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REVIEW

Small recipient chest cavity from fibrotic lung disease in lung transplantation: Physiology matters

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Lung transplantation is an established management strategy for advanced end-stage lung disease with the goal of restoring normal pulmonary physiology. This principle guided our management approach to the clinical challenge of a lung transplant recipient with a small chest cavity from fibrotic lung disease. Size matching should occur based on the recipient's predicted total lung capacity, which best reflects the recipient's normal chest cavity size. We present an instructive case that suggests that the small chest cavity size adjusts relatively quickly toward normal once the fibrotic lungs are removed, and normal allograft is implanted.
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Background

A small recipient chest cavity from fibrotic lung disease is a management challenge in the intraoperative and perioperative period of lung transplantation. The approach to donor-to-recipient sizing in this situation continues to be a matter of controversy. We describe our physiology-based management strategy focused on the goal of restoring normal pulmonary function.

Case report

A 66-year-old male, 5 ft 3 tall (63 in, 160 cm, predicted total lung capacity [pTLC] 5.7 liters) with progressive interstitial lung disease (ILD) was evaluated for lung transplant (LTx) candidacy. His ILD was complicated by a very severe restrictive ventilatory defect (forced vital capacity [FVC] 0.82 liter, 26% predicted; total lung capacity [TLC] 2.76 liters, 49% predicted), a very severe gas transfer defect (diffusion capacity for carbon monoxide 7% predicted) leading to hypoxemic and hypercarbic respiratory failure. He needed supplemental oxygen with 6 liters per minute (LPM) at rest and 10 LPM with activity. He was found to be an appropriate LTx candidate and was placed on the LTx waitlist with an acceptable donor height range of +8 to −8 in. A donor-lung offer from a 28-year-old female, 5 ft 8 tall (68 in, 173 cm, pTLC 5.63 liters), became available. The donor-to-recipient height ratio was 1.08, the pTLC ratio was 0.99, and the donor pTLC-to-recipient actual TLC ratio was 2.04 (Figure 1). After careful assessment and consideration, the donor lungs were accepted for LTx. The bilateral LTx was performed via clamshell incision and on central veno-arterial extracorporeal

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memebrane oxygenation support. Intraoperative volume resuscitation and correction of coagulopathy were needed. The size of the chest cavity intraoperatively was very small in comparison to the allograft. During weaning attempts from veno-arterial extracorporeal memebrane oxygenation, severe hypoxia occurred in the setting of significant lower lobe atelectasis leading to shunt physiology. To address this, the recipient was converted to bifemoral veno-venous extracorporeal memebrane oxygenation (VV-ECMO) (5 LPM blood flow, 2.5 LPM sweep flow). Cardiopulmonary stability was achieved, and his chest was closed.

On admission to the intensive care unit, a ventilator strategy to promote lung recruitment was implemented. This strategy included moderate PEEP at +10 cmH_2O, pressure control ventilation with the pressure control set to achieve tidal volumes (TV) greater than the estimated anatomical dead space of 120 to 150 ml and limiting sedation to facilitate spontaneous respiratory efforts, while maintaining lung protective ventilation parameters. On intensive care unit admission, a pressure control of +18 cm H_2O allowed for 180 to 200 ml TV. He was hemodynamically stable, warm, and well-perfused with intact end-organ function. However, persistent lactic acidosis was present. The resolution coincided with weaning off from inhaled epoprostenol. After 32 hours of VV-ECMO support, allograft function had significantly improved and he was successfully decannulated. On pressure control ventilation with PEEP +10 and pressure control +18 TV gradually improved from 300 to 400 ml by 48 hours after transplant. Of note, a 6 ml/kg donor predicted body weight TV was calculated to be 380 ml. Extubation to noninvasive ventilation via a mask interface with break periods on high flow nasal cannula was achieved on postoperative day (POD) 3, he was transferred to a step down unit in stable condition on POD 4 and was discharged home on POD 18.

On his 1-month post-transplant clinic visit, he was breathing well on room air. His pulmonary function studies showed a normal pattern and as expected for the early period after transplant evidence of restriction with an FVC of 1.40 liters (46.3% of predicted), forced expiratory volume in 1 second of 1.09 liter (44.9% of predicted) and a forced expiratory volume in 1 second/FVC ratio of 78%. Unfortunately, our patient developed a medical complication requiring readmission to the hospital with severe acute kidney injury complicated anuric renal failure requiring hemodialysis. His hospital course was complicated by bacteremia, sepsis, and multiple organ failure that was fatal.

