The process and safety of removing chest tubes 4 to 12 hours after robotic pulmonary lobectomy and segmentectomy

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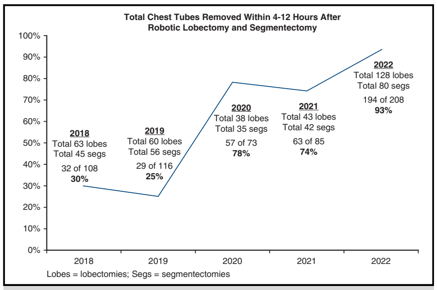
ABSTRACT

Objective: Chest tubes cause pain and morbidity.

Methods: This is a quality initiative study and review of patients who underwent robotic pulmonary resection by 1 surgeon (R.J.C.). The goal was to remove chest tubes within 4 to 12 hours after robotic segmentectomy and lobectomy. Primary outcome was removal without the need for reinsertion, thoracentesis, or any morbidity due to early removal of the chest tube. Secondary outcomes were symptomatic pneumothorax, pleural effusion, chylothorax, subcutaneous emphysema, and chest tube reinsertion or thoracentesis within 60 days of surgery.

Results: Between January 2018 and December 2022, 590 patients underwent robotic lobectomy or segmentectomy. Chest tubes were removed within 4 to 12 hours postoperatively in 63.5% of patients (375/590). In 2022, this was achieved in 91% after lobectomy (119/128) and 94% after segmentectomy (75/80). There were significantly more chest tubes removed within 4 to 12 hours postoperatively from 2020 to 2022 than pre-2020 ($P < .001$). Forty patients (6.8%) were discharged home on postoperative day 1 with a chest tube. Sixteen patients (2.7%) had post–chest tube removal increasing pneumothorax and subcutaneous emphysema; none required tube reinsertion. There was no 30-day or 90-day mortality. Twelve patients (2%) had an outpatient thoracentesis for effusion within 60 days. Twenty patients (3.3%) were readmitted, none seemingly related to effusions. Nonsmokers ($P = .04$) and segmentectomy ($P = .001$) were associated with chest tube removal within 4 to 12 hours of surgery.

Conclusions: Chest tubes can be safely removed within 4 to 12 hours after robotic segmentectomy and lobectomy. Factors associated with successful early chest tube removal are nonsmoking, segmentectomy, and team members becoming comfortable with the process. (JTCVS Open 2023;16:909-15)



Improvement in chest tube removal within 4 to 12 hours after robotic anatomic lung resection.

CENTRAL MESSAGE

Chest tubes can be removed within 4 to 12 hours after robotic lobectomy and segmentectomy in up to 90% of patients, with only 2% requiring thoracentesis within 60 days postoperatively.

PERSPECTIVE

Chest tubes are associated with pain, decreased mobility, decreased respiratory capacity, and increased work and resource use for the postoperative team. Removing chest tubes within 4 to 12 hours after robotic lobectomy and segmentectomy is safe and effective.

See Discussion on page 916.

The average length of stay after anatomic lung resection in the United States is variable and approximately 4 to 5 days.[1,2] Surgeons' postoperative algorithms and biases may determine postoperative length of stay and chest tube management. In an effort to improve postoperative pain and patient experience and to reduce morbidity, we have studied the early removal of chest tubes. In the past, our protocol was to remove chest tubes on the morning of postoperative day (POD) 1. We have shown that the amount of drainage of effluent is irrelevant to chest tube management if the effluent is not chyle or blood.[3] The optimal duration of chest tube drainage after anatomic lung resection remains

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The study design, including a waiver of patient consent, was approved by the Institutional Review Board at NYU Langone Health #i23-00662 (May 31, 2023).

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Abbreviations and Acronyms

CXR = chest x-ray
EQI = efficiency quality index
IQR = interquartile range
PACU = postanesthesia care unit
POD = postoperative day

unknown. We hypothesize that shorter chest tube duration is better for the patient in terms of improved pain and less morbidity. In this consecutive series of patients, we show our process and evaluate the safety and efficacy of removing chest tubes within 4 to 12 hours after robotic pulmonary lobectomy and segmentectomy with complete thoracic lymphadenectomy.

