Original Article

Clinical outcomes and staff satisfaction after adoption of digital chest drainage system for minimally invasive lung resections

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Background: Digital chest drainage systems (DCDS) provide reliable pleural drainage while quantifying fluid output and air leak. However, the benefits of DCDS in the contemporary era of minimally invasive thoracic surgery and enhanced recovery after surgery (ERAS) protocols have not been fully investigated. Additionally, hospital and resident staff experiences after implementation of a DCDS have not been fully explored. The objective of this study was to evaluate the clinical outcomes and hospital staff experience after adoption of a DCDS for minimally invasive lung resections.

Methods: A single-center retrospective review of patients who underwent minimally invasive lung resection (lobectomy, segmentectomy, and wedge resection) and received a DCDS from 11/1/2021 to 11/1/2022. DCDS patients were compared to sequential historical controls (3/1/2019–6/30/2021) who received a analog chest drainage system. For the analog system, chest tubes were removed when no bubbles were observed in the water seal compartment with Valsalva, cough, and in variable positions. With a DCDS, chest tubes were removed when the air leak was less than 30 cc/min for 8 hours, with no spikes. All patients followed an institutional ERAS protocol. Primary outcomes were length of stay (LOS) and chest tube duration. Hospital staff and residents were surveyed regarding their experience.

Results: One hundred and twenty-four patients received DCDS, and 248 received an analog chest drainage system. There was a reduction in mean LOS (3.6 *vs.* 4.4 days, P=0.01) and chest tube duration (2.7 *vs.* 3.6 days, P=0.03) in the DCDS group. Hospital staff (n=77, 46% response rate) reported the DCDS easier to use (60%, P<0.001) and easier to care for patients with (65%, P<0.001) compared to the analog system. Surgical residents (n=28, 56% response rate) reported increased confidence in interpretation of air leak (75%, P<0.001) and decision-making surrounding chest tube removal (79%, P<0.001).

Conclusions: Using a DCDS can reduce LOS and chest tube duration in the contemporary setting of minimally invasive lung resections and ERAS protocols. Increased confidence of resident decision-making for chest tube removal may contribute to improved outcomes.

Keywords: Thoracic; minimally invasive lung resection; chest drain; outcomes

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Introduction

For patients undergoing lung resection, chest drain management is an essential component of postoperative care, as these drains allow for control of residual fluid in the chest and of air leaks (1). Unfortunately, management of air leaks can be challenging, and persistent air leaks are a major cause of prolonged hospitalization (2). Chest drainage after lung resection is most commonly accomplished with an analog chest drain composed of chambers that allow for collection of intrathoracic fluid, monitoring of pulmonary air leak, and regulation of intrapleural pressure (1-3). Though these analog systems are relatively cheap and disposable, there are disadvantages, the most notable being how air leaks are observed. In the analog units, the presence of an air leak is confirmed by visualizing bubbles in a compartment of the chest drainage system containing water (4). This is a subjective measurement and can lead to increased interobserver variability of air leak interpretation and agreement of when to remove chest drains (5).

More recently, there has been an increased adoption of digital chest drainage systems (DCDS). These systems provide a digital measurement of both fluid output and air leak, are reusable, and often do not require wall attachment for externally applied suction (6). In several observational studies and a recent meta-analysis, the use of a DCDS has been associated with a shorter duration of chest tube placement and reduced length of stay (LOS) (4,7-14). This may be due to increased confidence in the interpretation of air leaks and subsequent decrease in clinical practice variability (15,16). However, other studies have found no difference in LOS or chest tube duration with a DCDS (17,18).

Notably, several of the studies demonstrating the benefit of DCDS included patients undergoing lung resection via thoracotomy (4,7-9). Additionally, these studies were performed prior to the advent of thoracic surgery enhanced recovery after surgery (ERAS) protocols, which are already designed to streamline postoperative care and have been shown to reduce LOS (19-21). In the 2019 Guidelines for ERAS, the use of DCDS received a strong recommendation but low-level evidence rating due to conflicting results (22).

Therefore, there remains a gap in the literature regarding the utility of DCDS in the contemporary era of minimally invasive thoracic surgery and ERAS protocols. Additionally, the experience of hospital staff after adopting a DCDS has not been fully explored. We sought to determine the clinical outcomes and hospital staff experience following implementation of a DCDS for minimally invasive lung resections, with the hypothesis that use of these units would lead to reduced hospital LOS and a shorter chest tube duration. We present this article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1747/rc).

Highlight box

Key findings

- In this study, we observed a one-day reduction in hospital length of stay (LOS) and chest tube duration for minimally invasive lung resections after implementation of a digital chest drainage system (DCDS).

