use of daily and postpull chest roentgenograms; (4) use of digital drainage systems; and (5) management of prolonged air leak. To formulate the consensus statements, a task force of 15 general thoracic surgeons was invited to review the existing literature on this topic. Consensus was obtained using a modified Delphi method consisting of 2 rounds of voting until 75% agreement on the statements was reached. A total of 13 consensus statements are provided to encourage standardization and stimulate additional research in this important area.

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MANAGEMENT OF PLEURAL DRAINS AFTER PULMONARY LOBECTOMY EXPERT CONSENSUS STATEMENTS

1. A single pleural drain may be associated with less pain and shorter length of stay compared with 2 drains.
2. A 19F to 24F pleural drain is appropriate after a standard lobectomy.
3. The choice of a conventional chest tube vs a channel pleural drain should be based on surgeon preference and cost.
4. Early transition to water seal is preferred when a conventional chest tube and a traditional analog drainage system are used for pleural drainage.
5. A drainage threshold of 450 mL or less over 24 hours for nonbloody and nonchylous effusions is a reasonable threshold to allow safe removal of a pleural drain.
6. Routine daily chest roentgenograms are not required in a stable patient after lobectomy.

The Appendix can be viewed in the online version of this article [https://doi.org/10.1016/j.athoracsur.2024.04.016] on http://www.annalsthoracicsurgery.org.

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7. A chest roentgenogram after removal of a pleural drain can be safely omitted in a patient who is clinically stable and has not required a clamp trial.
8. Digital air leak systems are at least comparable to traditional analog systems. They may provide additional benefits such as delivery of a regulated form of suction, decreased interobserver variability, and improved patient mobility.
9. Digital air leak monitoring devices have an increased absolute cost compared with analog systems and may be potentially cost-effective only if use leads to a decrease in length of stay compared with analog systems.
10. Early discharge with a pleural drain and close outpatient follow-up can be considered but must be weighed against the risks.
11. Pleurodesis with an autologous blood patch is safe and effective for patients with a prolonged air leak after lobectomy and is preferred over chemical pleurodesis.
12. There is insufficient evidence to recommend the use of endobronchial valves in patients with a prolonged air leak after lobectomy.
13. A bronchopleural fistula or a system leak should be excluded before reoperation for a prolonged air leak after lobectomy.

Pulmonary lobectomy is the most common procedure performed by thoracic surgeons in the United States.[1] Standard practice is for all patients who undergo lobectomy to be managed with 1 or more pleural drains. Consequently, care of these drains is a universal component of thoracic surgical practice. Nonetheless, few guidelines have been published on this topic despite the plethora of published literature. Recognizing this need, The Society of Thoracic Surgeons (STS) Workforce of Evidence-Based Surgery convened a task force to develop this expert consensus document.

GOAL. The goal of this consensus document was to provide guidance regarding pleural drains in 5 specific areas:

1. Choice of drain (number, size, and type)
2. Management (suction vs water seal, criteria for removal)
3. Imaging recommendations (daily and post-pull chest roentgenograms)
4. Digital drainage systems
5. Management of prolonged air leak (PAL)

METHODOLOGY. A writing group consisting of experts in the field of general thoracic surgery was enlisted by the STS Workforce on Evidence-Based Surgery. Key questions regarding chest tube management after lobectomy were defined among the writing group. Relevant literature was searched in MEDLINE for articles published in English since 1990. Given the relative paucity of comparative effectiveness research pertinent to this topic, the writing group decided to proceed with the development of an Expert Consensus Document, forgoing formal recommendations with a class rating and level of evidence as used in STS clinical practice guidelines.

Using the available literature and expert opinion among the writing group members, consensus statements were then developed using a modified Delphi method. The proposed statements were subject to a vote using a 5-point Likert scale.[2] An 80% response rate among the authors was required, and statements in which 75% of respondents selected "agree" or "strongly agree" were considered to have reached consensus. The proposed statements and the writing group's respective voting results are included in the Appendix.

CHOICE OF PLEURAL DRAINS

Pleural drainage after lobectomy has traditionally involved 2 large-bore, semirigid pleural drains to evacuate air and fluid from the pleural space.[3] Although this technique may provide the best means for lung reexpansion, such a practice may also increase postoperative pain and reduce early mobilization. Consequently, many studies have challenged this convention and investigated the use of a single conventional chest tube, as well as alternative flexible and smaller-size catheters.