MATERIALS AND METHODS

Study Design

This was a quality improvement initiative by one surgeon (R.J.C) to remove chest tubes sooner, within 4 to 12 hours after planned robotic anatomic lung resection, which was an improvement from our previous protocol that removed chest tubes in the morning on POD 1. All perioperative data were retrospectively collected and reviewed. The study design, including a waiver of patient consent, was approved by the Institutional Review Board at NYU Langone Health #i23-00662 (May 31, 2023). Primary outcome was successful chest tube removal within 4 to 12 hours after robotic anatomic lung resection. We defined success as after removal of the chest tube, the patient did not require any intervention such as chest tube reinsertion or thoracentesis and did not develop morbidity or mortality that could be due to the early chest tube removal. Secondary outcomes were symptomatic pneumothorax, pleural effusion, chylothorax, increasing subcutaneous emphysema, and chest tube reinsertion or the need for thoracentesis within 60 days of surgery.

Perioperative Management

All patients were evaluated in the standard fashion for lung resection using testing such as computed tomography scan, integrated positron emission tomography, pulmonary function testing, and stress test in selected patients as we have previously published.[4] Lung resection was conducted with the da Vinci Xi Surgical System (Intuitive Surgical) through a portal 4-arm approach and an additional assist port as we have reported[5] with minor changes, such as placing the robotic ports above the ninth rib and the most posterior port 4 cm distal from the spinous process.[6]

At the conclusion of the operation, a single 24Fr chest tube was inserted in the access port and connected to a digital drainage system. The Thopaz (Medela Healthcare) was used from 2018 to 2020 and the Thoraguard Centese system (Centese) was used from 2020 onward. At the time of closure, we watched the remaining lung fully inflate under direct vision with a camera, and the single 24Fr chest tube was placed posteriorly and apically and placed to −20 cmH_2O of suction.

Upon arrival in the postanesthesia care unit (PACU), a portable chest x-ray (CXR) was obtained. Patients were given ice cream (3.6 fl oz) by mouth as a provocative test for chylothorax in the PACU as soon as able. Between 4 and 12 hours postoperatively, chest tubes were removed if the following criteria were met: (1) the patient is clinically stable without low pulse oximetry readings for that patient's baseline; (2) there is no new or enlarging subcutaneous emphysema; (3) the CXR shows complete lung expansion or a fixed pleural space deficit not larger than expected[7]; (4) there is no cloudy or milky chest tube effluent and the effluent is not frank blood; and (5) there is no air leak on the digital system as defined by a leak of 30 mL/minute or less and only negative numbers on the pleural assessment test on the Centese system as the patient takes deep breaths. If these 5 criteria were met, the chest tube was removed within 4 to 12 hours of the completion of surgery and a CXR was obtained.

If there was an air leak as defined by a leak of 30 mL/min or greater or a positive pleural assessment on the Centese system or if the effusion was suspicious for chyle or blood, the tube was not removed. If the effluent was suspicious for chyle, the chest tube was kept in place and the drainage sent for a triglyceride level, and if greater than 110 mg/mL, a chylothorax is diagnosed and treated medically (as we have previously described) with a low-fat to no-fat diet at home after discharge.[8] If negative, the tube was removed irrespective of volume. If the patient had increasing subcutaneous emphysema on examination before removal, a repeat CXR was obtained and if it continued, the suction on the tube was increased to −40 cm H_2O. If increasing the suction did not resolve the problem, another chest tube was reinserted.

Our postoperative care algorithm, which has been described, was used.[9,10] If patients had a pneumothorax on the PACU CXR, our protocol was to observe if the patient was clinically stable, irrespective of its size.[10] We repeat the CXR in 2 to 4 hours, and if there was no increase to the pneumothorax, the patient remained clinically stable, and there was no new or increasing subcutaneous emphysema, we did not intervene except to add nasal cannula oxygen. Additionally, our oral pain management regimen, as previously reported,[11] consisted of acetaminophen, gabapentin, ibuprofen, and oxycodone as needed.

Those who did not meet the 5 criteria for chest tube removal on the morning of POD 1 were discharged home by 8 AM with the chest tube in place attached to a digital drainage system. They were given cephalexin 250 mg by mouth once per day until the tube was removed. Patients and their families were given detailed instructions regarding care of the chest tube and digital drainage system at home and were instructed to text a daily picture of the system to the surgeon along with their home pulse oximetry reading of oxygen saturation and heart rate. Once the air leak resolved at home as defined by flow less than 30 mL/min consistently and a negative pleural assessment, the patient returned to the office (on weekdays) or the emergency department (on weekends) for removal of the chest tube. Select patients who had their chest tubes removed on the day of surgery who chose to go home on the day of surgery were allowed to do so if clinically stable.

Major and minor adverse events and readmissions within 60 days of the operation were included in the perioperative data. Minor and major complications were defined as grade I to II and grade III or higher, respectively, on the Clavien-Dindo classification system.

