Published by Elsevier Inc.

https://doi.org/10.1016/j.athoracsur.2025.03.005

Transplant & Mechanical Support: Research

Robotic Lung Transplantation: Feasibility, Initial Experience, and 3-Year Outcomes

Dominic Emerson, MD,[1] Dominick Megna, MD,[1] Allen A. Razavi, MD,[1] Laura DiChiacchio, MD, PhD,[1] Jad Malas, MD,[1] Reinaldo Rampolla, MD,[2] Joanna Chikwe, MD,[1] and Pedro Catarino, MD[1]

ABSTRACT

BACKGROUND Lung transplantation is performed through clamshell or sternotomy incisions, which may contribute to morbidity and limit patient eligibility. Robotic lung transplantation offers a less-invasive alternative, but data informing treatment choice are limited. This study was therefore designed to evaluate midterm outcomes of robotic and minimally invasive lung transplantation.

METHODS Consecutive patients undergoing robotic or minimally invasive lung transplant (defined by <6-cm minithoracotomy) from October 2021 to February 2025 were included in a prospective registry. The primary end point was 1-year survival. A linear mixed-effects regression model compared postoperative pulmonary function. Median follow-up time was 1.8 years (interquartile range, 1-4 years).

RESULTS During the study period, 209 lung transplants, including 111 (53.1%) minimally invasive (21 robotic [10%] and 90 nonrobotic [43.1%]), were performed at a single center. Three patients were converted from robotic to nonrobotic approaches. The robotic cohort had similar risk factors and lung allocation scores but longer median waiting list times (50 days vs 22.5 days, $P = .02$) compared with nonrobotic minimally invasive recipients, and mean ischemic time was 486 minutes vs 406 minutes ($P = .02$), respectively. There were no significant differences in postoperative ventilator support <48 hours (76.2% vs 75.6%, $P = .79$), early severe primary graft dysfunction (4.8% vs 8.9%, $P = .53$), hospital stay (14.1 vs 14.3 days, $P = .95$), postoperative pulmonary function, or 1-year unadjusted survival (95.0% vs 95.5%, log-rank $P = .84$) in robotic compared with nonrobotic minimally invasive recipients.

CONCLUSIONS This experience with robotic lung transplantation suggests it is associated with midterm outcomes similar to nonrobotic lung transplantation, despite longer ischemic times.

(Ann Thorac Surg 2025;119:1107-16)

Outcomes of lung transplantation have improved substantially in the last decade, driven predominantly by improved medical management leading to decreased waiting list mortality and improved recipient outcomes, despite increasing patient age and risk.[1-3] Preoperative and postoperative management and donor organ preservation have progressed substantially; however, intraoperative management and the tenets of the procedure have remained largely the same since the first transplants in the 1960s, despite major technical developments, including

The Supplemental Tables and Supplemental Figure can be viewed in the online version of this article [https://doi.org/10.1016/j.athoracsur.2025.03.005] on https://www.annalsthoracicsurgery.org.

Accepted for publication Mar 10, 2025.

[1]Department of Cardiac Surgery, Smidt Heart Institute, Cedars-Sinai Medical Center, Los Angeles, California; and [2]Department of Pulmonary and Critical Care Medicine, Comprehensive Transplant Center, Cedars-Sinai Medical Center, Los Angeles, California

Address correspondence to Dr Emerson, Department of Cardiac Surgery, Smidt Heart Institute, Cedars-Sinai Medical Center, 127 S San Vicente Blvd, Pavilion, Ste A3600, Los Angeles, CA 90048; email: dominic.emerson@cshs.org.

robotic approaches in oncologic pulmonary surgery and other solid-organ transplants.[4-7]

Significant morbidity associated with the traditional sternotomy and clamshell approaches to lung transplantation led our center to develop a minimally invasive, robotic approach to lung transplantation by taking advantage of technical developments long established in thoracic oncologic resection, thoracoscopic approaches to lung transplantation described by the Hanover group, and our own experience with minimally invasive lung transplant.[8,9] In October 2021, the first reported robotic single-lung transplant was performed successfully by our team at Cedars-Sinai, Los Angeles, followed by the first reported robotic double-lung transplant by the same team in 2022.[10]

Since then, robotic lung transplantation has expanded to represent >10% of our annual lung transplant case volume, and robotic techniques have been applied to lung transplants in other centers, with technical advances including a totally thoracoscopic approach.[11,12] However, data informing treatment choice are limited. This study was therefore designed to evaluate midterm results of minimally invasive and robotic lung transplantation and describe the clinical, technical, and programmatic lessons learned from our early experience.

MATERIAL AND METHODS

DATA SOURCE. We analyzed a prospectively collected institutional data set including all lung transplants performed between October 2021 and February 2025 stratified by incision, including standard open lung transplant (sternotomy and clamshell), minimally invasive lung transplant (defined as a <6-cm thoracotomy) using a nonrobotic approach, and robotic lung transplant. This data set was linked with the institutional United Network for Organ Sharing Standard Transplant Analysis and Research files, excluding patients with repeat lung transplantation, unvalidated records, and multiorgan listing. The Cedars-Sinai Medical Center Institutional Review Board approved the study (STUDY00001188) on February 19, 2021, with a waiver of informed consent.