What is known and what is new?

- DCDSs have been shown to reduce LOS and chest tube duration. However, many of the previous studies examining the benefit of a DCDS included patients undergoing lung resection via thoracotomy, and prior to the widespread use of thoracic surgery enhanced recovery after surgery (ERAS) protocols.
- In this study, we observed a benefit of a DCDS for patients undergoing minimally invasive lung resection, in the presence of a pre-existing ERAS protocol.

What is the implication, and what should change now?

- This study shares a single center's experience following implementation of a DCDS, with contemporary thoracic surgery patients and operative techniques. In this setting, we still demonstrate the ability of a DCDS to reduce chest tube duration and hospital LOS. Other institutions should consider addition of a DCDS to their thoracic surgery ERAS protocols.

Methods

Study design, setting, and participants

We conducted a retrospective analysis of patients who underwent minimally invasive [robotic- and video-assisted thoracic surgery (VATS)] lung resections at UMass Memorial Medical Center from November 2021 to November 2022 and received a Thopaz$^+$ DCDS (Medela, Baar, Switzerland) following surgery. Sequential historical controls who received an Atrium Oasis analog chest drain (Atrium Medical Corp., Hudson, NH, USA) from March 2019 to June 2021 were obtained from the institutional Society of Thoracic Surgeons (STS) database. The use of DCDS was based exclusively on the device availability; there were no clinical selection criteria. The DCDS was used on all patients whenever possible starting on November 1, 2021. If patients received an analog chest drainage

system following surgery, it was because a DCDS was not available for use in the hospital. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The UMass Chan Medical School Institutional Review Board (No. H00019427) reviewed and approved this study on March 1, 2023. Due to the retrospective design of this study, an informed consent waiver was granted.

Data collection

Preoperative patient characteristics included: age, sex, preoperative forced expiratory volume in 1 second (FEV1), smoking history, and body mass index (BMI) and disease category (cancer or non-cancer). Operative variables included operative approach (robotic or VATS), primary lobe, and procedure type (wedge resection, segmentectomy, lobectomy, bilobectomy). Procedure type was then further classified as either anatomic (segmentectomy, lobectomy, bilobectomy) or non-anatomic (wedge) resections. Primary outcomes were hospital LOS, chest tube duration in days, and proportion of patients with their chest tube removed on postoperative day (POD) one or two. Secondary outcomes included complications relevant to chest tube management and postoperative complications. This included percentage of patients discharged alive, percentage of patients discharged with a chest tube, 30-day readmission, 30-day mortality, prolonged air leak greater than 5 days, pneumonia, pneumothorax requiring chest tube reinsertion, acute respiratory distress syndrome, respiratory failure, atrial arrhythmia, ventricular arrhythmia, deep vein thrombosis, myocardial infarction, urinary tract infection, and urinary retention. In order to better capture the number of patients who had a complicated hospital course, an "any complication" variable was creating by counting the number of patients who experienced any of the recorded postoperative complications.

Hospital staff survey

After one year of using the DCDS (November 2022), a brief Likert-style survey was administered to hospital nursing staff and surgical residents to evaluate their perceptions and experience with DCDS. The survey included two questions for all staff asking them to (I) rate the difficulty of using the DCDS compared to the previous system, and (II) rate the difficulty of caring for patients with the DCDS compared to the previous system. In addition to these questions, surgical residents were asked to (I) rate their confidence level with interpretation of air leak compared to the prior system, and (II) rate their confidence level regarding decision making surrounding chest tube management compared to the prior system. Respondents who indicated on the survey that they had never worked with the DCDS device were excluded from final analysis.

Statistical analysis

Initial comparisons between the two groups were performed using a chi square test or Fisher's exact test for categorical variables. Continuous variables were summarized using median with interquartile range (IQR), or mean with standard deviation (SD), based on normality of the distribution. Continuous variables were compared using *t*-tests or a Mann-Whitney *U* test. Data that were missing were excluded from statistical analysis. We then performed univariate and multivariable linear regression predicting hospital LOS and chest tube duration in order to control for an increase in robotic cases in the DCDS group, as well as factors associated with prolonged air leak following lung resection including reduced BMI and FEV1, and upper lobe resections (5,23,24). Three linear regression models were fit for each primary outcome (LOS and chest tube duration). First was a univariate model, second was a multivariable model that included all clinically relevant variables, and third was a multivariable model that used forward selection beginning with the list of all clinically relevant variables and keeping only those with a P value of <0.05. A power analysis was performed for all linear regression models. Staff survey results were analyzed using a Chi-squared test of distribution. All analyses were performed in SAS version 9.4. Results were considered significant when a P value of less than 0.05 was observed.