Pleural Space Reintervention Postoperatively

Indications for reinsertion of the chest tube were if the patient had symptomatic shortness of breath with reduction of their oxygen saturation on pulse oximetry or an increasing pneumothorax or increasing subcutaneous emphysema. Our criteria to perform a postoperative thoracentesis were (1) increasing shortness of breath with reduction of oxygen saturation on pulse oximetry; (2) CXR with increasing pleural effusion when compared with earlier postoperative CXR; or (3) pleural effusion as measured by us on ultrasound of greater than 700 mL. We did not attempt to measure effusion volume on CXRs or computed tomography scans. Patients did not receive routine CXRs or ultrasounds of the chest unless symptomatic. Home criteria for thoracentesis by home physician were not objectively defined or standardized given the various doctors that patients encountered once discharged.

Statistical Analysis

Descriptive analyses are used to report patients' baseline characteristics, intraoperative course, and postoperative outcomes. Categorical variables are reported as frequencies and percentages. Continuous non-normally distributed variables are reported as median with interquartile range (IQR). Chi-square test was performed to identify difference in percentage of chest tubes removed over the years. Multivariate analysis was performed to identify factors associated with early chest tube removal. Statistical analyses were performed with IBM SPSS Statistics, version 26.0 (IBM).

RESULTS

From January 2018 to December 2022, 590 consecutive patients who needed anatomic pulmonary resections underwent robotic resection as shown in Table 1. This included 332 lobectomies and 258 segmentectomies. The highest volume of operations occurred in 2022, during which 128 lobectomies and 80 segmentectomies were performed. There were 348 female patients (59%) and the median age was 69 years (IQR, 61-76). Most patients, 88% (520/590), underwent pulmonary resection for malignancy. Current or former smokers made up 62% (368/590) of the study group. Median forced expiratory volume in 1 second was 91% of predicted (IQR, 77-104), and median diffusing capacity for carbon monoxide was 80% of predicted (IQR, 68-93). The median lymph node count was 27 (median of 5 N2 and 3 N1 stations). There were no conversions to thoracotomy in this series of 590 patients, and no patients received transfusions in the postoperative period.

Overall, 63.5% (375/590) of patients had their chest tubes removed within 4 to 12 hours. This was achieved in 58.7% (195/332) of lobectomies and 68.6% (177/258) of segmentectomies. The removal of chest tubes within 4 to 12 hours increased over the 5-year study period (Figure 1). In 2018, we removed 29.6% (32/108) of patients' chest tubes within 4 to 12 hours versus 93.3% (194/208) in 2022. The percentage of chest tubes removed early was more in 2022 compared with 2018 for both segmentectomy and lobectomy as shown in Table 2. In 2018, chest tubes were removed within 4 to 12 hours in 46.7% (21/45) of segmentectomies compared with 17.5% (11/63) of lobectomies. In 2022, chest tubes were removed within 4 to 12 hours in 94% of patients after segmentectomy (75/80) and 91% of patients after lobectomy (119/128). There were significantly more chest tubes removed within 4 to 12 hours postoperatively from 2020 to 2022 than before 2020 ($P < .001$).

TABLE 1. Patient demographics by year and over the 5-year study period

Variable	2018 n = 108	2019 n = 116	2020 n = 73	2021 n = 85	2022 n = 208	Overall n = 590
Age, y, median	67	69	70	70	69	69
Sex, n (%)						
Female	63 (58.3)	69 (59.5)	45 (61.6)	44 (51.8)	127 (61.1)	348 (59)
Male	45 (41.7)	47 (40.5)	28 (38.4)	41 (48.2)	81 (38.9)	242 (41)
BMI, kg/m^2, median	24.9	25.2	26.7	25.3	24.8	25.2
Neoadjuvant treatment, n (%)	13 (12)	8 (6.9)	4 (5.5)	6 (7)	24 (11)	55 (9.3)
FEV_1 %, median	87	87	88	92	94	91
D_{LCO} %, median	79	81	87	86	78	80
ECOG, n (%)						
0	55 (51)	62 (53.4)	53 (72.6)	45 (52.9)	129 (62)	344 (58.3)
1	48 (44.4)	53 (45.7)	20 (27.4)	37 (43.5)	74 (35.6)	232 (39.3)
2	4 (3.7)	1 (0.9)		3 (3.5)	2 (1)	10 (1.7)
3	1 (0.9)				3 (1.4)	4 (0.7)
Hypertension, n (%)	55 (50.9)	64 (55.2)	42 (57.5)	59 (69.4)	110 (52.9)	330 (55.9)
Hyperlipidemia, n (%)	34 (31.5)	64 (55.2)	27 (37)	47 (55.3)	110 (52.9)	282 (47.8)
Coronary artery disease, n (%)	22 (20.4)	25 (21.6)	12 (16.4)	23 (27)	41 (19.7)	123 (20.8)
Diabetes mellitus, n (%)	28 (26)	25 (21.6)	10 (13.7)	9 (10.6)	31 (6.3)	103 (17.5)
Previous ipsilateral thoracic surgery, n (%)	11 (10.2)	7 (6)	2 (2.7)	5 (5.9)	19 (9.1)	44 (7.5)
Pathologic stage, n						
IA, IB	54	64	43	52	141	
IIA, IIB	10	11	5	4	11	
IIIA, IIIB	7	9	3	7	17	
IV	7	3	2	3	8	