PATIENTS AND OPERATIVE TECHNIQUES. Patient selection and operative technique evolved substantially during the study period. To minimize conflicts between the robotic arms in reduced working spaces, initially only patients with chronic obstructive pulmonary disease were considered for robotic lung transplant, but this quickly changed to include patients with fibrotic lung disease. The actual total lung capacity for patients was used as a surrogate for potential space in the chest, and patients were selected for a robotic approach if the actual total lung capacity was >3 L, with consideration on a case-by-case basis for patients with actual total lung capacity of 2 to 3 L. For the same reason, height <63 inches was considered a relative contraindication to a robotic approach.

Initially, robotic assistance was reserved for implantation of the donor lungs, and the recipient pneumonectomy was performed using a minimally invasive technique with long instruments. This subsequently evolved so that the pneumonectomy and implant were both performed with robotic assistance. Incisions included a 6-cm thoracotomy (occasionally increased up to 8 cm, depending on the pathology as, for example, stiff, fibrotic lungs may not be deliverable through a 6-cm incision) in the fourth intercostal space.

Port placement for the right chest was generally (1) third intercostal space, midaxillary line (left hand); (2) anterior apex of the primary incision (camera); (3) fifth intercostal space, anterior axillary line (retractor); (4), sixth intercostal space, midaxillary line (right hand). For the left chest, arm placement included: (1), sixth intercostal space, midaxillary line (left hand); (2), fifth intercostal space, anterior axillary line (retractor); (3) anterior apex of the primary incision (camera); (4), third intercostal space, midaxillary line (right hand) (Figure 1; Feature Illustration). An additional 1-m incision was made at the eighth intercostal space, as posterior as possible, to allow the left atrial clamp to be inserted.

A custom minimally invasive clamp for the left atrium was used as previously described, and an angled clamp was placed through the primary incision for the pulmonary artery.[4] After insertion of the donor lung, the bronchus, then left atrium, then pulmonary artery were anastomosed. We use a 3-0 polydiaxone suture for the bronchus, a 4-0 polytetrafluoroethylene suture with an everting technique for the left atrium, and a 3-0 polypropylene suture for the pulmonary artery.

STATISTICAL ANALYSIS. The primary end point was 1-year survival. Secondary end points included primary graft dysfunction, intraoperative or postoperative venoarterial extracorporeal membrane oxygenation (VA-ECMO), ischemic time, postoperative ventilator support <48 hours, grade 3 primary graft dysfunction ≤72 hours, hospital length of stay, and postoperative pulmonary function.

Baseline characteristics and operative data are reported as mean ± SD or median with interquartile range (IQR) for continuous variables, depending on the overall distribution, and proportions for categorical variables (Tables 1 and 2). All analyses were performed on an intention-to-treat basis regardless of any intraoperative conversions. Between-group comparisons were performed using the Student *t* test or Wilcoxon rank sum test for continuous variables, depending on the variable distribution. Categorical variables were analyzed using the Pearson χ^2 test or the Fisher exact test where appropriate. Missing data were addressed with complete case analysis, where cases with only complete data were used (Supplemental Table 1).

Longitudinal changes in forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) were evaluated using a repeated-measures linear mixed-effects regression model. In the model, time (treated as a categorical variable corresponding to 3, 6, and 12 months), group (robot vs direct), and their interaction were included as fixed effects. A random intercept was specified for each patient to account for within-patient correlations, and an autoregressive covariance structure was used to model the serial correlation of repeated measurements over time. Model-based estimates of the mean response (least squares means) were calculated for each group at each time point. Statistical significance was defined as a *P* value <.05 (Supplemental Tables 2, 3).

Median FEV_1 and FVC and IQR are presented in Table 3 with associated *P* values derived from the repeated-measure linear mixed-effects model. The model did not adjust for any covariates and included an interaction term between the approach (robotic vs direct) and time (3, 6, and 12 months). Survival curves were constructed using the Kaplan-Meier method and compared between robotic and direct minimally invasive lung transplant cohorts using a log-rank test. Right censoring was performed at 1 year for posttransplant survival. Median follow up time was 22 months (IQR, 14.6-24.2 months) for the entire cohort and 13 months (IQR, 5.9-21.8 months) for the robotic minimally invasive lung transplant cohort. All tests were 2-tailed with an α-level of 0.05. All statistical analyses were performed using SAS 9.4 software (SAS Institute, Inc, Cary, NC).