Operative technique and chest tube management

Three surgeons performed all lung resections. Surgeries were booked as robotic, and a VATS approach was utilized only if there was no robotic operating room time available. Intraoperatively, reinforced staple lines were rarely used, and the use of pleural sealant was variable and surgeon dependent. Patients received one 24-French chest tube. Postoperatively, all patients in both the control and DCDS groups followed our institutional ERAS protocol, which has been in place since March of 2019 (21). On POD zero, the chest tube was placed to externally applied suction in the operating room and transitioned to water seal in

the post-anesthesia care unit (PACU). A chest X-ray was also obtained, and output was tracked every 4 hours until the following day. The externally applied suction for the analog chest drain was provided by wall suction with the pressure regulation on the unit set to –20 cm H_2O. For the digital chest drain, externally applied suction was provided by setting the suction on the unit to –20 cm H_2O. The chest tube was placed to water seal for the analog units by removing the wall suction from the drain. For the DCDS, the water seal was achieved by setting the externally applied suction to "physiologic mode" of –8 cm H_2O.

On POD1, a portable chest X-ray was obtained. If patients did not have an air leak, and there was low chest tube fluid output (Feiran Lou <300, Mark W. Maxfield <400, Karl Uy <500), the chest tube was removed, and an X-ray was obtained 2 hours later. If an air leak was present, the chest tube was kept in place, and the air leak was monitored daily. Chest tubes were removed once air leaks had resolved. With an analog device, that would mean cessation of bubbles with Valsalva, cough, and in variable positions. With a DCDS, chest tubes were removed when the air leak was less than 30 cc/min for 8 hours, with no spikes on top of the –8 cm H_2O externally applied suction, consistent with previously described removal criteria (7). Clamp trials were used liberally with analog devices if there was question of the presence of an air leak. With the DCDS, clamp trials were very rarely utilized. Patients were discharged home with a chest tube if they had a prolonged air leak greater than 5 days and met all other criteria for discharge. For these patients, the home chest drain setup was achieved by attaching the chest tube to a one-way Heimlich valve, which was attached to a Foley catheter leg bag. Our other discharge criteria include patients not requiring supplemental oxygen, being able to ambulate independently and having pain adequately controlled with oral medications.

Results

There were 134 minimally invasive lung resections over the one-year study period (robotic or VATS), of whom 124 (93%) received DCDS. Patients who did not receive a DCDS in the study time period were excluded from final analysis. In the final groups, there were 124 patients included in the DCDS group and 248 patients in the historical control group. There were no differences observed in age (P=0.86), sex (P=0.65), smoking status (P=0.54), smoking pack years (P=0.34), preoperative BMI (P=0.40), or preoperative FEV1 (P=0.17). There was no significant difference in percentage of patients who underwent lung resection for cancer (P=0.15). There was no difference in distribution of primary lobe (P=0.56) or procedure type (anatomic or non-anatomic resection) (P=0.28). There was a significant increase in the proportion of robotic cases between the DCDS group and controls (DCDS =81.5% robotic, controls =45.6%, P<0.001). Baseline patient characteristics are presented in *Table 1*.

In the DCDS group, we observed a reduction in mean LOS compared to the control group (3.6 *vs.* 4.4 days, P=0.01). The median LOS for both groups was 3.0 days, but there was a more narrow IQR of the DCDS group which was significantly different from the controls (DCDS IQR: 2.0–4.0 *vs.* controls IQR: 2.0–5.0, P=0.005). The DCDS group had a nearly 1-day reduction in mean chest tube duration (2.7 *vs.* 3.6 days, P=0.03) (*Table 2*). There was a significant increase in proportion of patients in the DCDS group who had their chest tube removed on POD1 compared to the controls (48.4% *vs.* 26.9%, P<0.001). There was also a significant increase in the proportion of patients in the DCDS group who had their chest tube removed on either POD1 or POD2 (70.2% *vs.* 53.1%, P=0.002). We then subdivided the groups into anatomic (segmentectomy, lobectomy, bilobectomy) and non-anatomic (wedge) lung resections. In the anatomic group, there was a reduced median LOS (3.0 *vs.* 4.0 days, P=0.16) and reduced mean chest tube duration (3.4 *vs.* 4.2 days, P=0.17), but these did not reach significance. In the non-anatomic group, there was a significant reduction in median LOS (2.0 *vs.* 3.0 days, P=0.008). There was a reduction in mean chest tube duration (1.7 *vs.* 2.3 days, P=0.07) that did not reach statistical significance (*Table 2*).

