

Randomized trial of digital versus analog pleural drainage in patients with or without a pulmonary air leak after lung resection

Sebastien Gilbert, MD,^{a,b} Anna L. McGuire, MD,^c Sonam Maghera, BSc,^d Sudhir R. Sundaresan, MD,^a Andrew J. Seely, MD, PhD,^{a,b} Donna E. Maziak, MD,^a Farid M. Shamji, MD,^a and P. James Villeneuve, MD, PhD^{a,b}

ABSTRACT

Objective: An unclear aspect of digital pleural drainage technology is whether it can benefit all lung resection patients or only those who have a postoperative air leak. The aim of this study was to evaluate the impact of digital pleural drainage on time to chest tube removal and length of hospitalization, taking into consideration postoperative air leak status.

Methods: A single-center, randomized, controlled, open-label, parallel-group trial was conducted. On postoperative day 1, stratification according to air leak status was performed by 2 independent, blinded observers. Patients were randomized to a water-sealed, pleural drainage device (analog) or to a digital device (digital).

Results: In both air leak groups (no air leak = 87; air leak = 85), patient factors and operative details were comparable. In the no air leak group, the difference in median chest tube drainage between analog and digital randomization arms was not statistically significant (3 days vs 2.9 days; $P = .05$). Median length of stay was also comparable in that group (analog = 4.3 days; digital = 4 days; $P = .09$). In patients with an air leak, similar findings were observed for chest tube duration (analog = 5.6 days; digital = 4.9 days; $P = .11$) and length of stay (analog = 6.2 days; digital = 6.2 days; $P = .36$). Chest tube clamping trials were significantly reduced in the digital arm of the air leak absent (0% vs 16%; $P = .01$) and air leak present groups (23% vs 50%; $P = .01$).

Conclusions: Although digital devices decreased tube clamping trials, the impact on duration of chest tube drainage and hospital stay was not statistically significant, even after stratifying by postoperative air leak status. (J Thorac Cardiovasc Surg 2015;150:1243-51)



Sebastien Gilbert, MD

Central Message

Although digital devices decreased clamping trials, their impact on chest tube duration or length of stay was not statistically significant.

Perspective

In contrast to previous literature, this trial evaluated the impact of digital pleural drainage technology while taking into account postoperative air leak status after lung surgery. Based on the results, we cannot recommend its use as an intervention aimed solely at reducing length of stay. We acknowledge that this technological advance presents other opportunities to improve patient care.

See Editorial Commentary page 1252.

From the ^aDivision of Thoracic Surgery, University of Ottawa, The Ottawa Hospital;

^bOttawa Hospital Research Institute, Ottawa, Ontario; the ^cDivision of Thoracic Surgery, University of British Columbia, Vancouver, British Columbia; and

^dFaculty of Medicine, University of Ottawa, Ottawa, Ontario, Canada.

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Address for reprints: Sebastien Gilbert, MD, Division of Thoracic Surgery, University of Ottawa, The Ottawa Hospital, General Campus, Ste 6363, 501 Smyth Rd, Ottawa, Ontario K1H 8L6, Canada (E-mail: sgilbert@toh.on.ca).

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Digital pleural drainage devices make use of electronic sensors to measure and record air leak flow from chest tubes, and they can provide a graphical display of air leak trend over time. Trials comparing digital systems to conventional, water-sealed, analog systems have shown an association among use of digital drainage devices, decreased duration of chest tube drainage, and shorter duration of hospitalization.¹⁻⁴ This association is presumably related to chest tube management being more efficient as a result of technologic advances in pleural pressure regulation, air leak measurement accuracy, and air leak trend monitoring.

Abbreviations and Acronyms

CI = confidence interval
 CONSORT = Consolidated Standards of Reporting Trials

Given that previous trials have not defined a participant's air leak status before randomization, the impact of this postoperative factor on the apparent benefits of the technology is largely unknown. The objective of this study was to examine the relationships among digital pleural drainage, time to chest tube removal, and length of hospital stay, taking into consideration postoperative air leak status. The hypothesis was that clinical outcomes associated with the use of digital drainage devices would improve, irrespective of air leak status after lung resection.

METHODS**Patient Enrollment and Selection**

Prior to initiation of the trial, approval was obtained from the institutional research ethics board. The trial was designed and implemented according to the 2010 Consolidated Standards of Reporting Trials.⁵ This is a single-institution, randomized, controlled, open-label, parallel-group trial involving 6 participating thoracic surgeons. A preliminary study was conducted, comparing interobserver agreement in the assessment of pulmonary air leaks using analog versus digital systems.⁶ As a result, the thoracic surgery team was introduced to the new technology prior to initiation of the trial.

Patients scheduled to undergo elective, sublobar, or lobar pulmonary resection for benign or neoplastic disease were potential candidates for inclusion in the trial. Exclusion criteria were as follows: development of tension pneumothorax; pneumonectomy; previous randomization at the time of an earlier operation; elapsed randomization window; treatment plan to remove, or removal of, all chest drains within 36 hours after surgery; transfer to the intensive care unit prior to randomization; inability to provide informed consent; and age <18 years. Eligible patients who had their chest tubes removed promptly after surgery (at ≤36 hours) were excluded from the trial because they would have remained in the study for a very short period of time (≤12 hours), and contributed data of limited clinical relevance to outcomes.