NUMBER OF PLEURAL DRAINS. The use of 1 vs 2 pleural drains has been well studied. Three meta-analyses on this topic[4-6] concluded that use of a single tube is associated with reduced pain scores and shorter length of stay (LOS). The most recent meta-analysis evaluated 11 randomized clinical trials (RCTs) with a total of 1214 patients.[4] Most of these studies were performed in China, with sample sizes ranging from 43 to 183 patients per trial. All patients underwent lobectomy with no significant difference in air leak or reintervention rates. However, pain scores, duration of drainage, and overall LOS were significantly reduced in the single pleural drain group. Two earlier meta-analyses from 2016 reached similar findings.[5,6]

Several publications have addressed a strategy of no pleural tube use after pulmonary resection. A meta-analysis by Li and colleagues[7] evaluated 12 studies with 1381 patients and reported reduced

LOS and pain scores in the "no chest tube" group compared with patients with a chest tube. However, only a small proportion of patients underwent anatomic resection (n = 212; 15%), and no difference in LOS was noted in this subgroup. Consequently, the members of the expert consensus panel deemed there to be insufficient data to make a recommendation on the practice of omitting a chest tube.

PLEURAL TUBE SIZE. Few studies have addressed the optimal size of a conventional chest tube after lobectomy. However, trauma studies have suggested that smaller-size tubes are as effective as larger tubes to drain hemothoraces.[8,9] The consensus group identified only 2 papers that specifically studied patients who had undergone lobectomy. The first was a prospective, single-center observational study of 383 patients from a single center in the United Kingdom.[10] Tube size ranged from 18F to 32F, with the majority being 28F. The study investigators noted a significant decrease in subcutaneous emphysema with a 28F or larger pleural tube and no difference in narcotic requirements. In contrast, a retrospective study compared the use of 8F and 24F pleural drains in 168 patients undergoing thoracoscopic lobectomy. Lower pain scores and reduced LOS were observed in the 8F drain group, with no difference in pleural drain reinsertion rate or hemorrhage.[11]

Given the paucity of clinical data, the recommendation of the consensus panel was made on the basis of the clinical practice of its members. For a standard, uncomplicated lobectomy, a size 19F to 24F tube is endorsed. Larger tubes may be appropriate for patients with extensive adhesiolysis or a higher risk of postoperative hemorrhage.

TYPE OF PLEURAL DRAIN. Postoperative pain after thoracic surgery is often attributed to pleural drains. Rigid tubes placed through the intercostal space may lead to compression of the adjacent nerve and result in neuropathic pain. Consequently, surgeons have considered alternative pleural drains that are less rigid and may theoretically cause less pain. However, such channel ("Blake") drains have a smaller cross-sectional area and may not evacuate fluid and air as efficiently as standard pleural tubes.

Only 1 randomized trial specifically compared channel drains with conventional chest tubes.[12] In this study, 100 consecutive patients were randomized to either a 19F channel drain or a conventional chest tube. However, the size and number of pleural drains used were not reported, nor was the proportion of patients who underwent lobectomy. The study investigators reported lower pain scores in the channel drain group, without drain-related complications, and no difference in overall LOS.

Three retrospective studies also demonstrated the safety of channel drains after pulmonary surgery.[13-15] For instance, a series from Japan reviewed 148 patients, the majority of whom (76%) underwent lobectomy.[13] An equal number of patients received a 19F channel drain and a 32F conventional tube. The study investigators observed no difference in fluid drainage or LOS between the groups. Importantly, channel drains were inferior to conventional tubes in evacuating air in the presence of an air leak. These investigators also reported that suction was required for channel drains to achieve fluid drainage comparable to conventional chest tubes.

Given the lack of clarity from the literature, the members of the consensus group recommended that the choice of a conventional chest tube vs a channel pleural drain should be left to the discretion of the surgeon.

CONSENSUS STATEMENTS.

1. A single pleural drain may be associated with less pain and shorter length of stay compared with 2 drains.
2. A 19F to 24F pleural drain is appropriate after a standard lobectomy.
3. The choice of a conventional chest tube vs a channel pleural drain should be based on surgeon preference and cost.

MANAGEMENT OF PLEURAL DRAINS

Postoperative management of pleural drains is a balance between 2 opposing strategies. On the one hand, early transition to water seal and drain removal should reduce patient discomfort and LOS. On the other hand, a strategy of active suction may promote earlier pleural apposition and resolution of air leak. Indeed, a higher threshold for drain removal may reduce subsequent development of pleural effusions and the need for reintervention. Although practices vary widely among surgeons and institutions, these issues have been subjected to rigorous clinical investigation.

WATER SEAL VS SUCTION. Decisions regarding water seal vs suction are frequently made on the basis of opinion and dogma rather than scientific evidence. Nonetheless, several studies have been

TABLE 1 Randomized Clinical Trials Evaluating Suction Levels for Traditional and Digital Drainage Systems