There were no significant differences in the proportion of patients discharged alive (DCDS =99.2%, controls =100%) or in 30-day mortality (DCDS =0.8%, controls =0%). One patient died in the DCDS group due to respiratory failure on POD10. There were 10 patients in the control group (4.0%) and 5 in the DCDS group (4.0%) who were discharged home with a chest tube (P=0.99). There was no significant difference between groups with regard to patients experiencing any postoperative complication (DCDS =22.6%, controls =29.0%, P=0.19). Regarding pulmonary complications, 16 patients in the DCDS group (12.9%) and 22 controls (8.9%) had a prolonged air leak (P=0.23). There were no differences between the groups in rates of pneumonia (1.6% *vs.* 1.6%, P=0.99), pneumothorax requiring chest tube reinsertion (2.4% *vs.*

Table 1 Baseline patient characteristics

Variable	DCDS (n=124)	Controls (n=248)	P value
Age (years), mean (SD)	65.5 (10.6)	65.7 (10.4)	0.86
Sex, n (%)			0.65
Male	51 (41.1)	96 (38.7)	
Female	73 (58.9)	152 (61.3)	
Smoking status, n (%)			0.54
Current	32 (25.8)	70 (28.2)	
Former	77 (62.1)	140 (56.5)	
Never	15 (12.1)	38 (15.3)	
Smoking pack years, mean (SD)	40.4 (27.2)	43.3 (23.7)	0.34
BMI (kg/m^2), mean (SD)	29.5 (6.9)	28.8 (7.3)	0.40
Preoperative FEV1, mean (SD)	86.4 (20.0)	83.3 (19.0)	0.17
Disease category, n (%)			0.15
Cancer	93 (75.0)	202 (81.5)	
Non-cancer	31 (25.0)	46 (18.5)	
Operative approach, n (%)			<0.001
Robotic	101 (81.5)	113 (45.6)	
VATS	23 (18.5)	135 (54.4)	
Primary lobe, n (%)[†]			0.56
Upper	65 (52.4)	135 (54.9)	
Middle	6 (4.8)	20 (8.1)	
Lower	46 (37.1)	79 (32.1)	
Multiple lobes	7 (5.6)	12 (4.9)	
Procedure type, n (%)			0.28
Anatomic	76 (61.3)	166 (66.9)	
Non-anatomic	48 (38.7)	82 (33.1)	

[†], 2 missing patients in controls. Missing data were excluded from statistical analysis. DCDS, digital chest drainage system; SD, standard deviation; BMI, body mass index; FEV1, forced expiratory volume in 1 second; VATS, video-assisted thoracic surgery.

1.6%, P=0.59), acute respiratory distress syndrome (0% *vs.* 0.4%, P=0.99), or respiratory failure (1.6% *vs.* 2.4%, P=0.72). Cardiovascular complications including atrial and ventricular arrhythmias requiring treatment, deep venous thrombosis, and myocardial infarction did not differ between groups. There was a decreased rate of urinary retention in the DCDS group compared with controls (4.8% *vs.* 12.5%, P=0.02) (*Table 3*).

We then performed univariate and multivariable linear regression predicting hospital LOS and chest tube duration. Regarding LOS, the DCDS group had a mean decrease of 0.78 days compared with the controls (P=0.02). In our initial multivariable model including all clinically relevant variables, the DCDS group had a mean decrease of 0.75 days compared with controls (P=0.0498). Robotic lung resections, BMI, FEV1, and lobe were not significant predictors of LOS. In our subsequent forward selection model, only FEV1 was significantly associated with LOS with a mean reduction of 0.02 days for every additional 1 unit of FEV1 (P=0.04). There was a mean reduction of

Table 2 Primary outcomes

Outcome	DCDS (n=124)	Controls (n=248)	P value
All lung resections			
Length of stay (days), mean (SD)	3.6 (2.6)	4.4 (3.3)	0.01
Length of stay (days), median (IQR)	3.0 (2.0–4.0)	3.0 (2.0–5.0)	0.005
Chest tube duration (days), mean (SD)	2.7 (3.1)	3.6 (4.0)	0.03
Chest tube removed POD1, n (%)[†]	60 (48.4)	66 (26.9)	<0.001
Chest tube removed POD1 or POD2, n (%)[†]	87 (70.2)	130 (53.1)	0.002
Anatomic resections[‡]			
Length of stay (days), median (IQR)	3.0 (3.0–5.0)	4.0 (3.0–6.0)	0.16
Chest tube duration (days), mean (SD)	3.4 (3.7)	4.2 (4.4)	0.17
Non-anatomic resections[‡]			
Length of stay (days), median (IQR)	2.0 (1.0–3.0)	3.0 (2.0–4.0)	0.008
Chest tube duration (days), mean (SD)	1.7 (1.5)	2.3 (2.5)	0.07