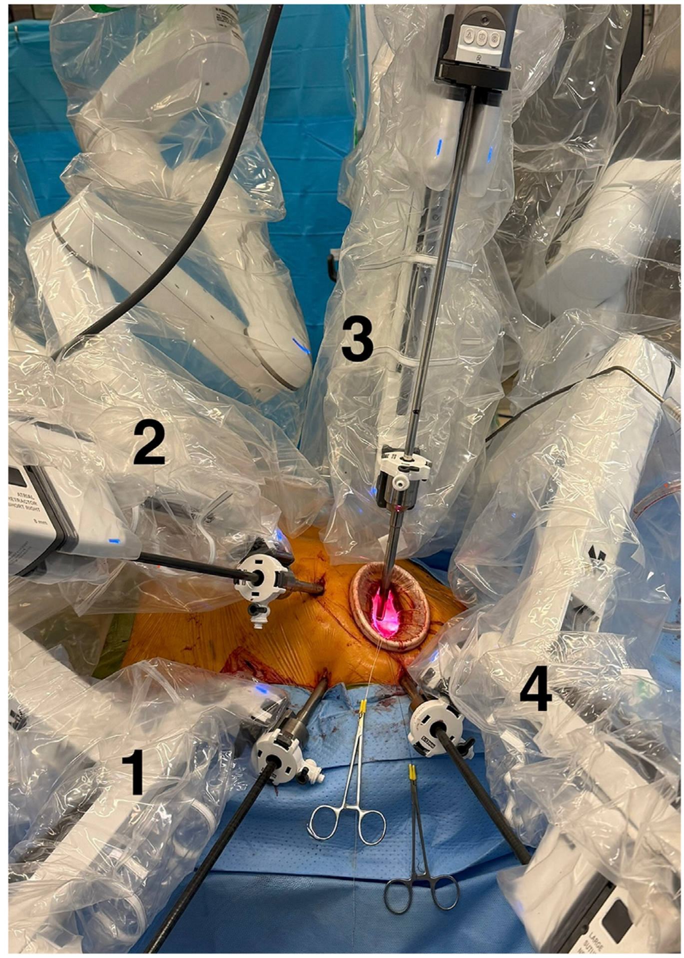


FIGURE 1 Setup for left robotic lung transplant. (1) Left hand, (2) retractor, (3) camera, (4) right hand.

RESULTS

ROBOTIC LUNG TRANSPLANTS. During the study period, 209 lung transplants were performed, including 111 minimally invasive lung transplants (53.1%), comprising 21 robotic lung transplants (10%) and 90 nonrobotic lung transplants (43.1%). Most of robotic patients (62% [n = 13]) were men, and pulmonary fibrosis was the most common pathology (57.1% [n = 12]) (Table 1). Of the 21 robotic minimally invasive lung transplants, 13 were bilateral, 6 were right-sided single-lung, and 2 were left-sided single-lung transplants. Three patients were converted from robotic to nonrobotic approaches because of prolonged ischemic time, difficult anatomy, and high pulmonary arterial pressure. These conversions were predominantly during the early phase of this technique, occurred in a controlled fashion, and all transplants were completed through the 6-cm anterior thoracotomy incision.

Median cold and warm ischemic times were 460 minutes (IQR, 285.25-854.5 minutes) and 68.5 minutes (IQR, 60.25-79.25 minutes), respectively. Warm ischemic times trended lower for left

Ann Thorac Surg
2025;119:1107–16

TABLE 1 Baseline Minimally Invasive Lung Transplant Characteristics by Approach

Baseline Characteristics	Robotic Lung Transplant (n = 21)	Minimally Invasive Lung Transplant (n = 90)	*P* Value
Recipient characteristics			
Age, y	66 (64.0–72.0)	67 (61.0–70.0)	.41
Height, cm	170.2 (165.1–180.3)	166.4 (160.0–175.3)	.06
Weight, kg	70.8 (62.1–85.7)	68.3 (59.0–76.7)	.30
Diabetes	19 (4)	22.2 (20)	.75
Creatinine, mg/dL	0.8 (0.7–0.9)	0.8 (0.6–0.9)	.71
Waiting list time, d	50 (21.0–98.0)	22.5 (8.0–51.0)	.02
Male sex	61.9 (13)	64.4 (58)	.83
White race	52.4 (11)	41.1 (37)	.12
Recipient pathology			.01
Alpha-1 antitrypsin deficiency	4.8 (1)	0 (0)	
Bronchiectasis	0 (0)	1.1 (1)	
COPD/emphysema	28.6 (6)	4.4 (4)	
Hypersensitivity pneumonitis	9.5 (2)	11.1 (10)	
Pulmonary Fibrosis	57.1 (12)	73.3 (66)	
Idiopathic Pulmonary Fibrosis	50 (6/12)	46.9 (31/66)	
Pulmonary Fibrosis Other	41.7 (5/12)	45.5 (30/66)	
COVID-19–related pulmonary fibrosis	8.3 (1)	7.6 (5/66)	
Nonspecific interstitial pneumonia	0 (0)	3.3 (3)	
Rheumatoid disease	0 (0)	4.4 (4)	
Type O blood	28.6 (6)	54.4 (49)	.03
Pretransplant location			.71
Home	81 (17)	82.2 (74)	
Hospitalized, non-ICU	19 (4)	16.7 (15)	
Hospitalized, ICU	0 (0)	1.1 (1)	
Functional status			.06
Mild limitation	14.3 (3)	2.2 (2)	
Moderate limitation	76.2 (16)	86.7 (78)	
Severe limitation	9.5 (2)	11.1 (10)	
Donor characteristics			
Age, y	31 (24.0–46.0)	35.5 (22.0–47.0)	.94
Height, cm	176.5 (165.0–180.0)	167.8 (163.0–173.5)	.01
Weight, cm	74.7 (69.2–89.2)	74.5 (68.1–85.1)	.48
Male sex	76.2 (16)	61.1 (55)	.20
Sex mismatch	23.8 (5)	25.6 (23)	.87
PaO_2/FiO_2 ratio <200	23.8 (5)	34.4 (31)	.26
Donor type			.63
Donation after brain death	95.2 (20)	92.2 (83)	
Donation after circulatory death	4.8 (1)	7.8 (7)	

Values are expressed as percentage (n) or median (interquartile range). COPD, chronic obstructive lung disease; COVID-19, coronavirus disease 2019; FiO_2, fraction of inspired oxygen; ICU, intensive care unit.

compared with right lung implants (64.7 minutes [IQR, 58.0-72.0 minutes] vs 73.9 minutes [IQR, 66.5-83.0 minutes], $P = .05$). Nine robotic lung transplants (43%) were performed with VA-ECMO support (Table 2). Unplanned conversion to VA-ECMO support occurred in 3 patients for elevated pulmonary pressures during implantation (2 patients) and inability to tolerate single-lung ventilation (1 patient). All conversions to VA-ECMO support were performed without significant hemodynamic compromise.