Discussion

LTx is an established management strategy for advanced end-stage lung disease with the goal to restore normal pulmonary physiology, so that the LTx recipient can experience improved quality of life and live longer than with their original disease. However, size matching is currently a matter of controversy. When considering an appropriate donor, recipient chest cavity adaptation to fibrotic lung disease can underlie the selection of a donor on the shorter end of acceptable height range, when height is used as a key guiding parameter for size matching and thoracic size estimation.[1] The goal to restore normal pulmonary physiology guided our management approach to the clinical challenge of an LTx recipient with a small chest cavity from fibrotic lung disease. The chest cavity in fibrotic lung disease is small because of the shrunken, stiff, and fibrotic lung. Clinical experience has demonstrated, however, that the chest cavity will return to normal following transplantation.[1,2] With this knowledge, the parameter that best reflects the sizing goal to restore normal physiology is the recipient pTLC, as it best reflects the recipient's normal chest cavity size. Using the pTLC ratio as the size-matching parameter and aiming for a reasonably size-matched allograft is, in our opinion, the best approach to achieve the goal of restoring normal physiology.[1,3] Consistent with this, the Toronto lung transplant program has shown that donor-to-recipient pTLC size-matching, based on a ratio of >0.8: <1.2, im-

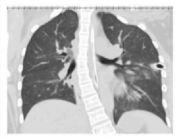
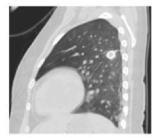
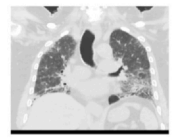
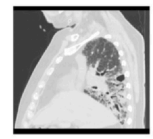
Parameter	Donor	Recipient	D/R ratio
Age, Sex, BMI	28, Female, 30	66, Male, 25.8	
Height (in, cm)	68 in, 173 cm	63 in, 160 cm	1.08
pTLC (L)	5.63	5.7	0.99
TLC (L)	*5.63*	2.7	2.04
CT Coronal & Saggital	 	 	
CXR measurements (cm)	Left: 23.6, Right: 20.8, Diaphragm: 28.9	Left: 14.6, Right: 13.6 Diaphragm: 25.5	1.6, 1.5 1.13

Figure 1 Summary of donor-to-recipient sizing parameters. BMI, body mass index; cm, centimeter; CT, computer tomography; CXR, chest X-ray; in, inch; pTLC, predicted total lung capacity; TLC, total lung capacity.

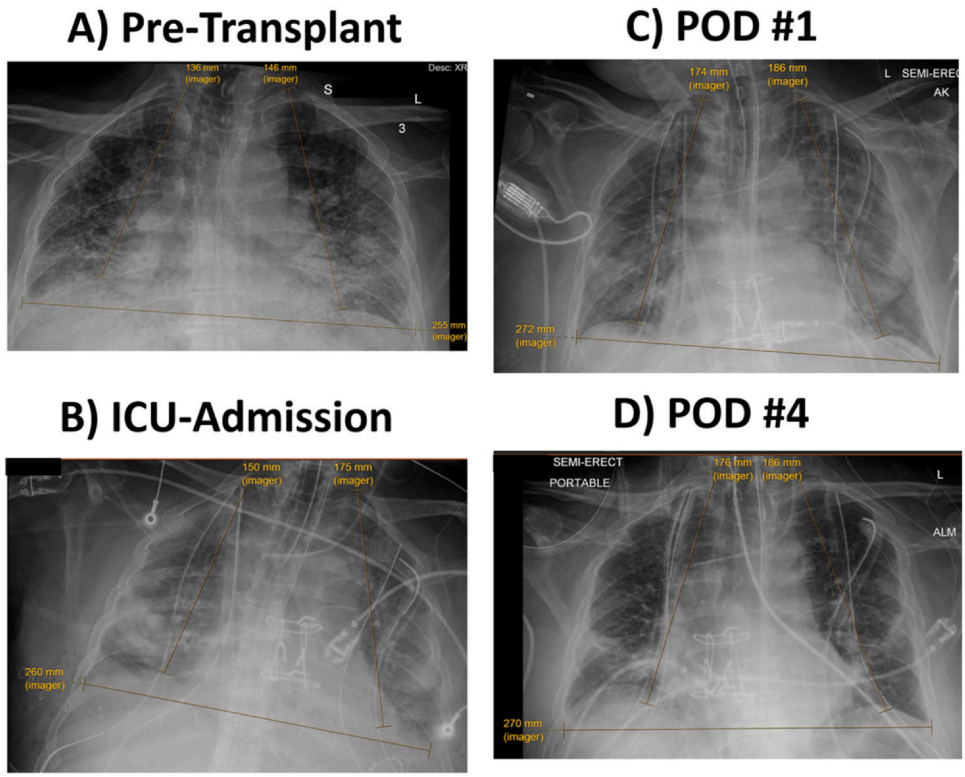


Figure 2 Serial chest X-rays at defined time points. Right lung left lung and diaphragm measurements as indicated. ICU, intensive care unit; mm, millimeter; POD, postoperative day.