[†], data for removal of chest tubes is missing for 3 patients. Missing data were excluded from statistical analysis. [‡], there was a total of 76 anatomic and 48 non-anatomic lung resections in the DCDS group. There were 166 anatomic and 82 non-anatomic lung resections in the control group. DCDS, digital chest drainage system; SD, standard deviation; IQR, interquartile range; POD, postoperative day.

Table 3 Secondary outcomes and postoperative complications

Variable	DCDS (n=124)	Controls (n=248)	P value
Discharged alive	123 (99.2)	248 (100.0)	0.33
Discharged with chest tube	5 (4.0)	10 (4.0)	0.99
30-day readmission	9 (7.3)	24 (9.7)	0.43
30-day mortality	1 (0.8)	0	0.33
Any complication	28 (22.6)	72 (29.0)	0.19
Pulmonary complications			
Air leak >5 days	16 (12.9)	22 (8.9)	0.23
Pneumonia	2 (1.6)	4 (1.6)	0.99
Pneumothorax (requiring chest tube reinsertion)	3 (2.4)	4 (1.6)	0.59
Acute respiratory distress syndrome	0	1 (0.4)	0.99
Respiratory failure	2 (1.6)	6 (2.4)	0.72
Cardiovascular complications			
Atrial arrhythmia requiring treatment	4 (3.2)	13 (5.2)	0.38
Ventricular arrhythmia requiring treatment	1 (0.8)	2 (0.8)	0.99
DVT requiring treatment	0	2 (0.8)	0.55
Myocardial infarction	0	0	n/a
Other complications			
Urinary tract infection	2 (1.6)	6 (2.4)	0.72
Urinary retention	6 (4.8)	31 (12.5)	0.02

Data are presented as number of patients with corresponding percentages. DCDS, digital chest drainage system; DVT, deep vein thrombosis; n/a, not available.

Table 4 Linear regression models predicting length of stay

Model	Number	Estimate	95% CI	P value	r^2
Univariate	372			0.02	0.014
DCDS (*vs.* control)		−0.78	−1.45, −0.11	0.02	
Multivariable, all clinically relevant	350			0.07	0.037
DCDS (*vs.* control)		−0.75	−1.50, −0.0006	0.0498	
Robotic (*vs.* VATS)		0.33	−0.39, 1.05	0.36	
BMI, per additional one unit		−0.02	−0.06, 0.03	0.47	
FEV1, per additional one unit		−0.02	−0.03, 0.001	0.07	
Lobe (*vs.* lower)				0.27	
Middle		0.94	−0.42, 2.31	0.18	
Multiple		−0.73	−2.32, 0.86	0.37	
Upper		0.38	−0.34, 1.10	0.30	
Multivariable, forward selection	351			0.01	0.024
DCDS (*vs.* control)		−0.68	−1.37, 0.02	0.06	
FEV1, per additional one unit		−0.02	−0.03, −0.0008	0.04	

CI, confidence interval; DCDS, digital chest drainage system; VATS, video assisted thoracic surgery; BMI, body mass index; FEV1, forced expiratory volume in one second.

0.68 days in the DCDS group compared with controls, that did not reach significance (P=0.06) (*Table 4*). However, a subsequent power analysis of the forward selection model revealed a power of 74.8% (Table S1).

In the univariate analysis predicting chest tube duration, the DCDS group had a mean reduction in chest tube duration of 0.84 days compared with controls (P=0.04). In our initial multivariable model of all clinically relevant variables, the DCDS group had a mean reduction of 0.96 days (P=0.04) compared with controls. Preoperative BMI was also found to be significantly associated with chest tube duration. Robotic lung resection, FEV1 and lobe were not found to be significant predictors of chest tube duration. In our forward selection model, only BMI was significantly associated with reduced chest tube duration with a mean reduction of 0.07 days for every additional 1 BMI unit (P=0.02). The DCDS group had a mean reduction of chest tube duration by 0.80 days that did not reach significance (P=0.052) (*Table 5*). On subsequent power analysis, the forward selection model reached a power of 82.2% (Table S2).