Author, Reference, and Year	System	Comparison Groups	Population	Conclusion
Cerfolio,[16] 2001	Traditional	WS vs −20 mm Hg	n = 140 total n = 78 lobectomy or bilobectomy	Decreased AL duration with WS
Marshall,[17] 2002	Traditional	WS vs −20 mm Hg	n = 68 total n = 49 lobectomy	Decreased AL duration with WS
Brunelli,[18] 2004	Traditional	WS vs −20 mm Hg	n = 150 All lobectomy	No difference in AL or CT duration
Alphonso,[19] 2005	Traditional	WS vs −20 mm Hg	n = 239 total n = 111 lobectomy	No difference in AL duration
Prokakis,[20] 2008	Traditional	WS vs −20 mm Hg	n = 91 All lobectomy or bilobectomy	No difference in AL duration
Gocyk,[21] 2016	Traditional	WS vs −20 mm Hg	n = 254 n = 141 lobectomy	No difference in AL duration Decreased CT duration and PAL in the WS group
Brunelli,[27] 2013	Digital	Regulated suction (−11 mm Hg to −20 mm Hg) vs −2 mm Hg	n = 100 All lobectomy	Nonsignificant trend in AL duration favoring regulated seal
Lijkendijk,[29] 2019	Digital	−5 mm Hg vs −20 mm Hg	n = 106 All lobectomy	No difference in AL duration or LOS
Holbek,[28] 2018	Digital	−2 mm Hg vs −10 mm Hg	n = 228 All lobectomy	Decreased AL duration and LOS in −2 mm Hg group

AL, air leak; CT, chest tube; LOS, length of stay; PAL, prolonged air leak; WS, water seal.

conducted on this topic. These are discussed later and favor a strategy of early transition to water seal. These studies focus predominantly on patients with a conventional chest tube and an analog drainage system. Use of channel ("Blake") drains and digital drainage systems will be considered separately.

In total, 6 RCTs,[16-21] 3 systematic reviews or meta-analyses,[22-24] and 2 clinical practice guidelines[25,26] have been published on this topic (Table 1). In an RCT by Gocyk and colleagues,[21] 254 patients were randomized to either water seal or −20 cm H_2O suction on the first postoperative day if the remaining lung was fully expanded. These investigators reported a decreased time to drain removal (5.6 days vs 4.5 days) and a reduction in PAL (5.6% vs 0.7%) in the water seal group.

The 3 published systematic reviews found no benefit to suction, with similar drain duration, LOS, and rate of PAL between water seal and suction strategies. However, it was also consistently observed that the incidence of a residual pleural space was higher in the water seal group. Finally, the European Society of Thoracic Surgeons[25] guidelines for enhanced recovery after lung surgery concluded that "there does not appear to be an advantage to the routine application of external suction in terms of shortening the duration of air leak, chest drainage or length of stay."

It is important to understand that these studies are not directly applicable to digital drainage systems. Digital systems do not have a traditional water seal mode. Instead, a regulated suction mode is used, in which a preset negative pressure level is maintained in the presence of an air leak. Even at very low preset suction levels, if an air leak is present, the device exerts active suction.

Three randomized studies have investigated different levels of suction with digital systems (Table 1).[27-29] Unfortunately, each study evaluated varied levels of suction, and the outcomes did not consistently favor the lower-suction vs the higher-suction group. Given these inconsistent results, and that ambulation is possible irrespective of the suction setting, the consensus group opted against making any specific recommendations regarding suction levels with digital systems.

The evacuation of fluid and air from channel drains is not equivalent to that achieved by rigid pleural tubes. Although this issue has not been well studied, 1 publication reported that fluid drainage and sufficiency of air evacuation were lower in patients with channel drains.[13] The authors of that report concluded that "suction is required for the Blake drain to obtain fluid drainage performance comparable to that of the water-sealed chest drain. When air leakage occurs, air evacuation by the Blake drain tends to be insufficient, irrespective of suction conditions."[13]

VOLUME THRESHOLDS FOR DRAIN REMOVAL. Efforts to reduce LOS after pulmonary resection have

TABLE 2 Randomized Studies Evaluating Volume Thresholds for Drain Removal After Lobectomy

Author, Reference, and Year	Population	Volume Threshold	Conclusion
Zhang,[32] 2014	n = 90	300 mL/24 h vs 100 mL/24 h	LOS less with 300 mL/24 h No difference in thoracentesis
Xie,[33] 2015	n = 168	150 mL/24 h (A) 300 mL/24 h (B) 450 mL/24 h (C)	LOS less for B and C; more thoracentesis in C
Motono,[34] 2019	n = 70	450 mL/24 h vs 200 mL/24 h	Less drain duration with 450 mL/24 h; no thoracentesis necessary
Stamenovic,[35] 2022	n = 80	250 mL/kg/d vs 5 mL/kg/d	Less drain duration and LOS in the 5 mL/kg/d group

LOS, length of stay.

renewed focus on the appropriate volume threshold for drain removal. A higher-volume threshold to remove these drains may, theoretically, lead to a higher rate of pleural effusion with the consequent need for thoracentesis. Moreover, all the studies on this topic assume that no air leak is present and that the fluid is nonchylous and nonbloody before the drain is removed. However, the criteria to define output as "nonbloody" are subjective. Furthermore, to our knowledge, no studies have documented whether there are adverse consequences to removing a chest tube with "bloody" output.