After randomization, patients who were transferred to the intensive care unit were excluded from the analysis, because critical illness and the need for mechanical ventilation usually lead to more-conservative chest tube management than that outlined in the study protocol. Patients for whom the intervention was discontinued because of reoperation for complications were analyzed in their respective randomization arms.

Clinical Outcomes

The primary study outcome was length of hospitalization, as defined by the interval between the end of surgery and the time of discharge from inpatient thoracic surgical care. The secondary outcome was duration of chest tube drainage, defined as the interval between the end of surgery and the removal of the last chest drain, or the end of surgery and discharge from the hospital with an indwelling drain. Length of stay was tabulated in discrete units of days; duration of chest tube drainage was calculated in hours and converted into days.

Ancillary outcomes included the following: complications related to chest tube removal (eg, new or worsening pneumothorax and/or increasing

subcutaneous emphysema requiring chest tube reinsertion); number of pleural drain clamping trials; pleural drain fluid output; discharge from the hospital with an indwelling pleural drain; and number of postoperative chest radiographs after randomization. Other complications were compiled using our prospective, thoracic morbidity and mortality tracking system (ottawa.tmm.org).⁷

A chest tube management guideline was agreed on for the trial (Figure 1). In general, suction is applied to chest tubes immediately after surgery and discontinued on the first postoperative day, providing that subcutaneous emphysema is either absent or mild, and that the ipsilateral pneumothorax is determined to be ≤30% on chest radiograph. Suction would be resumed in the event of clinical deterioration after discontinuation. For this trial, subcutaneous emphysema was defined as mild when it was not readily visible and could be detected only by chest wall palpation or chest radiograph. Each posterior rib interspace occupied by a pneumothorax on chest radiograph accounted for a 10% volume estimate.

Serous or serosanguinous drainage of ≤250 mL in a 24-hour period was considered an acceptable fluid output threshold for chest tube removal. The fluid output criterion is an estimate of 24-hour pleural fluid turnover (0.15 mL/kg/hour) in a 70-kg patient.⁸ For patients randomized to the digital device, the air leak flow parameters that indicated a resolved air leak and were considered safe for chest tube removal were as follows: air leak ≤40 mL/minute, with negative pressure applied (>8 mm Hg) or ≤20 mL/minute, while on gravity mode (≤8 mm Hg) for a minimum of 12 hours.

The air leak status of each participant was evaluated at least once daily at the time of morning inpatient rounds, and was documented in the trial database. For the analog system, an air leak was considered absent or resolved when bubbling was no longer seen in the water seal chamber on bedside assessment by the surgical team. With the digital device, a target intrapleural pressure was set and maintained by a feedback loop between electronic pressure sensors monitoring the pleural space and the unit's self-contained pump. When suction was applied using analog devices, a connection was made to an external suction source, and a target suction pressure was selected.

Air Leak Group Assignment and Randomization

Our clinical experience has been that the presence or absence of a postoperative air leak after lung resection can have a significant impact on duration of chest tube drainage and length of stay. Prerandomization stratification according to postoperative air leak status was implemented to minimize the impact of air leak duration as a confounding factor in the relationship between the intervention and the primary outcome. On postoperative day 1, independent assessments by 2 members of the surgical team were performed to determine air leak status. Participants were divided into 2 groups: those with an air leak (air leak present) and those without (air leak absent).

The air leak assessment was performed using an analog drainage system (Pleur Evac A-6002-08; Teleflex, Inc, Research Triangle Park, NC) set to -20 cm of water suction while patients purposely coughed 3 separate times. An air leak was considered to be present when air bubbles were seen in the water seal chamber from ≥2 of 3 coughs. If disagreement occurred, a third surgeon provided the decisive assessment. This air leak classification process was carried out only once, immediately prior to randomization.

The randomization window was defined as 24 to 48 hours after the end of surgery, to ensure that patients with a self-limited pulmonary air leak lasting <24 hours would be assigned to the more clinically appropriate group (ie, air leak absent). Within each air leak group, patients were randomized to either continued pleural drainage with the analog system, or pleural drainage with the digital system (Thopaz; Medela, Inc, Baar, Switzerland).