The staff satisfaction survey was administered to 167 nurses and residents, and we received 91 responses (54%). Fourteen people were excluded from analysis for never having worked with a DCDS device, for a total of 77 eligible responses (49 nursing staff, 28 surgical residents). Most respondents (60%) rated the DCDS as easier to use (P<0.001), and 65% (P<0.001) rated the DCDS easier to care for patients with compared to the previous system. This finding remained consistent when responses were grouped into nursing staff and residents. Sixty-one percent of nurses agreed with both statements (P<0.001). Fifty-seven percent of surgical residents rated the DCDS as easier to use and 71% rated the DCDS as easier to care for patients with, compared to the previous system (*Figure 1*). Seventy-five percent of surgical residents rated their confidence surrounding air leak interpretation as somewhat or significantly more confident compared to the prior system (P<0.001). Seventy-nine percent of residents rated their decision-making surrounding chest tube management as somewhat or significantly more confident when compared to the prior chest drainage system (P<0.001) (*Figure 2*).

Discussion

Our results demonstrate that the use of DCDS can result in shorter hospital LOS and reduced chest tube duration in patients undergoing a minimally invasive lung resection,

Table 5 Linear regression models predicting chest tube duration

Model	Number	Estimate	95% CI	P value	r^2
Univariate	369			0.04	0.011
DCDS (*vs.* control)		−0.84	−1.65, −0.03	0.04	
Multivariable, all clinically relevant	349			0.04	0.042
DCDS (*vs.* control)		−0.96	−1.85, −0.07	0.04	
Robotic (*vs.* VATS)		0.66	−0.19, 1.52	0.13	
BMI, per additional one unit		−0.07	−0.12, −0.02	0.01	
FEV1, per additional one unit		0.008	−0.01, 0.03	0.42	
Lobe (*vs.* lower)				0.47	
Middle		0.13	−1.50, 1.77	0.87	
Multiple		0.63	−1.26, 2.53	0.51	
Upper		0.67	−0.19, 1.53	0.13	
Multivariable, forward selection	369			0.007	0.027
DCDS (*vs.* control)		−0.80	−1.60, 0.005	0.052	
BMI, per additional one unit		−0.07	−0.12, −0.01	0.02	

CI, confidence interval; DCDS, digital chest drainage system; VATS, video assisted thoracic surgery; BMI, body mass index; FEV1, forced expiratory volume in one second.

with a higher proportion of patients having their chest tube removed on POD1. Notably, these improvements in outcomes were observed in the setting of a preexisting ERAS protocol and did not come at the expense of staff satisfaction.

The overall LOS was reduced in our study by one day following adoption of a DCDS for minimally invasive lung resections, which is consistent with the literature. A recent randomized trial demonstrated a one-day reduction in LOS and chest tube duration for patients undergoing VATS lobectomy, though this study utilized the Drentech Palm Evo (REDAX) digital system (25). In a similar study, Geraci *et al.* observed a 1-day reduction in LOS associated with a DCDS for patients undergoing robotic lung resections (n=27 lobectomy, n=15 segmentectomy, n=8 wedge resection). Again, though, they utilized a different chest drainage device (Thoraguard, Centese, Omaha, NE, USA) than our institution (11).

The difference in type of DCDS utilized in previous studies is notable, as chest drainage systems (both analog and digital) are not all designed or constructed the same. This is particularly true when considering how different drainage systems create a seal for the thoracic cavity and manage externally applied suction. A seal for the thoracic cavity can be achieved using water ("wet" seal) or with mechanical components ("dry" seal). Similarly, when considering the application of externally applied suction, regulation can be achieved by using either water ("wet" suction) or with mechanical components ("dry" suction). This allows for classification of chest drains as "wet-wet", "dry-dry", or hybrid "wet-dry" systems (26,27). As a consequence of their different designs, performance may vary significantly between chest drainage units (26). In fact, several studies examining the performance of chest drains have shown considerable variation with respect to air flow rates, ability to respond to sudden increases in intrapleural pressures, and their ability to regulate externally applied suction (3,26-28). Therefore, we believe it is important to evaluate the performance of each digital drainage system on an individual basis, rather than treating digital drainage systems or analog systems as single entities.