Numerous observational trials[30,31] and prospective randomized trials,[32-35] as well as 2 meta-analyses,[36,37] have been published on this topic. All randomized trials included only patients who underwent lobectomy or bilobectomy (Table 2). Although the volume thresholds varied, 2 of the trials specifically addressed the safety of a drainage threshold of 450 mL/d. In a study by Xie and colleagues,[33] 168 consecutive patients who underwent video-assisted thoracoscopic surgery (VATS) lobectomy were randomized to 1 of 3 groups on the basis of the threshold for drain removal: (1) 150 mL/d, (2) 300 mL/d, or (3) 450 mL/d. Patients in both the second and third groups had a significant reduction in pain scores and LOS. However, the rate of thoracentesis was higher in the third group (0% vs 2% vs 15%). In contrast, a more recent trial by Motono and colleagues[34] randomized 70 patients who underwent lobectomy to drain removal with a threshold of either 200 or 450 mL/d, and thoracentesis was not required in either group. The 2 meta-analyses also concluded that tubes can be safely removed with high output; however, "high-output" in these trials was considered 250 to 300 mL/d. Guidelines from the European Society of Thoracic Surgeons[25] also support a threshold of 450 mL/d for drain removal.

In considering the totality of the published literature, inclusive of both observational and randomized trials, as well as individual clinical practice, the consensus group endorses a threshold of 450 mL/d for safe removal of a pleural drain after lobectomy.

CONSENSUS STATEMENTS.

4. Early transition to water seal is preferred when a conventional chest tube and a traditional analog drainage system are used for pleural drainage.
5. A drainage threshold of 450 mL or less over 24 hours for nonbloody and nonchylous effusions is a reasonable threshold to allow safe removal of a pleural drain.

IMAGING RECOMMENDATIONS

Daily chest roentgenograms are routinely performed after pulmonary resections. This examination is inexpensive, readily available, and can detect important postoperative complications such as hemothorax and pneumothorax, atelectasis, and pleural effusions. Despite these advantages, there are valid reasons to consider limiting the use of postoperative chest roentgenograms, and it is unclear whether daily chest roentgenograms translate into clinically measurable benefit. Many abnormalities on chest roentgenograms do not require intervention and may resolve spontaneously. Furthermore, chest roentgenograms are associated with cumulative costs and time for interpretation. Finally, minor findings on chest roentgenograms often lead to additional imaging that may increase LOS for patients with an otherwise uncomplicated postoperative course.

LITERATURE CHARACTERISTICS. Numerous publications, including prospective randomized trials and meta-analyses, have investigated the clinical benefit

TABLE 3 Studies Evaluating the Utility of Daily Chest Roentgenograms

Author, Reference, and Year	Population	Study Design	Control Group	Conclusion
Graham,[40] 1998	Thoracotomy n = 100 total n = 37 lobectomy	Single center, prospective	None	No benefit
Whitehouse,[41] 2009	Thoracotomy n = 74 n = 11 lobectomy	Single center, prospective	Yes: 8 patients without chest roentgenograms	No benefit
Cerfolio,[42] 2011	Thoracotomy n = 1037 n = 609 lobectomy	Single center, retrospective	None	No benefit
Haddad,[43] 2017	VATS n = 55 n = 37 lobectomy	Single center, prospective	Yes: historical control subjects	No benefit

VATS, video-assisted thoracic surgery.

of daily chest roentgenograms in postanesthesia care units (PACUs) and intensive care units.[38,39] No randomized studies have been published on patients undergoing pulmonary resection. Most reports are therefore limited to single-center retrospective data, although prospective observational trials and systematic reviews also have been published. We considered the literature on 3 types of chest roentgenograms: (1) daily chest roentgenograms and (2) chest roentgenograms obtained once the pleural drain has been removed ("postpull chest roentgenograms") and (3) chest roentgenograms performed in the PACU ("PACU chest roentgenograms").

DAILY CHEST ROENTGENOGRAMS. A total of 4 original publications have reported on the utility of daily chest roentgenograms after pulmonary surgery: 3 retrospective single-center studies[40-42] and 1 prospective single-center[43] study (Table 3). In addition, a systematic review has been published.[44]

There are important limitations to these publications. First, these studies were not limited to lobectomy patients. Indeed, a wide variety of intrathoracic procedures (eg, lobectomy, wedge resection, decortication, and esophageal surgery) were included. Only 55% of total reported cases underwent a lobectomy. Furthermore, 88% of the lobectomy cases were performed in a single institution, and none of these studies used a comparable control group.