BMI, Body mass index; *FEV_1*, forced expiratory volume in 1 second; *D_{LCO}*, diffusing capacity for carbon monoxide; *ECOG*, Eastern Cooperative Oncology Group Score.

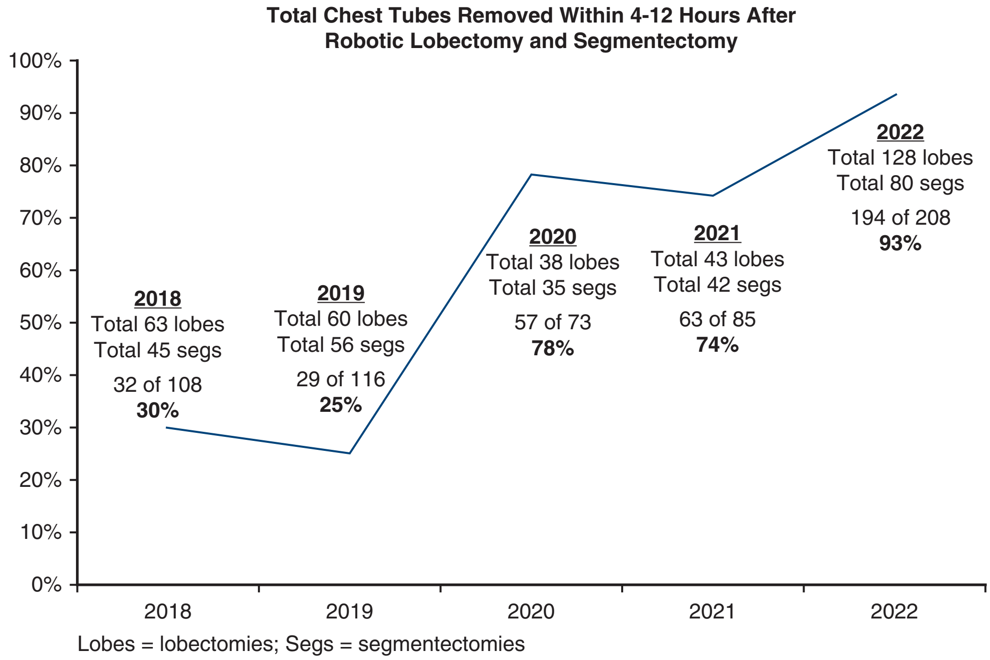

FIGURE 1. Percentage of chest tubes removed within 4 to 12 hours postoperatively by year after robotic pulmonary lobectomy and segmentectomy each year of the study.

On multivariate analysis, factors associated with early chest tube removal included never smokers ($P = .04$) and segmentectomy ($P = .001$). Neither the forced expiratory volume in 1 second percent nor the diffusing capacity for carbon monoxide percent was predictive. Factors associated with chest tube removal after 12 hours included higher Eastern Cooperative Oncology Group performance status ($P < .001$).

Overall, 6.8% of patients (40/590) were discharged home with a chest tube to a digital drainage system because of a postoperative air leak in 37 patients and a chylothorax in 3 patients. After chest tube removal, 16 patients (2.7%) had significant pneumothorax on CXR or subcutaneous emphysema that was observed in the hospital and after discharge via home pulse oximetry readings and daily text message communication to the surgeon. None of these patients required chest tube reinsertion. Three patients after lobectomy had a postoperative chylothorax that all resolved with medical therapy after a low-fat diet on PODs 5, 7, and 8. Of note, 1 patient had bilateral pulmonary resections 6 weeks apart, each complicated by chylothorax and all of his lymph nodes in both chests were benign on final pathology. Twelve patients (2%) had thoracentesis performed within 60 days after surgery, 4 performed at our institution as per our strict protocol and 8 at home.