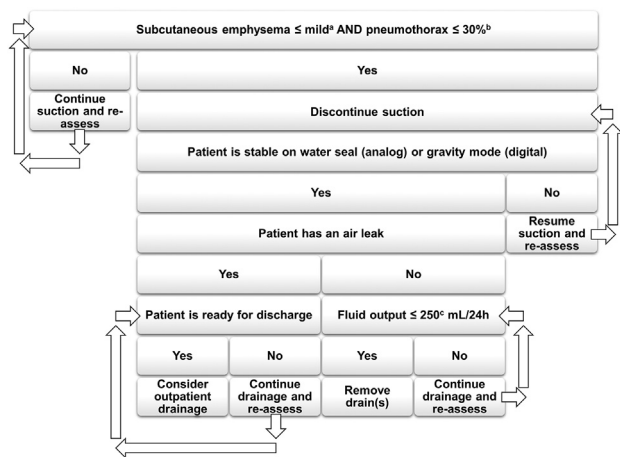


FIGURE 1. Chest tube management. “Mild” subcutaneous emphysema is not visible on examination and can only be detected by palpation of the chest wall or by chest radiograph. On chest radiograph, the pneumothorax size was estimated at 10% for each posterior rib interspace visualized between the apex of the pleural cavity and the apex of the lung. Fluid is serous or serosanguinous, and volume is an estimate based on a 70-kg patient whose pleural fluid reabsorption rate is 15% of whole-body lymphatic flow (WBLF = 1 mL/kg/hr).⁸

Variable-size randomization blocks (6-16) with a 1:1 ratio were generated using atmospheric noise entropy (www.random.org). A computer programmer within the research team created an encrypted randomization database and was the only person with authorized access. Blinding was not possible because of the significant differences in size and function between the analog and digital drainage systems. However, the operating surgeon was blinded to the air leak group assignment, as a means to reduce potential bias in postoperative bedside assessment and clinical management.

Statistical Analysis

Using historical data from 200 lung resection patients, the median length of stay after lung resection was estimated at 5 days (SD: 1.78). To determine if the use of digital devices could significantly shorten hospitalization, by 1 full day, the required sample size was 40 patients in each of the 4 randomization arms (n = 160; α-error = 5%; β-error = 20%). Using our prospective morbidity and mortality database, we anticipated that 5% to 10% of patients might need to either return to the operating room or be transferred to the intensive care unit for mechanical ventilatory support. Therefore, the final sample size was increased by 10%, to 176 patients, to account for loss of statistical power from eligible patients who cannot be randomized, and those who cannot receive the allocated intervention after randomization.

Categoric variables were analyzed for statistical significance using the Fisher exact test. Numeric variables were compared using the Student *t* test or the Wilcoxon rank sum test, as appropriate. Length of stay was analyzed using Poisson regression, with adjustment for statistical imbalances in baseline characteristics between randomization arms.

The duration of chest tube drainage was analyzed using the Kaplan-Meier method with the log-rank test of statistical significance. All tests of significance were 2-sided. Numeric continuous data are expressed as the median, with interquartile range (IQR) (25th-75th percentile). Statistical calculations were performed and verified by a professional statistician, using SPSS 22 (IBM Corp, Armonk, NY) and SAS 9 (SAS Institute, Inc, Cary, NC).

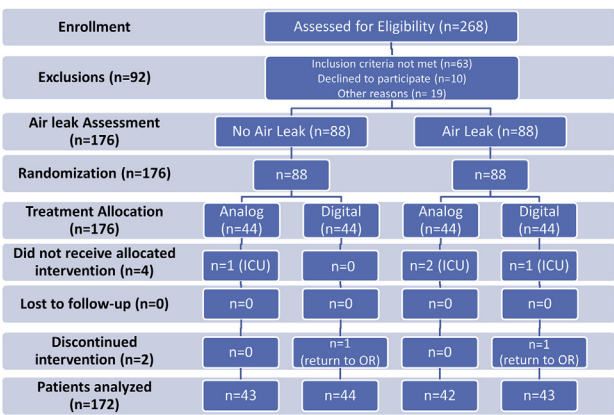


FIGURE 2. CONSORT (Consolidated Standards of Reporting Trials) diagram illustrating the flow of patients during the trial. ICU, Intensive care unit; OR, operating room.

RESULTS

A total of 268 patients were assessed for eligibility, between December 2012 and May 2014. A total of 92 patients were excluded; 4 of 176 (2%) did not receive the allocated intervention, owing to postoperative transfer to the intensive care unit, leaving 172 patients for analysis. The reasons for exclusion of the other 19 patients were as follows: 17 could not be entered because accrual had been completed in the air leak–present group; the remaining 2 underwent exploratory surgery and were found to have an unresectable tumor.

The flow of patients during the trial is detailed in the CONSORT (Consolidated Standards of Reporting Trials) diagram (Figure 2). Randomization occurred within 7 hours of eligibility for 90% of the patients (median = 4 hours, with range: 2-6 hours). In both air leak groups (air leak–absent = 87; air leak–present = 85), the randomization arms (analog vs digital) were statistically similar with regard to the following patient characteristics: age, gender, body mass index, smoking history, Charlson comorbidity index, dyspnea score, diagnosis, and lung function (Table 1). The only exception was a higher median percentage predicted forced expiratory volume in 1 second in patients with no air leak, randomized to the digital device (no air leak analog = 81% [range: 66%-92%]; no air leak digital = 90% [range: 80%-102%]; *P* = .01).

Most patients underwent a minimally invasive anatomic resection (eg, lobectomy, segmentectomy), and no significant difference was observed in the type of resection or use of a video-assisted thoracoscopic surgery approach between randomization arms. Although the incidence of pleural adhesions was similar between the randomization arms of each air leak group, this finding was more common in patients who had a postoperative air leak at randomization (25 of 85 [29.5%] vs 11 of 87 [12.5%]; *P* = .01).