In our study, we also observed a reduction in LOS for minimally invasive wedge resections, which is a novel finding. Interestingly, our overall reduced LOS was observed in the setting of a preexisting ERAS protocol, which had already reduced the LOS for minimally invasive lung resections by one day using an analog chest drainage system (21). The additional reduction in LOS

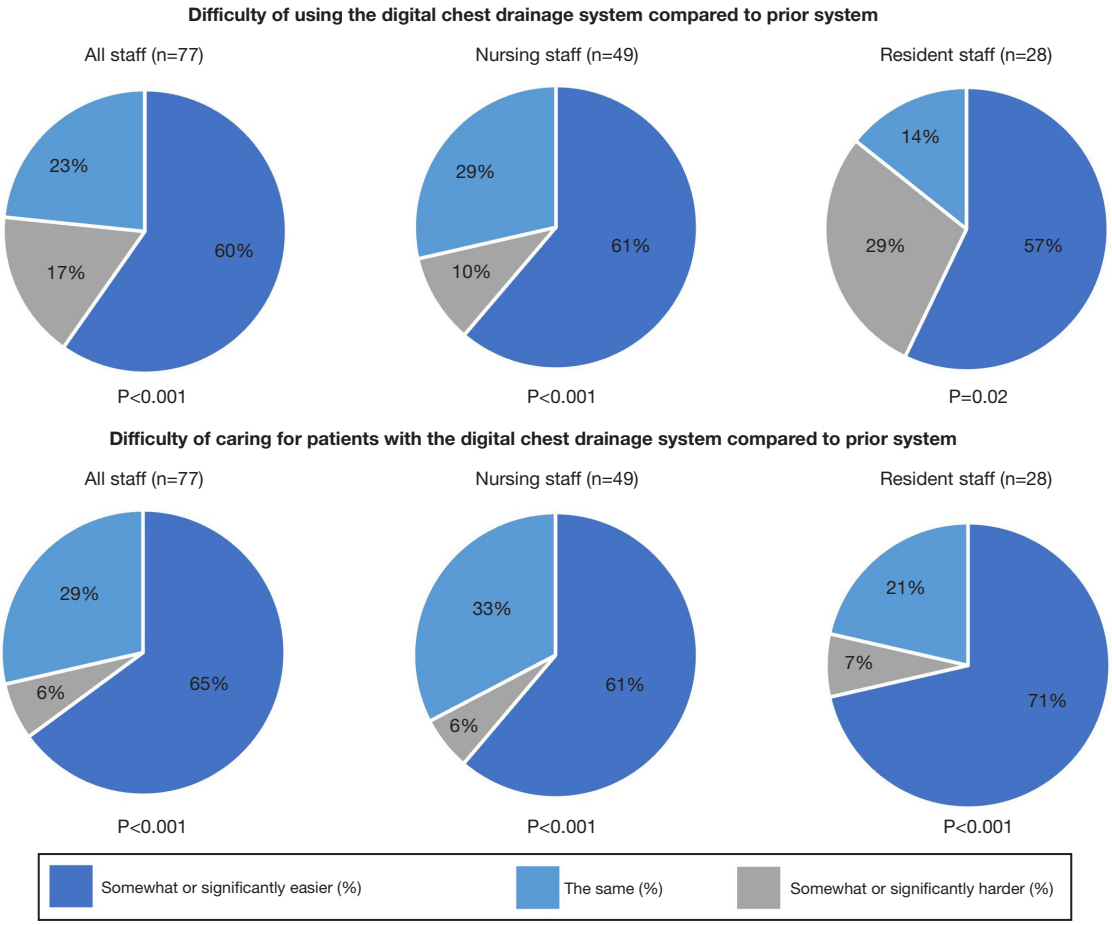

Figure 1 Staff satisfaction survey results: residents and nursing staff.

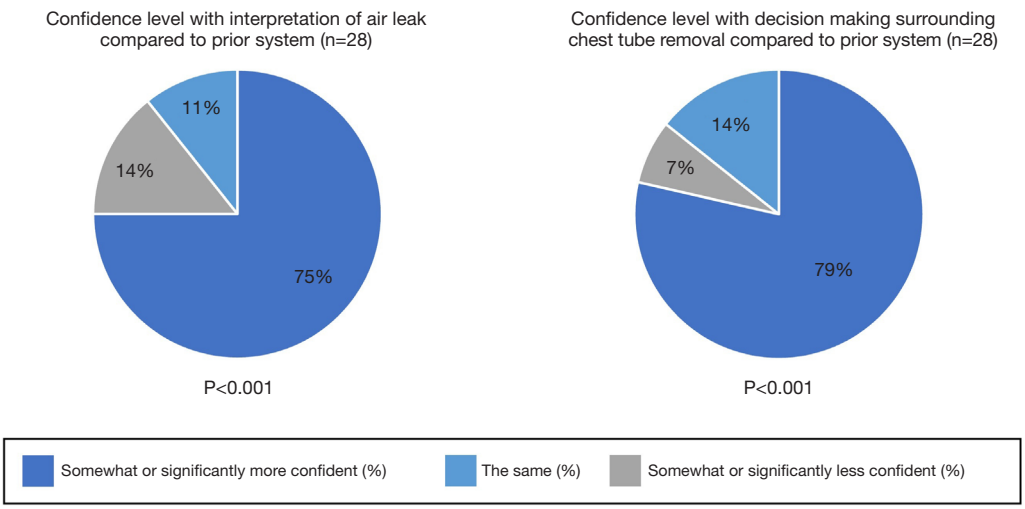

Figure 2 Resident-specific survey results.