Early outcomes are presented in Table 3. There was 1 in-hospital death at 12 days due to massive gastrointestinal bleeding. Freedom from grade 3 primary graft dysfunction at 72 hours was 95%. The average time to extubation was 1.5 days (IQR, 1-2 days), and the median hospital stay was 14.5 days (IQR, 12-20 days). Seventy percent of patients were discharged home. Of note, all lung transplant immunosuppression and postoperative care management strategies were implemented in a standard fashion, independent of approach.

TABLE 2 Operative Characteristics

Operative Characteristics	Robotic Lung Transplant (n = 21)	Minimally Invasive Lung Transplant (n = 90)	*P* Value
Total ischemic time, min	486 (366–780)	408 (306–498)	0.02
Warm ischemic time, min	68.5 (60.25–79.25)	n/a	n/a
Right lung	70 (66.5–83)	n/a	n/a
Left lung	62 (58–72)	n/a	n/a
Procedure type			0.36
Bilateral sequential lung	61.9 (13)	50 (45)	
Single left lung	9.5 (2)	23.3 (21)	
Single right lung	28.6 (6)	26.7 (24)	
Pump configuration			0.25
VA-ECMO	42.9 (9)	27.8 (25)	
Cardiopulmonary bypass	0 (0)	5.6 (5)	
Off pump	57.1 (12)	66.7 (60)	

Values are expressed as percentage (n) or median (interquartile range) VA-ECMO, venoarterial extracorporeal membrane oxygenation (n/a, not available.).

Follow-up was 100% complete for all patients. Overall survival was 90.5%, with 1 late death due to mucormycosis.

MINIMALLY INVASIVE LUNG TRANSPLANTS WITHOUT ROBOTIC ASSISTANCE. During the study period, 90 patients underwent nonrobotic minimally invasive lung transplants. Compared with the robotic cohort, the nonrobotic cohort was similar baseline recipient demographics (Table 1). Although recipient pathology varied significantly ($P = .01$), the most common lung failure etiology in both groups was pulmonary fibrosis (57.1% vs 73.3%). Robotic minimally invasive lung transplant recipients had longer median waiting list times (50.0 days vs 22.5 days, $P = .02$) compared with nonrobotic recipients, but donor profiles were otherwise similar.

Support with VA-ECMO was used more frequently in the robotic minimally invasive lung transplant group than in the nonrobotic group (42.9% vs. 27.8%; $P = .25$). Median total ischemic time (cold + warm) was significantly longer in the robotic cohort (486 minutes [IQR, 366-780 minutes] vs 408 minutes [IQR, 306-498 minutes], $P = .02$), driven in part by a trend toward more bilateral lung transplants (61.9% vs 50.0%, $P = .36$) (Table 2) in robotic minimally invasive lung transplant patients and the increasing use of 10 °C storage with planned delay. Warm ischemic time was not routinely recorded in the direct minimally invasive lung transplant data set and could not be compared.

Postoperatively, short-term outcomes were also generally similar between groups. Ventilator support duration <48 hours (76.2% vs 75%, $P = .79$), the incidence of primary graft dysfunction grade 3 at 72 hours (4.8% vs 8.9%, $P = .53$), and hospital stay (14.1 vs 14.3 days, $P = .95$) were not statistically different for the robotic and nonrobotic cohorts, respectively. One early death (5.0%) occurred in the robotic group, and there were none in the nonrobotic minimally invasive cohort ($P = .03$) (Table 3), but unadjusted Kaplan-Meier analysis demonstrated comparable 1-year survival between the groups (log-rank $P = .84$) (Figure 3). At 3, 6, and 12 months, FEV_1 and FVC were similar between robotic and direct minimally invasive cohorts (all $P > .05$) (Table 3). For both FEV_1 and FVC, the interaction between approach (robotic vs direct) and time (3, 6, and 12 months) did not differ significantly (all interaction $P > .15$) (Supplemental Tables 2, 3). Short-term outcomes, survival, and pulmonary function were unchanged in the as-treated analysis (Supplemental Table 4; Supplemental Figure).

STANDARD LUNG TRANSPLANT APPROACHES. During the study period, 98 lung transplants were performed using sternotomy (n = 71), clamshell (n = 19), or thoracotomy incisions >6 cm (n = 8). The mean age of these patients was 56.9 ± 10.1 years, and the median waiting list time was 25.5 days (IQR, 13-75 days). The median total ischemic time was 6.9 hours (IQR, 5.8-8.9 hours), and 43 transplants (43.8%) were performed with VA-ECMO support. The median hospital stay was 19 days (IQR, 13.7-30 days), 30-day mortality was 1.0% (n = 1), severe primary graft dysfunction (grade 3) rate at 72 hours was 18.4% (n = 18), and 1-year survival was 94.0% (IQR, 89.0%-99.0%). Median percent predicted FEV_1 at 3, 6, and 12 months was 74.5 L (IQR, 62-89 L), 76.5 L (IQR, 62-88 L), and 78 L (IQR, 65-93 L), respectively.

