



Technical Aspects of Lung Transplantation: Pediatric and Lobar Transplantation

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Fewer patients undergo pediatric lung transplantation (PLT) than adult lung transplantation. Size mismatch is the key factor that limits the availability of potential donors. Every candidate for PLT is in a different scenario in terms of age, height and weight, size of structures, indications for PLT, the concomitant presence of a cardiac anomaly, and other individual-specific factors; thus, a thorough understanding of pediatric patients' medical problems is essential. Living-donor lobar lung transplantation (LDLLT) has only been performed once in Korea to date. However, since each step in the LDLLT is a well-established procedure, including intrapericardial lobectomy, lung procurement, and lobar lung transplantation, qualified surgeons and lung transplantation teams are competent to perform LDLLT in clinically necessary situations.

Keywords: Lung transplantation, Lobar lung transplantation, Pediatric lung transplantation, Surgery

Introduction

The number of patients who undergo pediatric lung transplantation (PLT) is relatively small compared with adult lung transplantation. As of 2020, a total of 877 cases of lung transplantation including heart and lung transplantation had been performed in Korea. Only 49 cases (5.6%) were performed for patients younger than 18 years old, and 26 cases of PLT were performed at Asan Medical Center (AMC) [1] (Fig. 1). This ratio is comparable with the International Society for Heart and Lung Transplantation (ISHLT) data, with about 100 cases of PLT reported among over 4,000 cases of lung transplantations annually [2]. Common indications for PLT in the ISHLT database include cystic fibrosis, pulmonary arterial hypertension, and obliterative bronchiolitis [3]. The indications for PLT at AMC are quite different from those in the ISHLT database. Late-onset noninfectious pulmonary complications after hematopoietic stem cell transplantation (LONIPCs after HSCT) were the most common indications for PLT, in 14 patients, and there were only 3 patients with cystic fibrosis. LONIPCs after HSCT are an uncommon indication for PLT globally. The only large-scale study on LONIPCs

after HSCT, which included 105 cases in 20 centers over 18 years in Europe, was published in 2018 [4].

There are no significant differences in the operative technique for PLT compared with the adult cases because the anatomy and relationship of the bronchi and vessels are consistent [5]. However, size mismatch is the key factor that limits the availability of potential donors. In PLT, overcoming the shortage of donors and size mismatch is crucial. Additionally, PLT can be challenging when the patient has a combined cardiac anomaly, and a multidisciplinary team approach is always necessary to decide the best treatment option between heart-lung transplantation and lung transplantation only. Controlling bleeding after PLT in patients with congenital heart diseases such as pulmonary atresia or major aortopulmonary collateral arteries can be quite painful; thus, an emergency intervention to embolize systemic collateral vessels to the lungs before transplantation is beneficial. If the combined heart disease is a simple cardiac anomaly such as atrial or ventricular septal defect without Eisenmenger syndrome, lung transplantation can be successfully performed. After full dissection and bleeding control around the mediastinum, heart surgery is typically performed prior to lung transplantation



to shorten the cardiopulmonary bypass time for implanted lungs.

The first and only living-donor lobar lung transplantation (LDLLT) in Korea was performed on October 21, 2017 at AMC [6], and it was acknowledged as a legal operation in 2018. The LDLLT procedure for transplanting 2 lower lobes from 2 healthy donors to 1 recipient was developed more than 20 years ago as an alternative to cadaveric lung transplantation (CLT) [7]. Four operating rooms were used for the procedure: 1 for the recipient, 1 for preserving the extracted lobes, and 2 for harvesting the lower lobes from the parents. Prior to surgery, the lobes were chosen based on the results of chest computed tomography and the pulmonary function test. One of the advantages of LDLLT over CLT is to control the timing of surgery, which allows the patient's lungs to be replaced before the recipient's condition has deteriorated critically. Additionally, it can be beneficial for young patients with end-stage lung disease whose condition continues to deteriorate despite their low ranking on the CLT waiting list. LDLLT also has advantages in shortening the ischemia time because the lungs are typically removed and transplanted within the same hospital. Furthermore, the lobes from healthy donors continue to function normally without the risk of infection or atelectasis, resulting in fewer postoperative complications, including graft failure or bronchial dehiscence [6].

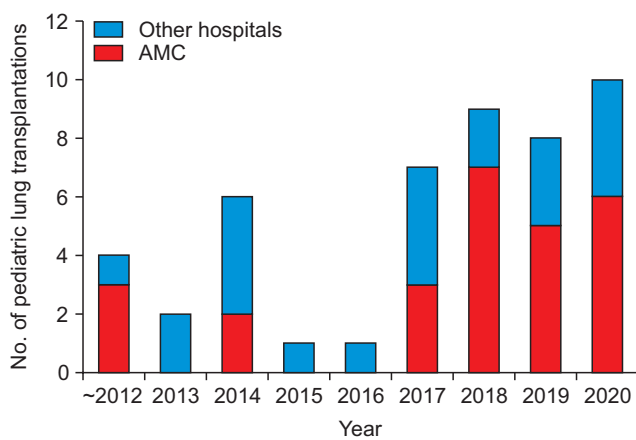


Fig. 1. The annual number of pediatric lung transplantations performed in Korea. AMC, Asan Medical Center.