TABLE 1. Patient characteristics and operative data

Characteristic	Group 1: Air leak absent (n = 87)			Group 2: Air leak present (n = 85)		
	Analog (n = 43)	Digital (n = 44)	P value	Analog (n = 42)	Digital (n = 43)	P value
Age (y)	67 (61-71)	69 (59-76)	.72	68 (60-75)	68 (60-72)	.44
Gender, male	10 (23)	18 (41)	.11	21 (50)	14 (33)	.13
Body mass index (kg/m ²)	29 (24-31)	28 (25-30)	.94	27 (23-30)	26 (18-37)	.17
Smoking (pack-y)	35 (0-47)	22 (0-40)	.40	30 (9-50)	30 (0-70)	.46
Charlson comorbidity index	1 (0-6)	2 (0-6)	.29	1.5 (0-4)	1 (0-8)	.73
MRC dyspnea score	1 (1-2)	1 (1-3)	.71	1 (1-2)	1 (1-2)	.74
Malignant diagnosis	41 (95)	41 (93)	1.0	37 (88)	40 (93)	.48
FEV1%	81 (66-92)	90 (80-102)	.01	76 (68-93)	76 (66-91)	.51
DLCO%	77 (69-87)	72 (67-88)	.51	75 (62-5)	69 (60-80)	.48
VATS (%)	72	84	.62	69	63	.54
Lobectomy	34 (79)	30 (68)	.20	37 (88)	31 (72)	.27
Pleural adhesions	4 (9)	7 (16)	.52	11 (26)	14 (33)	.64
Use of lung sealants	4 (9)	3 (7)	1.0	1 (2)	6 (14)	.11

For categoric variables, values are n (%); for continuous variables, values are median (25th and 75th percentiles). Bold indicates statistical significance. *MRC*, Medical Research Council; *FEV1*%, percentage predicted forced expiratory volume in 1 second; *DLCO*%, percentage predicted diffusion capacity for carbon monoxide; *VATS*, video-assisted thoracic surgery.

No significant difference was found between randomization arms in use of parenchymal sealants in either air leak group (analog, air leak–present = 1 of 42 [2%]; digital, air leak–present = 6 of 44 [14%]; $P = .06$; analog, air leak–absent = 4 of 43 [9%]; digital, air leak–absent = 3 of 44 [7%]; $P = .49$). The inclusion of patients who were initially excluded from the analysis (4 of 176 [2.2%]) had no significant impact on the results provided in Table 1.

Most patients had their pleural space drained with 2 chest tubes, regardless of air leak status or randomization group (158 of 172 [92%]). The randomization arms of each air leak group were similar with regard to pleural fluid volume parameters, including median 24-hour drainage (air leak–present, analog = 210 mL [IQR: 174-285 mL]; air leak–present, digital = 207 mL [IQR: 160-273 mL]; $P = .96$; air leak–absent, analog = 187 mL [IQR: 114-283 mL]; air leak–absent, digital = 194 mL [IQR: 127-282 mL]; $P = .76$), and median fluid output in the 24 hours preceding removal of the last chest tube (air leak–present, analog = 32 mL [IQR: 50-210 mL]; air leak–absent, digital = 175 mL [IQR: 94-330 mL]; $P = .15$; air leak–absent, analog = 120 mL [IQR: 70-257 mL]; air leak–absent, digital = 120 mL [IQR: 87-228 mL]; $P = .81$).

The median number of postoperative chest radiographs was not significantly different between randomization

arms (air leak–present, analog = 10 [IQR: 7-13]; air leak–present, digital = 8 [IQR: 7-11]; $P = .68$; air leak–absent, analog = 7 [IQR: 5-8]; air leak–absent, digital = 6 [IQR: 5-7]; $P = .48$). In patients with an air leak at randomization, there was no statistically significant difference in air leak duration between the analog and digital arms (analog = 4.7 days [IQR: 2.8-7.5 days]; digital = 3.7 days [IQR: 2.3-5.8 days]; $P = .14$). The presence of an ongoing air leak was the most-common limiting factor for chest tube removal in the latter group of patients (analog = 34 of 42 [81%]; digital = 36 of 43 [84%]; $P = .8$). Lastly, the digital and analog arms had similar rates of postoperative complications, whether an air leak was present (analog = 8 of 42 [19%]; digital = 7 of 42 [17%]; $P = .78$) or absent (analog = 6 of 43 [14%]; digital = 3 of 44 [7%]; $P = .31$) at the time of randomization.

In patients who did not have a postoperative air leak, the median duration of chest tube drainage (analog = 3 days [IQR: 2.9-4.9 days] vs digital = 2.9 days [IQR: 2.2-3.9 days]; $P = .05$), and the median length of stay (analog = 4 days [IQR: 3-5 days] vs digital = 4 days [IQR: 3-5 days]; $P = .09$) were statistically similar between patients treated with a digital versus analog device. In patients who had an air leak, similar findings were observed for duration of chest tube drainage

TABLE 2. Clinical outcomes

Outcome	Group 1: Air leak absent			Group 2: Air leak present		
	Analog	Digital	P value	Analog	Digital	P value
Length of stay (d)	4.0 (3.0-5.0)	4.0 (3.0-5.0)	.09	6.0 (5.0-9.0)	6.0 (4.0-8.0)	.36
Chest tube duration (d)	3.0 (2.9-4.9)	2.9 (2.2-3.9)	.05	5.6 (4.0-8.9)	4.9 (3.1-6.4)	.11

Values are median (25th and 75th percentiles).