TABLE 3 In-Hospital and Short-term Outcomes

Outcomes	Robotic Lung Transplant (n = 21)	Minimally Invasive Lung Transplant (n = 90)	*P* Value
In-hospital			
Posttransplant ventilator support			.79
<48 hours	76.2 (16)	75.6 (68)	
48–5 days	19 (4)	18.9 (17)	
>5 days	4.8 (1)	5.6 (5)	
Primary graft dysfunction 3 at 72 hours	4.8 (1)	8.9 (8)	.53
Epidural use	90.5 (19)	87.8 (79)	.73
Dialysis	0 (0/20)	2.2 (2)	.49
Stroke	0 (0/20)	2.2 (2)	.49
Reoperation	10 (2/20)	3.3 (3)	.20
Tracheostomy	5 (1/20)	3.3 (3)	.72
Intensive care unit length of stay, d	4.6 (4.0–6.3)	4.5 (3.5–7.7)	.85
Hospital length of stay, d	14.1 (11.8–20.5)	14.3 (12.0–17.1)	.95
Discharged on opioids	31.5 (6/19)	38.9 (35)	.63
30-day			
Readmission for any cause	10 (2/20)	13.3 (12)	.91
Death	5 (1/20)	0 (0)	.03
Postoperative pulmonary function testing			
Forced expiratory volume in 1 second, L			
3 months	79.0 (72.0–97.0)	85.0 (68.0–102.0)	.59
6 months	81.5 (75.0–90.0)	85.0 (68.0–104.0)	.57
12 months	77.0 (66.0–86.0)	84.5 (68.5–104.5)	.22
Forced vital capacity, L			
3 months	73.0 (66.0–87.0)	77.0 (63.0–92.0)	.41
6 months	78.0 (64.0–84.0)	82.0 (65.0–93.0)	.27
12 months	75.0 (60.0–87.0)	82.0 (73.0–101.0)	.13

Values are expressed as percentage (n) or median (interquartile range). *P* values for pulmonary function testing were attained from the linear mixed-effects regression model.

COMMENT

This series includes the first reported robotic single-lung and double-lung transplants in clinical practice and the largest cohort of robotic lung transplant patients reported to date, representing approximately two-thirds of current global experience with this technique. This report is also the first to provide midterm outcome data for robotic lung transplantation and indicates that clinical outcomes at a median follow-up of 13 months are similar to outcomes for nonrobotic approaches in published national data and our institutional experience.[1,9] We believe this supports the feasibility of robotic lung transplantation.

EDUCATION AND TRAINING. Our motivation for developing robotic lung transplant came from challenges teaching lung transplant through a 6-cm incision.[9,10] We found the robotic approach much easier to assist and teach using a dual console. Although median implant times for this approach of >1 hour are longer than typical, this has not compromised patient outcomes in our experience. Despite increased complexity in recipients and in teaching the technique, the robotic implants have become more efficient (Figure 4). We have shared our experience freely with centers adopting robotic lung transplantation.

Our team consists of cardiac surgeons; however, general thoracic surgeons have been most interested in adopting robotic techniques for lung transplantation so far. This may reflect their greater familiarity with robotic surgery, including robotic pneumonectomy and sleeve lobectomy, which share components of robotic lung transplantation and are common operations for many thoracic surgeons.

We recommend collaborating with existing programs to help understand the nuances of the technique and note that centers that have successfully performed these transplants have also invested extensive time simulating the transplant using low- and higher-fidelity simulations. These simulations are helpful for the surgeon on the console and for the bedside surgeon, both of whom are essential to the success of the procedure. Finally, familiarity with the open thoracotomy approach (as opposed to clamshell or

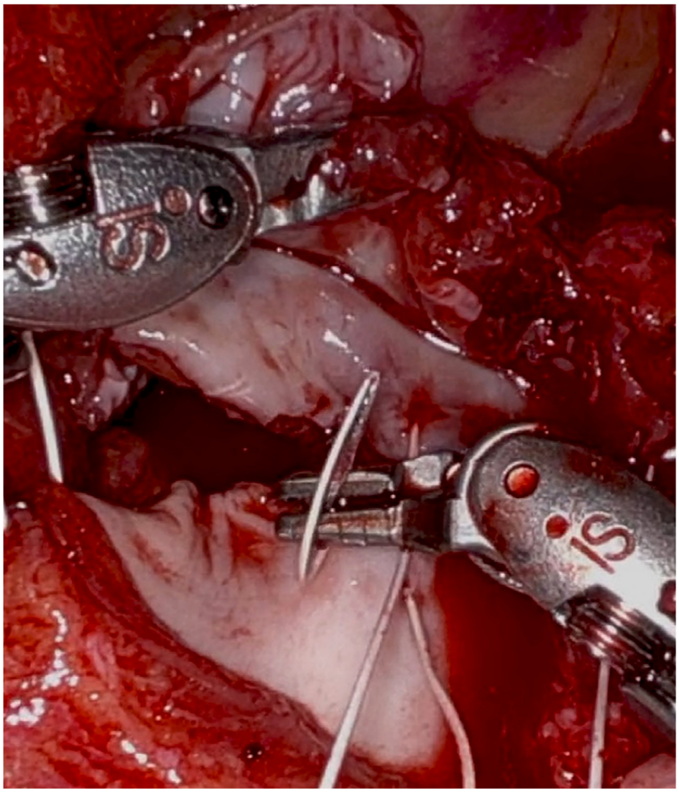


FIGURE 2 Intraoperative photo of the left atrial anastomosis with robotic assistance shows "sew toward the clamp" technique using backhand needle angles.

sternotomy) and simulating emergency conversion including VA-ECMO is essential.

LESSONS LEARNED. We initially selected recipients with chronic obstructive pulmonary disease for robotic lung transplant because the larger chest cavity facilitated a robotic approach (minimizing conflict between the robotic arms). We subsequently included patients with pulmonary fibrosis, who are significantly more challenging. Difficulty with limited working space is especially problematic in those with an actual total lung capacity of <2.5 L or with pathologies that lead to extensive scarring and adhesions (eg, coronavirus disease-related fibrosis). The height of the recipient can also play a role—patients <63 inches should be carefully examined for feasibility.