Despite these limitations, all these publications reached a similar conclusion: routine, daily chest roentgenograms in an otherwise stable patient do not provide a clinical benefit. The largest study, by Cerfolio and Bryant,[42] was a retrospective review of a prospectively maintained database. These investigators reported on 1037 patients, of whom 609 underwent a lobectomy.[42] Daily chest roentgenograms were performed on all patients. Chest roentgenograms changed the plan of care in 27% of patients who were not hypoxic. However, Cerfolio and Bryant[42] also noted that most of these changes were minor (eg, increasing the suction level) and did not affect the outcome. These investigators concluded that "daily CXRs [chest roentgenograms] are not needed in the vast majority of patients undergoing elective pulmonary resection."[42]

The single literature review on daily chest roentgenograms also advised against this practice. In the review by Reeb and colleagues,[44] 7 papers were identified, although only 3 reported on patients undergoing general thoracic surgery. This review was purely descriptive, without statistical analysis. However, these investigators concluded that a protocol of routine chest roentgenograms could be eliminated in favor of obtaining chest roentgenograms "on demand." Reeb and colleagues[44] acknowledged that the evidence base specifically for patients undergoing pulmonary resection was limited. Their conclusion was strengthened, however, by the robust literature on patients in intensive care units and patients undergoing cardiothoracic procedures for whom daily chest roentgenograms did not provide a clinical benefit.

POSTPULL CHEST ROENTGENOGRAMS. Publications on this topic are single-center series (3 retrospective and 1 prospective) on a total of 948 patients.[41,45-47] One systematic review from 2022 studied 3 of these papers.[48] These series included patients undergoing a variety of intrathoracic procedures, a minority of whom underwent a lobectomy (n = 280; 29.5%). Additionally, only 1 paper reported data on a comparable control group.

Nonetheless, these studies consistently concluded that a routine postpull chest roentgenogram is not necessary in stable patients who did not require a clamp trial. A clamp trial consists of clamping the chest tube for 4 hours to observe for any changes in the patient's clinical status or symptoms, after which a repeat chest roentgenogram is performed. For example, Porter and colleagues[45] reviewed 200 patients (80 of whom had a lobectomy) who had a routine postpull chest roentgenogram. Those patients with an acute clinical change immediately after tube removal were excluded.[45] Although 58% of patients had chest roentgenogram abnormalities, none required a therapeutic intervention. A similar study by Dezube and colleagues[47] reviewed 200 consecutive pulmonary resections (59 lobectomies). Pneumothorax was observed in 55% of postpull chest roentgenograms; however, 95% of these pneumothoraces were small, and none required reintervention. These investigators, albeit lacking randomized data, concluded that routine, postpull chest roentgenograms may not be indicated. Another study by Zukowski and colleagues[46] reviewed 433 patients (120 lobectomies) who had a postpull chest roentgenogram and documented that chest tube replacement was never necessary in asymptomatic patients. These investigators concluded that postpull chest roentgenograms can be "safely omitted in asymptomatic patients with appropriate clinical observation."[46]

POSTANESTHESIA CARE UNIT CHEST ROENTGENOGRAMS. Four original publications (2 prospective[40,49] and 2 retrospective[45,50]) have reported on the utility of PACU chest roentgenograms. In addition, 1 meta-analysis has been published on this topic.[48] All these publications have consistently concluded that PACU chest roentgenograms rarely lead to a clinical intervention and can be safely omitted. For instance, a retrospective study of 241 patients who underwent general thoracic surgery (80 lobectomies) observed that although 48% of PACU chest roentgenograms were "abnormal," none of these findings led to a clinical intervention.[45] The largest series retrospectively reviewed 1097 patients undergoing a variety of VATS procedures.[50] An abnormal chest roentgenogram was defined as a pneumothorax >5 cm, evidence of bleeding, or a malpositioned pleural drain. Only 4% of chest roentgenograms were deemed abnormal using this definition, and a clinical intervention was necessary in 0.9% of patients. The study investigators concluded that "these findings support the abandonment of routine CXRs [chest roentgenograms]… in favor of a more individualized approach."[50]

In summary, the consensus group agreed that the practice of obtaining multiple, routine chest roentgenograms in a stable patient after lobectomy does not lead to a measurable clinical benefit. However, we also acknowledge that the literature in this area is limited by a lack of RCTs. Consequently, the group believed that the decision to obtain a chest roentgenogram in the immediate postoperative period is best left to the discretion of the individual surgeon.

CONSENSUS STATEMENTS.

6. Routine daily chest roentgenograms are not required in a stable patient after lobectomy.
7. A chest roentgenogram after removal of a pleural drain can be safely omitted in a patient who is clinically stable and has not required a clamp trial.

DIGITAL DRAINAGE SYSTEMS

Digital drainage systems have several inherent advantages. They allow for patient mobilization regardless of suction setting, eliminate interobserver variability in assessment of an air leak, and allow temporal trends to be tracked.

There are, however, several practical limitations. First, air leak duration is not the only factor determining pleural tube duration. A drain may remain in place to evacuate fluid even if the air leak has resolved. Furthermore, many patients will leave the operating room without an air leak, thus diminishing the benefits of the digital system. Most importantly, there is an added cost inherent in the use of these systems. Consequently, cost-effectiveness of the digital systems is predicated on a consistent decrease in LOS.