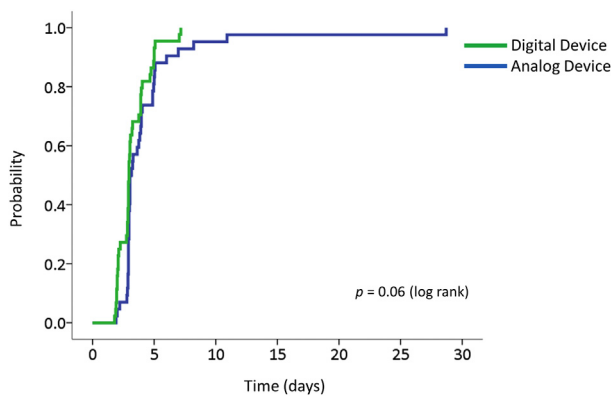


FIGURE 3. Freedom from pleural drain(s): air leak-absent group (n = 87).

(analog = 5.6 days [IQR: 4.0-8.9 days]; digital = 4.9 days [IQR: 3.1-6.4 days]; $P = .11$) and length of stay (analog = 6 days [IQR: 5-9 days]; digital = 6 days [IQR: 4-8 days]; $P = .36$) (Table 2).

Analysis of length of stay, using Poisson regression, adjusted for percent predicted forced expiratory volume in 1 second, showed no significant difference in outcomes between digital versus analog arms for either air leak group. Further analysis of the probability of being free of pleural drains over time after surgery (Figure 3) showed, for the air leak-absent group, no statistically significant difference in estimated median duration of chest tube drainage (analog = 3.1 days, 95% confidence interval [CI]: 2.9-3.4; digital = 2.9 days, 95% CI: 2.8-3.0; $P = .06$). Findings were similar in the air leak-present group (analog = 5.9 days, 95% CI: 5.2-6.7; digital = 5.1 days, 95% CI: 3.4-6.9; $P = .26$) (Figure 4).

Chest tube reinsertions for worsening pneumothorax or subcutaneous emphysema after chest tube removal occurred only in patients randomized to the analog device (air leak-present, analog = 3 of 42 [7%]; air leak-present, digital = 0 of 43 [0%]; $P = .12$; air leak-absent, analog = 2

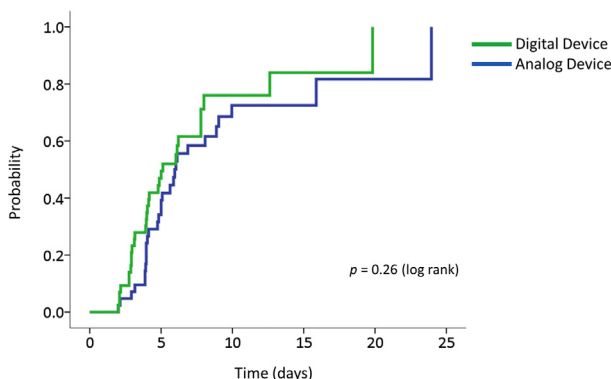


FIGURE 4. Freedom from pleural drain(s): air leak-present group (n = 85).

of 43 [5%]; air leak-absent, digital = 0 of 44 [0%]; $P = .24$). In the air leak-present group, no association was found between the type of drainage device and the proportion of patients leaving the hospital with an indwelling pleural drain (analog = 13 of 42 [31%]; digital = 13 of 43 [30%]; $P = 1.0$).

The median length of stay for patients who had an air leak and were discharged home with an indwelling pleural drain was similar between randomization arms (analog = 8.4 days [IQR: 5.5-11.4 days]; digital = 6.4 days [IQR: 5.4-8.5 days]; $P = .18$). Lastly, chest tube clamping trials were significantly reduced in patients treated with a digital device who had an air leak (analog = 21 of 42 [50%]; digital = 10 of 43 [23%]; $P = .01$) and in those without an air leak (analog = 7 of 43 [16%]; digital = 0 of 44 [0%]; $P = .01$). In patients who had an air leak, clamping of the last remaining chest tube prior to removal was significantly more frequent in the analog arm (analog = 14 of 21 [67%]; digital = 2 of 10 [20%]; $P = .02$). Inclusion of the 4 (2.2%) patients who did not receive the planned intervention because they were transferred to intensive care did not change the overall results significantly.

DISCUSSION

After stratification according to postoperative air leak status, random assignment to pleural drainage, with either a digital or analog device, did not have a significant impact on the primary outcome. Based on the results of this study, we cannot recommend use of a digital drainage device as a means to reduce length of stay after elective lung resection. The same conclusion can be drawn regarding the duration of chest tube drainage, although the difference was close to being statistically significant (ie, $P = .05$) in patients without an air leak who were randomized to the digital device.