Positioning and port placement is critical. Our initial report describes our port placement for the right chest, which we continue to use, with the exception of arm 3 (retractor), which is now placed through a separate incision 1 rib space below the primary incision.[10] A modified placement for the left chest avoids conflict with the heart and facilitates implantation. This includes a 6- to 8-cm thoracotomy in the fourth intercostal space, and arm placement as shown in Figure 1. The safest and most ergonomic approach to suturing all anastomoses is to start at the 4 o'clock position and, sewing in a clockwise direction, passing the suture from donor to recipient backhand along the posterior wall. This avoids damage to recipient tissue, which is rigidly fixed with the clamp for the vascular anastomoses (Figure 2).

The clamps used are as initially described: we use a custom minimally invasive clamp for the left atrium, which is placed through a separate 2-cm incision (later used for a chest tube) at the eighth intercostal space. Interference between the robotic arms and the left atrial clamp is minimized by ensuring a very posterior incision for the clamp. The pulmonary artery clamp is placed through the primary incision, adjacent to the camera. Air removal and the initial reperfusion period are conducted with the robot still docked, allowing any repair sutures that might be required after clamp removal to be placed robotically.

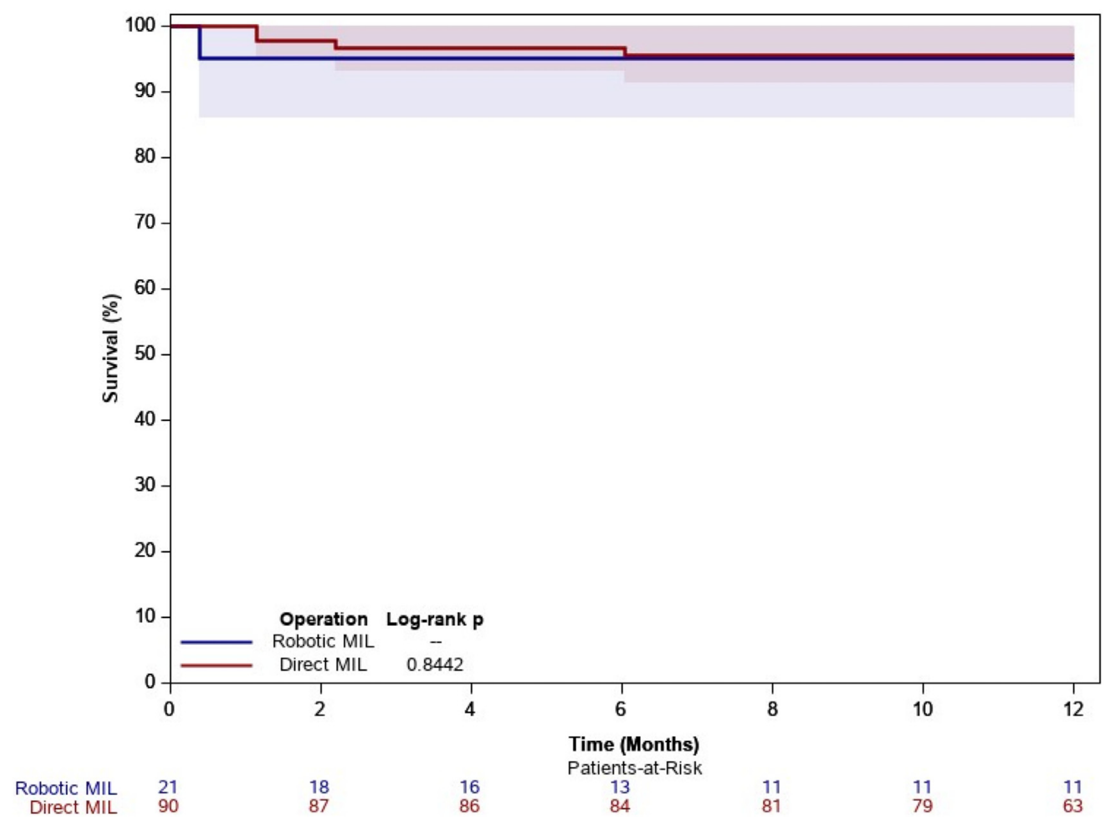


FIGURE 3 Unadjusted survival at 1 year after minimally invasive lung (MIL) transplantation using robotic and direct approaches. The shaded areas indicate the 95% CI.