proved post-LTx outcomes for patients with restrictive lung disease.[1,3] An exception to the concept of using recipient pTLC as the sizing parameter is disease processes that are associated with possibly irreversible alterations to chest wall physiology, such as pleuropulmonary fibroelastosis, radiation-induced pulmonary fibrosis, kyphoscoliosis, or ankylosing spondylitis.[4] Chest wall abnormalities, spinal deformities, or mediastinal fibrosis will require comprehensive evaluation to determine surgical feasibility and consideration of the impact of irreversible restriction anticipated post-transplant.[4,5]

At the time of the operation, the small recipient chest cavity (as reflected by actual TLC of the recipient) does increase intra- and perioperative complexity. A review of the literature shows different strategies to manage this challenge:

A. Only accepting relatively undersized lungs for recipients with small chest cavities
B. Trimming (nonanatomical resection of the lung) and lobectomy/lobar lung Tx
C. Leaving the chest open at the end of the operation
D. Physiology-based management approach with the goal to restore normal physiology in the long term

Regarding option A, there is evidence that significantly undersized allografts, as assessed by pTLC ratio, are associated with increased risks of primary graft dysfunction,[6] perioperative complications,[7] and decreased survival.[8] Trimming the lung and lobar transplantation (option B) can be an important option to expand the acceptable donor pool for recipients with very small pTLCs.[9] The Toronto lung transplant team showed that lobar lung transplant approach allowed to utilize donor lungs that would have had a pTLC ratio of 1.6, but after lobar reduction was size-matched based on an implanted pTLC ratio of 1.0. When, however, a lobar reduction is used to adjust as per pTLC ratio size-matched allograft to the size of the intraoperative small chest size in a recipient with fibrotic lung disease, there seems to be an association with worse outcomes.[10,11]

When a substantial size mismatch between the allografts and the intraoperative available chest cavity size is present, an attempt to close the chest can be associated with increased intrathoracic pressure, tamponade-like physiology, and hemodynamic compromise. Under those circumstances, leaving the chest open (option C) until the allograft and the chest cavity can adapt to each other can be an important option. Delayed chest closure is associated with comparable outcomes in this situation.[12] However, if feasible, immediate chest closure is preferable, as possible complications of a delayed chest closure approach, such as an increased risk for surgical site infections and prolonged hospital stays, can be avoided.[13]

We advocate for a management approach that facilitates the long-term goal of restoring normal physiology. VV-ECMO ensured adequate oxygenation and carbon dioxide removal until the chest wall remodeled and the compressed lower lobes could be recruited with the assistance of mechanical ventilation. This ultimately allowed for controlled ECMO weaning and decannulation. We used moderate posiitve end-expiratory pressure (PEEP) and had target TVs that needed to be significantly greater than the anatomical dead space, while still maintaining lung protective ventilation goals.

We limited sedation to allow for spontaneous respiratory efforts by the recipient, to facilitate diaphragmatic excursion, lower lobe recruitment, and early patient mobility. In addition, we performed bronchoscopies twice daily to ensure clear airways. Respiratory mechanics and allograft function improved substantially in our recipient with this management approach, and he was successfully extubated on POD 3. This suggests that the chest cavity size adjusts relatively quickly toward normal once the fibrotic lungs are removed and normal allograft is implanted (Figure 2).

Our patient was hemodynamically stable but had persistent lactic acidosis during the first 24 hours after the LTx. The resolution of the lactic acidosis coincided with weaning off from inhaled epoprostenol. The atelectatic lower lobes of the allografts were the probable source of the lactate,[14,15] likely exacerbated by the absence of bronchial circulation after transplant and the negative effect on the pulmonary blood flow to the atelectatic lung by the administration of inhaled epoprostenol. Weaning the inhaled epoprostenol and a strategy to recruit the lower lobes coincided with the resolution of lactic acidosis.

A limitation of our report is that the observations are limited to the early period after lung transplantation. In general, over time pulmonary function studies improve until peak lung function is achieved on average by 1 year after transplant.[16] As expected for the early follow-up period, pulmonary function studies showed a restrictive pattern in our patient; however, long-term follow-up information is not available. Previous studies suggested that irrespective of underlying lung disease leading to transplant the chest cavity will return toward normal following transplantation.[2,17]

In summary, the goal to restore normal pulmonary physiology should guide the approach to the clinical challenge of an LTx recipient with a small chest cavity from fibrotic lung disease. Size matching should occur based on the recipient's pTLC, as it best reflects the recipient's normal chest cavity size. Our case suggests that the chest cavity size adjusts relatively quickly toward normal once the fibrotic lungs are removed and normal allograft is implanted. Sizing based on a donor-to-recipient pTLC ratio of $>0.8:<1.2$ was associated with improved post-LTx outcomes for patients with ILD.[3]

Ethics statement

Patient consent was obtained.

Disclosure statement

All authors have no relevant conflicts of interest to disclose.

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