RANDOMIZED TRIALS AND SYSTEMATIC REVIEWS. There have been numerous randomized trials comparing digital and traditional systems. In summary, although several studies documented favorable reductions in pleural drain duration and LOS,[51-59] a similar number of studies demonstrated no significant benefit[60-68] with the digital systems.

For purposes of illustration, 3 randomized trials showed clinical benefits to patients whose chest tubes were managed with a digital system as opposed to an analog system. As an example, Brunelli and colleagues[51] reported a significant reduction in pleural drain duration (4.9 days vs

TABLE 4 Systematic Reviews and Meta-analyses Comparing Digital Drainage and Analog Systems

Author, Reference, and Year	Analysis	Number of Studies and Patients	Conclusion
Zhou,[69] 2018	SR with MA	10 studies (all RCTs) 1268 patients	Benefit to digital: drain duration, LOS, cost
Evans,[70] 2019	SR	13 studies (6 RCTs)[a] 1395 patients	Benefit to digital: drain duration, LOS, cost
Wang,[71] 2019	SR with MA	8 studies (5 RCTs) 1487 patients	Benefit to digital: drain duration, LOS
Aldaghlawi,[72] 2020	SR	23 studies (13 RCTs)[a] 3289 patients	Benefit to digital in less than 45% of studies
Chang,[73] 2022	SR with MA	21 studies (all RCTs)[b] 3399 patients	Benefit to digital: drain duration, LOS, cost
Zhou,[74] 2023	SR with MA	12 studies (all RCTs) 2000 patients	Benefit to digital: drain duration, LOS

[a]Included spontaneous pneumothorax as well as postoperative patients; [b]Evaluated suction and water seal strategies as well as digital systems. LOS, length of stay; MA, meta-analysis; RCT, randomized clinical trial; SR, systematic review.

4.0 days) and LOS (6.3 days vs 5.4 days) in a randomized trial of 166 patients who underwent lobectomy. Similarly, Cerfolio and Bryant[52] documented a decrease in drain duration (3.9 days vs 3.1 days) and LOS (4 days vs 3.3 days) in a trial of 100 patients. A multicenter, randomized trial of 381 patients who underwent anatomic resection observed a decrease in air leak duration (2.2 days vs 1.0 days), pleural drain duration (4.7 days vs 3.6 days), and LOS (5.6 days vs 4.6 days) in the digital system cohort.[58]

In contrast, other trials have suggested no clinical benefit with digital systems. For example, a multicenter trial randomized 231 patients who underwent VATS lobectomy and demonstrated similar pleural drain duration and LOS.[64] Another multicenter, prospective observational study documented *longer* air leak and drain duration with digital systems vs traditional drainage systems.[68]

Common to all these studies are inherent biases. It is not possible to blind clinicians to the type of system used. Furthermore, wide variability exists among studies regarding management of drains after resolution of an air leak. These biases may have a significant impact on the timing of drain removal and subsequent discharge.

Independently of these outcomes, multiple trials and prospective studies have demonstrated a clear benefit in the use of the digital devices with regard to patient and health care personnel satisfaction. Because the digital systems are self-contained, without the need for wall-mounted suction, patients report improved mobility and more comfort with the digital devices. Additionally, health care staff report higher satisfaction with the setup and maintenance of the devices and the interpretation of messages and warnings on the devices.[51,58,61] For instance, in the RCT reported by Bertolaccini and colleagues[61] of 98 patients, 94% of those patients with digital devices reported that it was "easy to move around with the device" compared with 31% in the control group ($P = .002$). In the same study, 98% of nurses rated the digital system as "easy" to set up as opposed to 23% for the analog system ($P = .001$).

Several systematic reviews and meta-analyses have also been published on this topic (Table 4).[69-74] Wang and colleagues[71] evaluated 8 studies (5 RCTs) for a total of 1487 patients and reported decreased pleural drain duration, LOS, and incidence of PAL with digital systems. However, the main outcomes of LOS and pleural drain duration were based on 2 studies only. A third meta-analysis, by Zhou and colleagues,[69] evaluated 12 RCTs, with similar conclusions. In contrast, a more recent systematic review of 23 studies found wide variability in outcomes, with only 44% of studies favoring digital systems.[72]

COST-EFFECTIVENESS. Some trials have suggested cost savings with the digital systems, largely driven by a reduction in LOS. One randomized trial demonstrated a cost savings of 476€ with the digital system.[51] Zhou and colleagues[69] suggested a cost savings of 443€ with the digital systems, but this observation was based on cost data from only 2 RCTs. In a formal cost-effectiveness analysis by the National Institute for Health and Care Excellence in the United Kingdom, digital drainage systems received a positive recommendation for national use on the basis of a reduction in chest tube duration and LOS.[70] These investigators noted a base-case cost savings of 111£ per patient when digital drainage systems were used postoperatively.