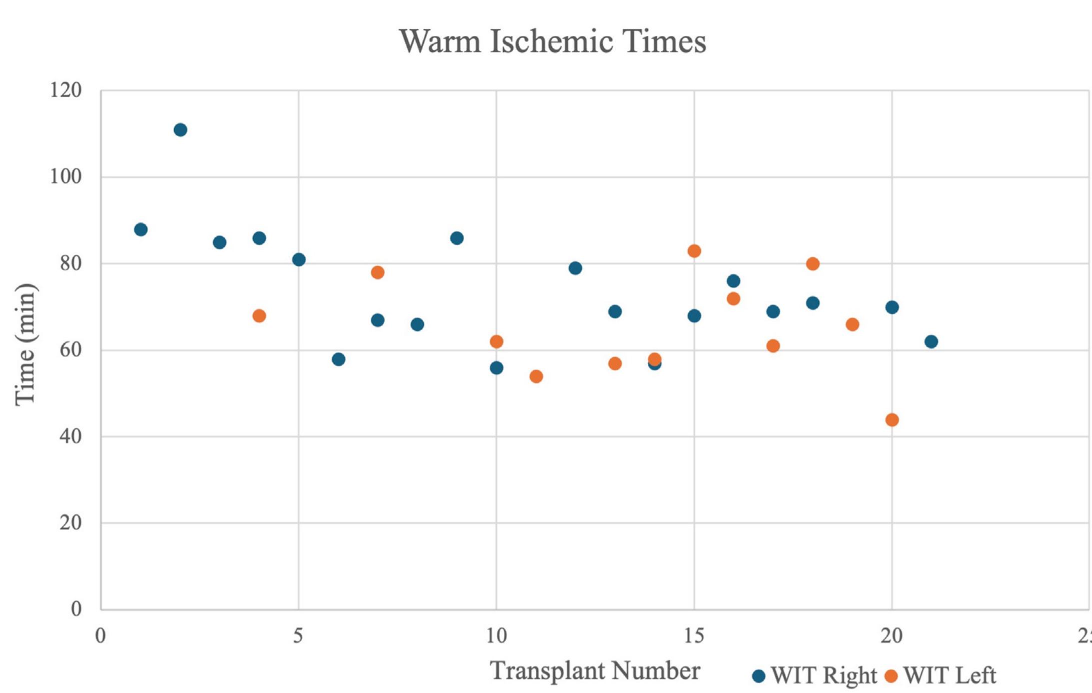
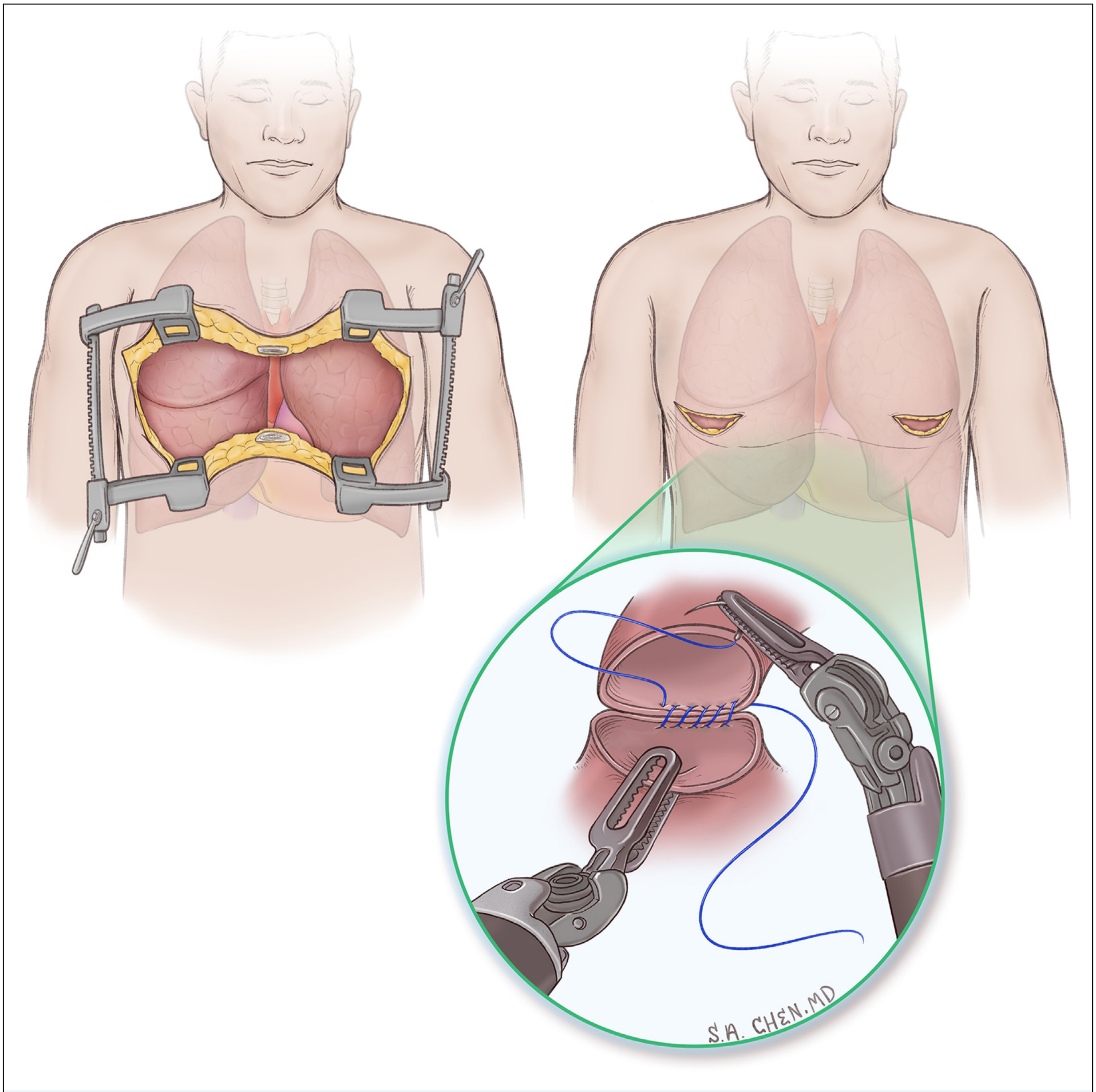


FIGURE 4 Warm ischemia times in robotic-assisted minimally invasive lung transplantation across increasing institutional experience. Each dot represents a single lung transplant, with warm ischemia times (WIT) plotted against cumulative case volume.