There was no 30-day or 90-day mortality. Minor morbidity occurred in 2.2% (13/590), most commonly new atrial fibrillation in 5 patients. Major morbidity occurred in 1% (6/590) of the patients. The 30-day readmission rate was 1.5% (9/590). None of these seemed due to the removal of chest tubes within 4 to 12 hours. These were for pain in 2 patients, shortness of breath in 3 patients, new-onset atrial fibrillation in 3 patients, and diffuse rash in 1 patient. In addition, 11 patients were brought back to the hospital within 30 days under observation status because of pain, cough, fatigue, or shortness of breath, all of whom were discharged within 23 hours. None of these 20 patients (9 patients for 30-day readmission and 11 patients for observation) seemed to have complications that were associated with early chest removal.

DISCUSSION

Quality outcomes and outstanding patient experience are our ultimate goals as surgeons. Quality outcomes include many factors that are measurable, especially when calculated for a specific operation using the novel metric efficiency quality index (EQI).[12] The EQI asks physicians, not administrators, for the best surrogates of quality for a specific operation. The EQI only uses and leverages data that have been verified by the doctor as accurate and meaningful. The metrics used by us for lobectomy and segmentectomy are those reported in this study and include the ability to perform minimally invasive surgery without conversion, R0 resection, complete thoracic lymphadenectomy, total operative time less than 120 minutes, estimated blood loss less than 20 mL, length of stay of 1 day, no readmissions, no 30- or 90-day mortality or major morbidity, and the quick, safe removal of chest tubes. This last metric was the focus of this study.

In our current report of 590 patients, the percentage of chest tubes that were removed within 4 to 12 hours postoperatively

TABLE 2. Operative details and postoperative outcomes

Variable	2018	2019	2020	2021	2022	Overall
Total robotic cases, n	108	116	73	85	208	590
Lobectomies	63	60	38	43	128	332
Segmentectomies	45	56	35	42	80	258
Lobectomy type, n						
RUL	26	22	13	16	53	130
RML	8	10	7	5	15	45
RLL	8	8	9	7	19	51
Left upper lobectomy	14	14	3	7	22	60
Left lower lobectomy	4	4	5	6	15	34
Bilobectomy (RUL and RML)	1	1		2	1	5
Bilobectomy (RML and RLL)	2	1	1		3	7
Sleeve resection		3	1	1	4	9
Chest tubes removed by 12 h, n (%)	32 (29.6)	29 (25)	57 (78)	63 (74.1)	194 (93.3)	375 (63.5)
Lobectomies	11 (17.5)	12 (20)	27 (71)	29 (67.4)	116 (90.6)	195 (58.7)
Segmentectomies	21 (46.7)	17 (30.3)	30 (85.7)	34 (81)	75 (93.8)	177 (68.6)
Home with chest tubes, n (%)	0	0	11 (15)	12 (14.1)	17 (8.2)	40 (6.8)
Lobectomies			6 (15.8)	8 (18.6)	12 (9.4)	26 (7.8)
Segmentectomies			5 (14.3)	4 (9.5)	5 (6.3)	14 (5.4)
Estimated blood loss, median	20	10	20	20	20	20
Operative time, min, median	90	93	90	92	101	92
R0 resection (%)	100	100	100	100	100	100
Lymph nodes removed, median	24	27	28	26	29	27
Total number of N2 stations, median	5	5	5	5	5	5
Total number of N1 stations, median	3	3	3	3	3	3
Chylothorax, n (%)	0	1 (0.9)	0	1 (1.2)	1 (0.5)	3 (0.5)
30-d readmission, n (%)	3 (2.8)	2 (1.7)	2 (2.7)	1 (1.2)	1 (0.5)	9 (1.5)
30-d mortality, n (%)	0	0	0	0	0	0
90-d mortality, n (%)	0	0	0	0	0	0

RUL, Right upper lobe; *RML*, right middle lobe; *RLL*, right lower lobe.

increased over the 5-year study period from 30% in 2018 to 93% in 2022. We ascribe this success to our experience, safety, and culture. In 2018, our entire team seemed unsure of its safety. If a member of the care team saw a single air leak reading of 30 mL/min or a positive number during the pleural assessment test, they reported this to the surgeon, which then heavily influenced our decision to remove the tube. As everyone became more confident with the safety of this practice and we saw patients do well after early removal of their tubes, our success with this protocol increased.