CONSENSUS STATEMENTS.

8. Digital air leak systems are at least comparable to traditional analog systems. They may provide additional benefits such as delivery of a regulated form of suction, decreased interobserver variability, and improved mobilization.
9. Digital air leak monitoring devices have an increased absolute cost compared with analog systems and may be potentially cost-effective only if use leads to a decrease in length of stay compared with analog systems.

MANAGEMENT OF PROLONGED AIR LEAK

PAL is defined as an air leak that persists for greater than 5 days after pulmonary surgery.[75] The basis of this definition is an expected LOS for lobectomy of 5 days. The Society of Thoracic Surgeons General Thoracic Database agreed on this definition at its inception in 2002; however, the median LOS in this database has since declined to 3 days.[76]

It is critical to differentiate an air leak from a bronchopleural fistula. An air leak arises from the remaining lung parenchyma or staple line. A bronchopleural fistula, conversely, results from injury to the central airways or dehiscence of the bronchial staple line. A bronchopleural fistula almost always requires urgent intervention and is not the subject of this review. Instead, we seek to address (1) management of a residual airspace, (2) safety of discharge with a pleural drain, (3) pleurodesis, (4) endobronchial valve (EBV) placement, and (5) reoperation.

RESIDUAL AIRSPACE. A residual airspace after pulmonary resection may significantly affect resolution of an air leak and will often need to be addressed. Several studies have reported on the use of adjunct surgical procedures to fill a residual air space after lobectomy, such as phrenic nerve blockade or paralysis and instillation of pneumoperitoneum. Although such procedures are intriguing, most of the publications describe retrospective cohort studies or case series with small numbers of patients.[77-80] High-quality prospective data to support such interventions are lacking.

Two randomized controlled trials examined the benefit of pleural tenting after upper lobectomy. Creation of a pleural tent involves dissecting the apical pleura off the endothoracic fascia, thereby allowing the pleura to contact the remaining pulmonary parenchyma. Okur and colleagues[81] conducted a trial of 40 patients undergoing upper lobectomy or bilobectomy. These investigators reported a shorter duration of pleural tube drainage (4.3 days vs 7.4 days) and LOS (7.6 days vs 9.4 days) in patients undergoing a pleural tent. Brunelli and colleagues[82] conducted a trial of 200 patients who underwent upper lobectomy, with similar results. A significant reduction in air leak (2.5 days vs 7.2 days), pleural drain duration (7 days vs 11.2 days), and LOS (8.2 days vs 11.6 days) was observed in the pleural tent group compared with patients without a pleural tent. Both trials were conducted before the era of minimally invasive surgery and enhanced recovery pathways, however. In addition, the tent was performed at the time of lobectomy as a prophylactic measure. Thus, the role of pleural tent in the treatment of PAL (rather than its prevention) in the contemporary era is unclear. However, procedures that enhance pleural apposition (pleural tent, phrenic nerve injection, pneumoperitoneum) may be considered to address an air leak in the setting of a large residual space, although robust data are lacking.

DISCHARGE WITH PLEURAL DRAIN. An emphasis on reducing LOS and containing health care costs has led to interest in discharging patients with a pleural drain, thus permitting patients to recover at home while the air leak resolves. Although this strategy allows for earlier discharge, significant concerns have been raised regarding readmission and subsequent development of empyema. The largest study of this practice pooled 253 patients who were discharged with a pleural tube from 4 academic medical centers.[83] Among this cohort, 49 patients (19%) were readmitted, 18 (7%) experienced empyema, and 3 (1%) died of subsequent complications. The most significant risk factor for empyema was pleural drain duration, with a 3-fold higher risk if the chest tube remained for longer than 20 days. A similar retrospective cohort study from Reinersman and colleagues[84] reported on 236 patients who were discharged with an indwelling pleural tube for PAL over a 10-year period. These investigators reported a readmission rate of 26% and an empyema rate of 17%. They concluded that "Dismissal with an indwelling chest tube is not without consequence, having significant risk for further complications and potential need for additional interventions."[84] However, these studies do not report outcomes of a control group. Certainly, the admission rate of those patients who were not discharged home with a chest tube would be 100%. Furthermore, it would be expected that some patients who remain admitted would also experience empyema.

In summary, the consensus group agreed that early discharge with a pleural drain with close outpatient follow-up can be considered but must be weighed against the risks. These risks include the development of empyema, as well as system malfunction such as drain blockage or inadvertent withdrawal.

PLEURODESIS. Pleurodesis for PAL can be readily performed at the bedside through the indwelling pleural drain. The 2 most commonly used techniques are chemical pleurodesis and autologous blood patch. Both techniques have been reported for PAL in the postoperative setting. In each technique, pleural apposition is required, without which resolution of the air leak will not occur.