FEATURE ILLUSTRATION Bilateral robotic lung transplant through a minithoracotomy vs clamshell incisions.

LIMITATIONS. As a single-center experience with a small sample size, the generalizability of our findings is limited, and our statistical power is reduced. Our early experience with robotic lung transplantation necessitates cautious interpretation of outcome comparisons, particularly considering a relatively short follow-up period. Furthermore, important factors, such as warm ischemic time, were not systematically captured in both cohorts and limit full comparison. All patients undergoing lung transplantation are evaluated using the same criteria, independent of approach, without conscious variation in practice. The longer median waiting list times observed in the robotic transplant cohort may reflect the relatively low sample size.

Our study was designed primarily to highlight the feasibility and technical nuances of robotic lung transplantation with preliminary early outcome data rather than to serve as a definitive comparison between robotic and direct minimally invasive approaches. Consequently, our survival analyses are unadjusted and limited by the small sample size, which precludes a robust

Ann Thorac Surg
2025;119:1107–16

multivariable analysis to control for potential confounders.

All patients assigned to the robotic approach, including those who were converted to open anastomosis, were included in the current analysis. Although we have provided an as-treated analysis in the Supplemental Materials that confirms previous findings, future studies with larger cohorts are needed to more precisely assess the impact of intraoperative conversion on outcomes. Future studies with larger cohorts will incorporate an as-treated analysis to more precisely assess the impact of intraoperative conversion on outcomes.

CONCLUSION

Since performing the first reported robotic lung transplant in 2021, we have completed another 20 transplants. Robotic lung transplants represent 12% (10 of 85) of the lung transplant volume at our center in 2024, and minimally invasive lung transplants represent >50% of our lung transplant activity. Early outcomes suggest these approaches are feasible and safe. We previously reported functional benefits with minimally invasive compared with standard approaches to lung transplantation.[9] Determining whether robotic lung transplantation also offers a functional or survival benefit and could expand the pool of patients eligible for lung transplantation will require a much larger multicenter cohort of robotic lung transplant recipients, which we have initiated.

FUNDING SOURCES

Allen A. Razavi is supported by grants from the National Institutes of Health, National Heart, Lung, and Blood Institute for advanced heart disease research (T32HL116273). This work was supported in part by Health Resources and Services Administration contract 234-2005-370011C. The content is the responsibility of the authors alone and does not necessarily reflect the views or policies of the Department of Health and Human Services, nor does mention of trade names, commercial products, or organizations imply endorsement by the United Stats Government.

DISCLOSURES

Dominic Emerson serves as a consultant (procedural proctor) for Intuitive Surgical; this role is for training purposes and did not influence the study design, data analysis, or interpretation of the results. The other authors have no conflicts of interest to disclose.

REFERENCES

1. Valapour M, Lehr CJ, Schladt DP, et al. OPTN/SRTR 2022 annual data report: lung. *Am J Transplant*. 2024;24:S394-S456. https://doi.org/10.1016/j.ajt.2024.01.017

2. Zhou AL, Karius AK, Ruck JM, et al. Outcomes of lung transplant candidates aged >70 years during the lung allocation score era. *Ann Thorac Surg*. 2024;117:725-732.

3. Anderson S, Reck dos Santos P, Langlais B, et al. Lung transplant outcomes for idiopathic pulmonary fibrosis: are we improving? *Ann Thorac Surg*. 2024;117:820-827.

4. Servais EL, Blasberg JD, Brown LM, et al. The Society of Thoracic Surgeons General Thoracic Surgery Database: 2022 update on outcomes and research. *Ann Thorac Surg*. 2023;115:43-49.

5. Towe CW, Servais EL, Brown LM, et al. The Society of Thoracic Surgeons General Thoracic Surgery Database: 2023 update on outcomes and research. *Ann Thorac Surg*. 2024;117:489-496.

6. Hoznek A, Zaki SK, Samadi DB, et al. Robotic assisted kidney transplantation: an initial experience. *J Urol*. 2002;167:1604-1606.

7. Khan AS, Scherer M, Panni R, et al. Total robotic liver transplant: the final frontier of minimally invasive surgery. *Am J Transplant*. 2024;24:1467-1472. https://doi.org/10.1016/j.ajt.2024.03.030

8. Fischer S, Struber M, Simon AR, et al. Video-assisted minimally invasive approach in clinical bilateral lung transplantation. *J Thorac Cardiovasc Surg*. 2001;122:1196-1198.

9. Thomas J, Chen Q, Malas J, et al. Impact of minimally invasive lung transplantation on early outcomes and analgesia use: a matched cohort study. *J Heart Lung Transplant*. 2024;43:1358-1366. https://doi.org/10.1016/j.healun.2024.01.01

10. Emerson D, Catarino P, Rampolla R, Chikwe J, Megna D. Robotic-assisted lung transplantation: first in man. *J Heart Lung Transplant*. 2024;43:158-161. https://doi.org/10.1016/j.healun.2023.09.019

11. Ascanio F, Abdallah NZ, Rosado J, et al. Towards standardization in robotic lung transplants: a novel approach in minimally invasive thoracic surgery. *Eur J Cardiothorac Surg*. 2025;76:ezaf042. https://doi.org/10.1093/ejcts/ezaf042

12. MacKenzie M. NYU Langone Health Performs Fully Robotic Lung Transplant. Sept. 11, 2024. *Healthcare Purchasing News*. Accessed March, 2025. https://www.hpnonline.com/surgical-critical-care/news/55139206/nyu-langone-health-performs-fully-robotic-lung-transplant