Operative technique

The surgical technique is described using figures (Figs. 2–9).

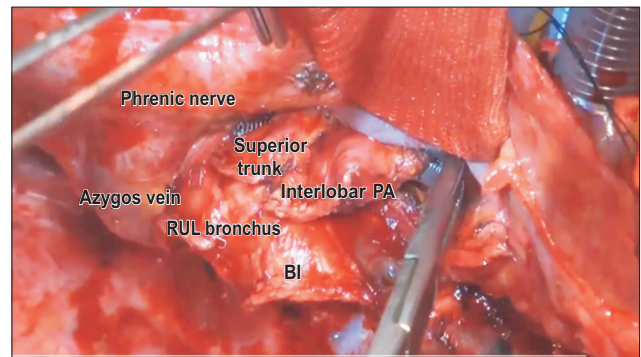


Fig. 2. Dissection and preparation for lung transplantation after pneumonectomy. The thorax is entered through a standard clamshell incision via the fourth intercostal space. Before performing pneumonectomy, central extracorporeal membrane oxygenator (ECMO) is applied after dissecting the thoracic structures. Central veno-arterial (right atrium–aorta) ECMO is the preferred approach at Asan Medical Center (AMC), but it can be adjusted according to the patient's preoperative ECMO status. When performing pneumonectomy, the recipient's superior trunk and interlobar pulmonary artery (PA) should be divided separately for trimming and adjusting with the donor lungs. The right upper lobe (RUL) and bronchus intermedius (BI) are divided separately as well. After opening the pericardium, precise and thorough dissection of the surrounding mediastinal structures is required for a secure and tension-less anastomosis during lung transplantation. Since the PA has been fully dissected from the superior vena cava and pericardium in this figure, the distance between the vascular clamp and PA bifurcation is sufficient to manipulate the PA stump.

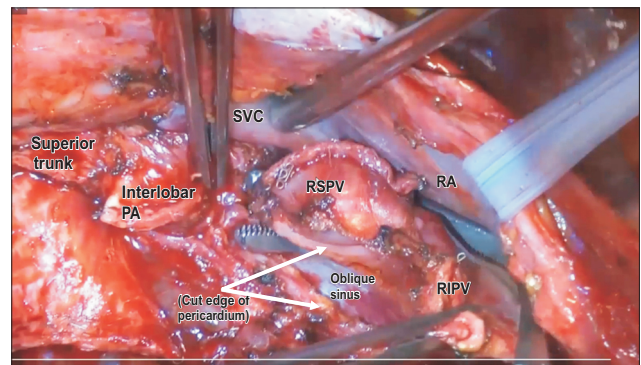


Fig. 3. Pulmonary vein (PV) preparation for lung transplantation. When preparing the PV for lung transplantation, dissecting the PV and left atrium (LA) circumferentially from the pericardium is essential. If the pericardium is completely detached from the PV-LA, the pericardial oblique sinus becomes visible, and clamping the LA is secure and safe with a low risk of slippage of the vascular clamp. The donor's PV can be anastomosed with the recipient's superior PV only in cases of lobar lung transplantation or if the donor lung is too small. It can also be done by slightly extending the LA incision into the inferior PV's anterior side. PA, pulmonary artery; RA, right atrium; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein; SVC, superior vena cava.

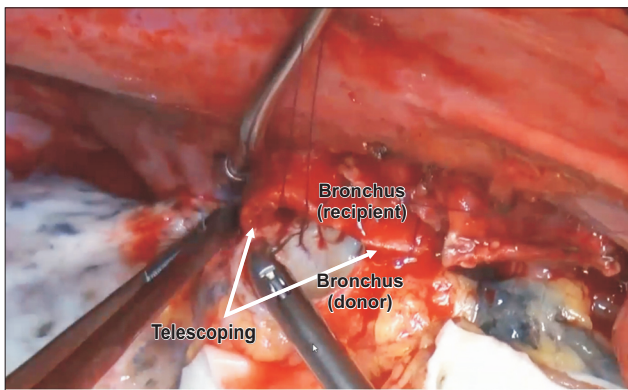


Fig. 4. Bronchus anastomosis. Although there may be an agreement to perform a continuous running suture on the membrane portion of the bronchus, the anastomotic method for the cartilaginous portion varies among surgeons. Both continuous sutures and multiple interrupted sutures have been thoroughly examined for their safety; I personally favor continuous running sutures. Telescoping the donor's bronchus into the recipient's bronchus is generally recommended to reduce anastomotic complications. Bronchial anastomosis can be completed with a 4-0 polydioxanone absorbable monofilament suture if the recipient weighs over 20 kg or is taller than 100 cm.