Chemical pleurodesis can be performed using a variety of sclerosing agents such as talcum powder[85] and doxycycline.[86] Regardless of the agent used, chemical pleurodesis has a high success rate. For instance, talc pleurodesis had a 98% success rate in a retrospective study of 41 postoperative patients.[85] However, there are very few publications on this topic, in contrast to the large number of studies on pleurodesis for spontaneous pneumothorax. Furthermore, chemical pleurodesis is associated with the potential for significant complications, including chest pain, fever, acute lung injury, and a potential reduction in pulmonary function.[87,88]

In contrast, autologous blood patch has been well studied and may involve less risk than chemical agents. The technique involves the injection of 50 to 120 mL of autologous blood directly into the pleural space through the pleural tube. The blood is allowed to dwell for 1 to 2 hours, and the procedure may be repeated if necessary.

Outcomes have been provided through several, albeit small, prospective trials. In 1 study, 20 patients who underwent lobectomy were randomized to autologous blood patch or conservative management. The study investigators reported a shorter time to pleural tube removal and LOS in the experimental group.[89] Similar results were observed in a randomized study of 25 patients published by Andreetti and colleagues.[90] Notably, no empyema was reported in any of these studies. A meta-analysis of autologous blood patch, pooling 10 studies with 198 patients, reported a success rate of 84% and an incidence of empyema of 1.5%.[91] A recent systematic review comprising 8 studies and 151 patients reported a success rate of 89% and an overall complication rate of 10%.[92] Given the prospective data supporting the effectiveness of autologous blood patch and the superior safety profile, the consensus panel recommends this technique over chemical pleurodesis.

ENDOBRONCHIAL VALVES. Placement of EBVs, initially reported for the palliation of advanced emphysema, has also been described for treatment of spontaneous pneumothorax and PAL.[93-100] Although the reversibility of this approach is appealing, there are several challenges to note. First, 2 procedures performed with the patient under anesthesia are required, to place and subsequently to remove the valves. Second, multiple valves are often required because of the presence of collateral ventilation. Indeed, anatomic isolation may be impossible, especially in postlobectomy patients. For instance, it may be determined by balloon occlusion that valves would need to be placed in all segments of the remaining lobe, given the collateral ventilation between segments. Furthermore, there are several well-described complications of EBV placement, including pneumothorax secondary to compensatory hyperexpansion of an ipsilateral lobe, respiratory failure, valve migration, pneumonia, and hemoptysis.[101] Finally, the cost of placing and then removing multiple valves should be acknowledged.

The 2 largest series of EBV placement were retrospective, multicenter trials that included a variety of patients, such as those with primary and secondary pneumothoraces as well as PAL. An Italian study included 74 patients (42 postoperative) with a success rate of 88%.[100] In contrast, a US study of 75 patients (28 postoperative) reported resolution of air leak in only 56% of cases and concluded that "the lack of rigorously designed studies demonstrating efficacy remains concerning."[99]

Given the paucity of prospective comparative trials, the consensus group concluded that, at present, there is insufficient evidence to recommend the use of EBVs in patients with a PAL after lobectomy. However, we do acknowledge that further study in this area is warranted.

SURGICAL INTERVENTION. Very few data have been published on surgical intervention for PAL. Certainly, reoperation for bronchopleural fistula or empyema is a well-defined indication for surgery. However, few publications report outcomes of reoperations to restaple or suture pulmonary parenchyma or to apply tissue sealants. The largest report identified 16 patients at a single center who underwent reoperation for

PAL.[102] The source of the air leak was identified in only 50% of cases, and surgical reexploration did not lead to an immediate cessation of air leak in any patient.

At present, surgical intervention for PAL involves complex clinical decision making that is based on surgeon experience, knowledge of the index operation, patient-related factors, and resource availability. Careful inspection of the drainage system to ensure the lack of a system leak and bronchoscopic inspection of the bronchial stump are prudent before committing to reoperation.

CONSENSUS STATEMENTS.

10. Early discharge with a pleural drain and close outpatient follow-up can be considered but must be weighed against the risks.
11. Pleurodesis with an autologous blood patch is safe and effective for patients with a prolonged air leak after lobectomy and is preferred over chemical pleurodesis.
12. There is insufficient evidence to recommend the use of endobronchial valves in patients with a prolonged air leak after lobectomy.
13. A bronchopleural fistula or a system leak should be excluded before reoperation for a prolonged air leak after lobectomy.

CONCLUSION. All thoracic surgeons are familiar with the management of pleural drains after lobectomy. Optimal management of these drains should reduce patient discomfort, LOS, and complications. However, we acknowledge that the literature surprisingly does not always provide clarity on this subject so central to the practice of thoracic surgery. Indeed, many important questions have yet to be addressed and require well-designed, prospective, randomized trials. Consequently, the recommendations made by the expert consensus group have been drawn from personal experience, as well as from interpretation of the existing evidence. Updates to these recommendations can certainly be provided as additional data emerge. Regardless, it is the hope of the consensus committee that this document will encourage standardization and stimulate additional research in this important area.

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