In contrast to previous trials, air leak duration was reported herein and no significant difference was observed between randomized groups.^{1,2,4} Air leak duration, time to chest tube removal, and length of hospitalization are often directly related. We anticipated that air leak duration would be a confounding factor and effectively minimized its effect by stratifying patients according to postoperative air leak status prior to randomization. Other potential confounding factors for length of stay (eg, comorbidity, extent of surgery, surgical approach, complication rate) were found to be evenly distributed between randomization arms, thereby further reducing the potential for bias in the results.

The data suggest that, regardless of postoperative air leak status, digital technology can alter chest tube management by significantly reducing clamping trials before removal of the last remaining chest tube. Routine chest tube clamping prior to removal is a practice of debatable

clinical usefulness.^{9,10} However, when properly implemented, selective clamping may be effective in evaluating patients prior to chest tube removal if a small but clinically significant air leak is suspected. The observed decrease in chest tube clamping may indicate that the surgical team perceived the digital drainage device as a more sensitive and reliable tool, and that the air leak trend data provided by the technology is considered clinically useful information. We observed that chest tube reinsertions for pneumothorax or increased subcutaneous emphysema after chest tube removal were confined to analog patients in both air leak groups. However, this apparent gain in the efficiency of chest tube management did not translate into a significant improvement in outcomes.

Monitoring of the pleural space with electronic sensors is still in its infancy, much like electrocardiographic monitoring was 50 years ago. Use of cardiac monitors is now considered standard care in many clinical situations, even if the best supportive evidence remains in the realm of expert opinion.¹¹ The adoption of more-advanced pleural space drainage technology may help identify opportunities to further improve safety and efficiency in the management of chest tubes after lung resection. Assumptions of clinical benefit from more advanced technology make intuitive sense, but ideally, they should be supported by scientific evidence.

Transitioning from analog to digital pleural drainage requires a period of adaptation and some changes in clinical strategy regarding bedside chest tube management. Examples of this phenomenon include the following: setting a target pleural pressure instead of a target suction level; acknowledging that removing a chest drain is considered safe, despite a measurable air leak; and having limited experimental data to interpret the clinical significance of air leak flow variability over time.^{12,13}

Potential advantages to consider in making this transition are continuous monitoring and recording capabilities, increased measurement accuracy, and improved interobserver reliability in the objective quantification of air leaks.^{6,14} The most recently published trial of digital pleural drainage devices seems to have been completed by investigators with experience in using the technology.⁴ Prior to initiating this protocol, our team received proper training on the features and operation of the digital device, but firsthand clinical experience was limited. In that sense, this study may be a more accurate representation of the context in which new devices are typically introduced into surgical practice. Whether the surgical team's level of experience with the technology can affect its impact on clinical outcomes remains unknown.

We acknowledge that this trial has inherent limitations that may hinder the generalizability of the results. The single-institution setting renders observations more susceptible to potential effects of institution-specific practices. In addition, misclassification bias may have occurred during air leak group assignment, owing to the relatively low accuracy of analog devices and the absence of gold-standard methodology to determine air leak status after surgery. The randomization process should have reduced the impact of this potential source of bias on outcomes. In addition, we recognize that the lack of blinding may have influenced the results to a degree that is difficult to quantify. The inability to implement blinding is a methodologic problem that this study shares with all previous digital pleural drainage trials.

We recognize that length of stay can be influenced by other factors that are difficult to objectively quantify. Therefore, uncontrolled sources of bias may have affected the relationship between the intervention and primary outcome. We selected a minimum difference of 1 day as a clinically relevant impact, since length of stay is usually tabulated in whole days instead of fractions of days. We are aware that the use of digital drainage devices could be associated with a significant reduction in length of stay of <1 day, and that the trial was not sufficiently powered to detect such small differences.

Additionally, we acknowledge that a 24-hour delay in randomization is an artifact of trial design that has no counterpart in clinical practice. However, the purpose of this delay was to minimize the potential for misclassification of patients with self-limited air leaks lasting <24 hours into the air leak-present group, and to maximize the probability of having randomization arms that are balanced statistically from the standpoint of air leak duration. This factor is important because air leak duration is a clinical determinant of the duration of chest tube drainage and length of stay. We concluded that a parallel-group design, with randomization 1 day after surgery, would best enable us to achieve our objectives. In addition, randomization was not scheduled immediately after surgery because little or no clinically relevant information can be gained on the impact of digital pleural drainage in lung resection patients who are discharged home within 24 to 48 hours after surgery. A very short hospital stay may not be an issue when trials are confined to lobectomy patients. We chose to include sublobar resection patients to obtain a study population that is more representative of those receiving treatment in a general thoracic surgery practice.

Despite the absence of a clear-cut benefit in duration of chest tube drainage or length of stay, we think that the technology holds promise for leading to a deeper

understanding of pleural space mechanics after pulmonary resection, and to refinement of evidence-based practice in chest tube management. A knowledge gap can be found in the clinical significance of the continuous stream of data provided by these devices, and in the processing of this additional information by those who care for patients with chest tubes. Research efforts to further evaluate the potential for digital pleural drainage devices to streamline the postoperative management of lung resection patients should be pursued.