after adoption of a DCDS further suggests that these systems still may produce meaningful clinical benefits in the setting of preexisting ERAS protocols. However, when considering the role of a DCDS in ERAS protocols, it is important to consider the other ERAS recommendations that each institution practices, as there is variation in the number of ERAS components implemented between hospitals (22,29).

We also found that the overall chest tube duration was reduced by one day after adopting the DCDS, and a higher proportion of patients had their chest tube removed on POD1. Again, this is consistent with previous studies (11,12,25). Importantly, in our study, there was no significant difference in occurrence of pneumothorax requiring chest tube reinsertion. This suggests that although chest tubes were overall removed earlier, it was not done prematurely. Though not significant, we did observe a higher proportion of patients with prolonged air leaks in the DCDS group, which was also observed by Geraci *et al.* (11). This may reflect an increased ability of the digital devices to detect small or intermittent air leaks. Alternatively, it could be that the digital systems themselves are leading to more air leaks due to them being continuous low-flow, low-vacuum pumps which may negatively impact the healing of lung parenchyma.

Interestingly, we observed a decreased rate of urinary retention in the DCDS group. There have been many factors identified in the surgical literature that can impact rates of postoperative urinary retention, including the use of certain anesthetics, epidurals, and exposure to opioids such as morphine for analgesia (30). These intraoperative and postoperative variables were not collected as part of this study and may be confounding factors for our reduced rate of urinary retention. However, there were no intentional changes in practice patterns with relation to management of urinary catheters. In addition to pharmacologic treatments, other factors such as early patient mobilization may help to reduce rates of postoperative urinary retention (30). Notably, Geraci *et al.* observed increased ease of patient ambulation with a digital chest drain, and the 2019 ERAS guidelines cite chest tubes as an important barrier to early mobilization (11,22). Therefore, a possible explanation for our reduced rates of urinary retention observed in this study may be related to earlier chest tube removal, leading to increased ease of patient ambulation, resulting in decreased rates of urinary retention.

The improved clinical outcomes after implementing a DCDS at our institution did not come at the expense of hospital staff satisfaction. The majority of our hospital staff enjoyed using the DCDS and found it easy to understand and implement. This is important, as the impact on hospital staff of implementing a DCDS is an area that has not been fully explored. When implementing new technology or protocol changes, it is important to not increase the burden on staff, to avoid burnout and reduced satisfaction (31). Though we did not perform a formal thematic analysis of open-ended survey questions, nearly all respondents commented that they preferred the new system. Surgical resident responses indicated that there was an increase in confidence surrounding interpretation of air leak and decision making about when to remove chest tubes with the DCDS. Though a different DCDS was used, a Bertolaccini *et al.* study observed a similar theme, with a reduction in degree of variability in air leak scores by staff (16). It is possible that this is one of the factors contributing to the reduced chest tube duration and LOS observed in many studies. The increase in provider confidence may lead to earlier chest tube removal, resulting in less pain for patients, allowing for improved pulmonary toileting and faster discharge (32).

Limitations of this study include the retrospective and single-center design. Because of its retrospective nature, we were unable to record intraoperative details that contribute to presence of an air leak, such as pleural adhesions, incomplete fissures, and number of staple fires used to divide the parenchyma (23). Inadequate power of the multivariable analyses may have limited our ability to detect a difference in LOS and chest tube duration. Additionally, this study included operations from three different surgeons, who used similar approaches to lung resections, with some noted differences (use of pleural sealant). Finally, the staff survey was not a formally validated tool, making it more susceptible to bias. The survey also only reflects our own institutional experience, and results at other hospitals may differ.

Conclusions

Even with an established ERAS protocol, implementation of DCDS can lead to improvement in clinical outcomes including hospital LOS and chest tube duration for patients undergoing minimally invasive lung resections. Other institutions should consider the addition of these DCDSs to their thoracic ERAS protocols.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1747/rc

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The UMass Chan Medical School Institutional Review Board (No. H00019427) reviewed and approved this study on March 1, 2023. Due to the retrospective design of this study, an informed consent waiver was granted.

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