We do not believe there was any difference intraoperatively over time to explain the improvement. We have used and taught passive retraction of the lung as opposed to active retraction to avoid causing remote air leaks from the staple line.[13] We believe we used the same surgical techniques in 2018 as in 2022, except for our increasing experience. We have not used a greater use of sealants. Furthermore, as we have described in the past,[14-16] we believe that a digital air leak system allows us to remove tubes sooner and with greater confidence, especially a system that has a pleural assessment feature. This mitigates interobserver variance and affords greater confidence that allows for the safe removal of tubes at any time of the day or night as opposed to preselected chest tube decision-making rounds. For these reasons, we believe the cost of the digital drainage system is certainly justified.

Chest tubes cause morbidity and pain to patients and add work for the surgical team. Despite the benefits of removing chest tubes early, there are limited data evaluating the safety and feasibility of tube removal on the day of surgery after robotic anatomic lung resection. In 2017, Murakami and colleagues[17] showed that early chest tube removal was feasible and safe after thoracoscopic major pulmonary resection. In 2013, Ueda and colleagues[18] omitted the chest tube in eligible patients without an increase in the risk of adverse events.

Despite these innovative reports, surgeons have remained reluctant to embrace this strategy. Our hesitancy is related to our mindset and safety concerns. Many still use the amount of drainage as a criterion for tube removal despite the lack of data for it. In addition, there is the impression that early removal, especially if drainage is high, will lead to the need for postoperative thoracentesis. This study suggests that is not true given the postoperative thoracentesis rate of only 2% (12 patients), of whom only 4 had objective criteria to suggest it was even needed. Furthermore, we have found that it was safe to carefully monitor post–chest tube removal subcutaneous emphysema and pneumothorax. These findings documented by radiologists and then flagged as urgent in the electronic medical records lead to many phone calls and alerts. These must be dealt with via education and clear, kind communication. We found, as have others, that there is often resolution of these minor pleural events without the need to replace a tube or place a pigtail catheter.[19,20] Almost every pleural space problem could be safely observed if the patient was asymptomatic. We also found that the role of repeat CXRs in these patients was of little to no value medically but may be needed and may provide legal value.

The present study designed by us in 2018 shows our own bias and dogma and fear of removing chest tubes earlier than 4 hours. We set the study not to remove any tubes before 4 hours postoperatively, which is an arbitrary number without any data to substantiate it. As an aside, because this current study concluded in December 2022, we have now been trying to remove chest tubes in the operating room in all patients who have no discernable air leak before extubation. Our early experience for this new, more innovative design that features no chest tube has been favorable so far and is promising. However, the data are early and incomplete, and further follow-up is needed.

Study Limitations

There are many limitations to this study. We did not measure the size of the pneumothorax on the postoperative films as we have tried in the past.[7] We do not think this is accurate. We did not report or measure the amount of chest tube drainage in the recovery room before tube removal. We tried to remove all fluid from the chest at the time of closure. These factors, however, are also the strengths of the study because we have shown that the quantification of these variables does not seem to matter in asymptomatic patients. Another weakness is that the amount of fluid on the postdischarge films was not quantified by ultrasound, CXR, or computed tomography. These often unnecessary studies create great consternation and concerns from pulmonologists, home physicians, and emergency department physicians who are used to treating these images and not patients. Continuous communication with the patient and the home doctors is required at every touch point. We favor providing the patient our cell phone number for real-time communication, sending patients home with a pulse oximetry and daily texts to avoid unnecessary trips to emergency departments. Another limitation is that this is a single surgeon's experience. Our patient population and experience may not be representative of other healthcare systems and practices across the country or the surgeon's robotic experience. A strength of this study is that this is a consecutive series of patients without selection. Many patients underwent complex resections, including 9 who underwent sleeve resections and 55 who had neoadjuvant treatment.

CONCLUSIONS

Chest tubes can be safely removed in most patients within 4 to 12 hours after robotic lobectomy and segmentectomy, even after aggressive thoracic lymphadenectomy. The volume of chest tube drainage does not matter, nor does the presence of a post–chest tube removal pneumothorax as long as the patient does not have hypoxia, tachycardia, or increasing subcutaneous emphysema and is otherwise clinically stable. Changing practice and reversing dogma are challenging. It requires constant communication with home physicians and patients as well as with our own care teams, many of whom will have questions and safety concerns about the process.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: chest tube removal, robotic pulmonary resection