Conflict of Interest Statement

Digital device disposable items were purchased from Medela, Inc, at a discounted price, for exclusive use in this research trial. Medela, Inc, was not involved in the study design, or in the collection, analysis, or interpretation of data, or preparation, review, or approval of this article. Dr Villeneuve reports grants and other from DePuy Johnson & Johnson, outside the submitted work. Dr Seely reports consulting fees from Therapeutic Monitoring Systems, outside the submitted work.

You can watch a Webcast of this AATS meeting presentation by going to: http://webcast.aats.org/2015/Video/Monday/04-25-15_6A_1435_Yoganathan.mp4

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Key Words: randomized controlled trial, prospective study, chest tubes, drainage, pleura, humans, length of stay

Discussion

Dr R. Cerfolio (Birmingham, Ala). Thank you to the AATS (American Association for Thoracic Surgery), and congratulations, Sebastian—a very, very good study, and congratulations for doing prospective randomized trials. I have no current conflict, but several years ago, I received an honorarium to talk about air leaks and digital air leak devices.

My main question to you—to keep it straightforward, because I know there will be a lot of questions from the audience—is design. The design of the study is the key to any study, the methodology. Why not just use the digital air leak device directly out of the operating room, and eliminate the inherent bias of looking at air leaks with an analog device?

Dr S. Gilbert (Ottawa, Ontario, Canada). Thank you very much, Dr Cerfolio. The question is a very interesting one, and certainly a pertinent suggestion for trial design in the future. This approach is certainly an interesting design that could potentially influence the degree of misclassification bias. However, what your question is really driving at is probably the known limitations of analog devices in assessing small air leaks. We set a rigorous protocol, for prerandomization air leak classification before the beginning of the trial, to maximize the sensitivity to detect small air leaks by assessing the patients on suction while they increased their intrathoracic pressure by coughing multiple times.

All patients were classified by 2 independent, experienced observers prior to randomization. We acknowledge that the methodology may not be perfect, but the results show that the error in classifying patients in each air leak group is very small, and that this approach prevented imbalances in air leak duration between randomization arms. Delaying randomization also prevented misclassification of patients with self-limited air leaks, lasting 24

hours or less, from being assigned to the air leak—present group. From a clinical standpoint, these patients are managed in the same manner as those without any detectable air leak and thus belong in the same air leak group. It seems unlikely that immediate postoperative randomization would have allowed us to achieve our goals. However, we know that this alternative approach would have been associated with more-complex trial logistics and increased cost.

Dr Cerfolio. Okay. Given the length of your answer and the multiple discussants, I will ask 1 more question, instead of 2 more. My last question is that you have said, and I quote: “There was probably less uncertainty”; it just reminds me of listening to some politicians giving lectures lately. I am not sure what that means—so let me ask you, if your mother had a lobectomy done tomorrow, would you want her to be on a digital device or an analog? In other words, what do you think is best in your practice, despite your study’s findings?

Dr Gilbert. I have thought about this issue. I do not know if my personal opinion matters to anyone in this room. I would say any surgeon is free to select the outcome on which to base their selection of drainage system. If, for you, it is a decision based on length of stay, then you have these data to factor into your decision. It is important to mention that there are other potential advantages to this technology, including evidence for improved patient satisfaction; the importance of these factors may vary from surgeon to surgeon or among different institutions.

There is also the problem of having different observers coming up with different answers as to the air leak status of a patient after lung resection. You might go to the bedside and determine that a given patient does not have an air leak. The nurse can go to the bedside an hour later and document that the same patient has an air leak. The resident may report to you later that same day that there was an air leak on the same patient at 6 AM. As you can see, it can become difficult to optimize the management of this patient, given that there is so much conflicting information regarding the air leak status. This phenomenon is referred to as interobserver reliability, which is typically poor with analog devices. The evidence shows that digital pleural drainage technology addresses that shortcoming very well.

Dr Cerfolio. So, Sebastian, is that yes, you would use a digital air leak device? Can I pin you down or not? Are you going to be like the politician?

Dr Gilbert. I would have to rely on people’s ability to analyze the evidence and make their own decision.

Dr Cerfolio. Okay, Hillary. (Laughter from participants)

Dr A. Bharat (*Chicago, Ill*). I have 2 quick questions, and a comment. Question number 1: Do you think the data that you are presenting using the data system can be

extrapolated to other digital devices? Question 2 is: This chest drainage system was applied as part of the research study—do you think lack of experience with this digital device could have confounded the results?

Having asked these questions, I think I would agree with your findings. The digital systems were developed partly to answer the question of whether the leak that you observed in the analog system is coming from the cut surface of the lung, or is, rather, a false leak resulting from a pleural space, or air getting introduced into the chest cavity. These digital systems deploy an air flow meter, but that still does not tell you whether the leak is coming from the lung or not. So, we have developed a technology at Northwestern University; instead of looking at the flow, we look at the gas composition. Given the fact that carbon dioxide is not present in the normal atmospheric air or pleural space, if it is detected, it accurately predicts whether there is a leak from the lung surface.

Dr Gilbert. Thank you very much for your comments, and for sharing your experience with us. To address your first question, I would say that if the other digital device measured and recorded air leak flow, and the patient population was similar, then the results we obtained could be extrapolated. This extrapolation would be more difficult to accomplish in the case of devices with different features providing additional data.

Your point regarding experience with digital devices is important. Previous trials of digital devices have been published by investigators who are highly experienced with the technology. I should say that integration of the technology requires some paradigm shift in the management of air leaks. For instance, surgeons have to accept that a measurable air leak is not necessarily clinically significant, and that chest tubes may be removed safely with an ongoing measurable air leak. This concept is not typically taught or emphasized when working with analog, water-sealed devices.

Dr M. Moon (*St. Louis, Mo*). Dr Cerfolio, do you want to make a comment?

Dr Cerfolio. I will make a brief comment. Any device that objectifies an inherently subjective patient measurement is going to be better. We do not hold thermometers up to the light to look at the temperature anymore; we read a number, and why should air leaks be different? With that, I will end my comments.

Dr F. Detterbeck (*New Haven, Conn*).

We did a randomized study with digital devices and found a difference in air leak and chest tube duration and length of stay, but one of the things that we did not really understand is that the chest tubes actually did not come out when the air leak resolved. If I understood your data correctly, it seems like your patients also had chest tubes in and stayed in the hospital for a relatively long time after

the air leak resolved. Do you have any thoughts about that, and whether, in fact, air leak duration is not what is driving chest tube duration and hospital stay? Because then, of course, measuring air leak more objectively is not going to matter.

Dr Gilbert. To your last point, regarding the driving factor for chest tubes remaining in place: We have analyzed chest radiograph data and fluid output data, and we have determined that air leak duration was the most common reason for continued chest tube drainage. The other issue you are pointing out, Dr Detterbeck, and thank you very much for doing so, is the effectiveness or efficiency in the chest tube–management algorithms. Obviously, there is always room for improvement. Our data show a difference between air leak duration and chest tube drainage duration, given that these 2 intervals do not exactly match one another. We additionally observed a difference of several hours between the times when all objective criteria for chest tube removal are met and when chest tubes are removed. The delay was not significantly different between the randomization arms in each air leak group.

Dr Moon. Dr Cerfolio?

Dr Cerfolio. I think that when you have an endpoint of length of stay, you have a problem, and it is not going to work, because there are so many social factors that go into length of stay. So I think that, as a primary endpoint, we could have discussed that, but I have critiqued his design enough. I do not think it is a great primary endpoint, unless you as a physician are willing to remove a chest tube at 7:00 AM, 12:00 PM, 6:00 PM, 12:00 AM, and so on, and most of us are not; we do not want to get called back in in the middle of the night. So that influences length of stay and chest tube duration. Length of stay is influenced by so many social factors; for example, we hear: “My brother cannot come pick me up tomorrow, his shoes are at the shop.” I mean, many factors contribute that are unrelated to health status. That is the problem with using length of stay as an endpoint. I do not think it is a surrogate for duration.

Dr T. Demmy (*Buffalo, NY*). No conflicts. I just wanted to follow up on that point. Just as when I did

cardiac surgery, it was a big paradigm shift to let people get extubated at 1:00 AM, rather than waiting for morning rounds—this is a big shift in dogma to trust this device to allow the tube to be taken out at midnight, when there are fewer people around, but the patient is still having a lot of pain, and by having the chest tube out, their pain level goes down, so maybe there is some improvement there. Do you want to comment on that?

But I guess the other question I had about design is that you used 250 cc’s of fluid per day for your criteria to remove the chest tube, which seemed to kind of blur your primary endpoint. Do you think the design might have been better if the fluid were taken out of the equation—because 400 cc’s is used in lots of series now, and actually, I use a much higher number if it is serous. Thank you.

Dr Gilbert. Thank you for your comments. Your first point was about trusting the technology. I think that, as we gain more experience with the technology, we might get to a point where we feel it is reliable enough to plan for chest tubes to be removed by an on-call physician, a physician extender, or a nurse, in the middle of the night, to provide symptomatic relief to the patient.

Your second comment was regarding fluid output. We based our calculation of fluid threshold for chest tube removal on data from Dr Miserocchi’s pleural fluid mechanics research; for a 70-kg man, the pleural fluid reabsorption rate should be approximately 250 mL. In the design phase of the trial, I had some ideas regarding the use of a more-aggressive fluid output threshold. However, to ensure compliance with the trial protocol, my co-investigators and I had to compromise and reach a consensus on what would be an acceptable fluid output threshold for chest tube removal.

Dr Moon. Any final thoughts?

Dr Cerfolio. My final thoughts are just congratulations to the AATS for putting a mundane, “nonsexy” topic like air leaks in the plenary session, and challenging the audience to continue to study the things that are most common: pain, air leaks, chest tube drainage. For these issues, we need prospective trials. Congratulations to Sebastian for doing the study. Thank you.