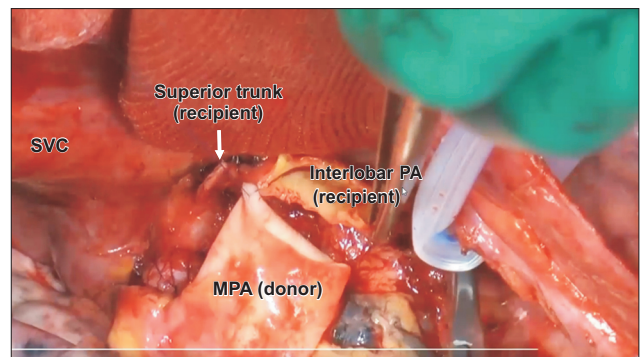


Fig. 5. Pulmonary artery (PA) anastomosis. A size discrepancy between the PAs of the donor and the recipient is a problem that is commonly encountered in individuals with end-stage lung disease, who frequently have pulmonary hypertension and PA enlargement. Anastomosis to the interlobar PA is a useful alternative if the donor main pulmonary artery (MPA) is too small compared to the recipient's MPA. Care should be taken to prevent kinking after anastomosing the donor MPA to the recipient MPA because of the redundant length of the anastomosed PA. Although 5-0 polypropylene sutures are usually used for PA and pulmonary vein anastomosis, some surgeons prefer absorbable monofilament sutures for vascular anastomosis in pediatric lung transplantation. After anastomosis of the PA, a bulldog clamp is applied to the donor PA to check for bleeding from the anastomosis site and to clear the operative field from the bulky vascular clamp (next figure). SVC, superior vena cava.

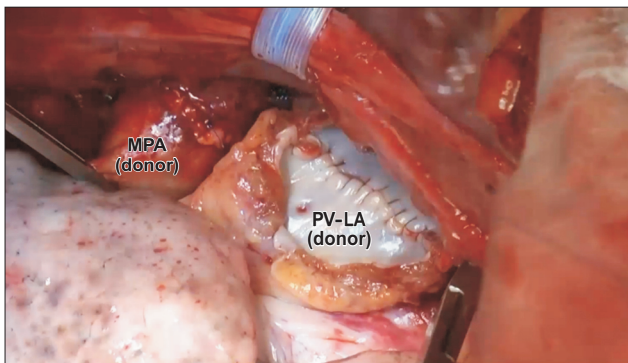


Fig. 6. Pulmonary vein (PV) anastomosis. We prefer the single running suture technique for PV anastomosis using a 5-0 polypropylene suture. When performing PV anastomosis, special attention should be paid to approximate the endocardium of the donor's and recipient's left atrium (LA). If necessary, an intraluminal 6-0 polypropylene suture might be used to reinforce a troublesome anastomosis site. Although some surgeons recommend everting horizontal mattress sutures for PV anastomosis to reduce potential embolic risk, continuous single running sutures are sufficient to secure an endocardium-approximating anastomosis with minimal bleeding risk. MPA, main pulmonary artery.

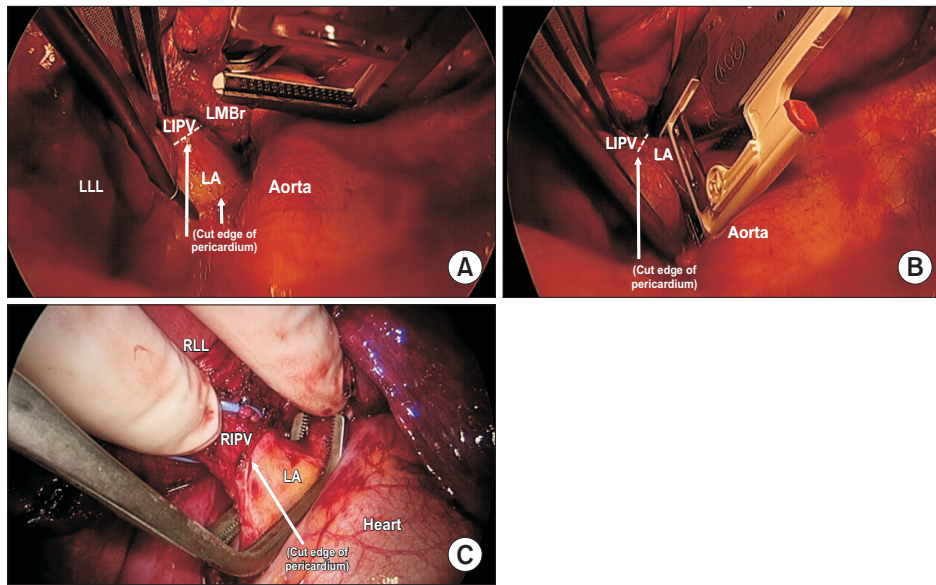


Fig. 7. Pulmonary vein (PV) division in living-donor lobar lung transplantation. After a circumferential incision of the pericardium encircling the inferior PV, the lower lobe is mildly retracted in order to place a vascular clamp with a sufficient cuff of the donor left atrium (LA). The recipient's LA can be controlled using a vascular stapler (A, B) or vascular clamp (C), according to the surgeon's preference. It is evident that the donor lobe's LA cuff is sufficiently preserved (B, C). LIPV, left inferior pulmonary vein; LMBr, left main bronchus; LLL, left lower lobe; RIPV, right inferior pulmonary vein; RLL, right lower lobe.

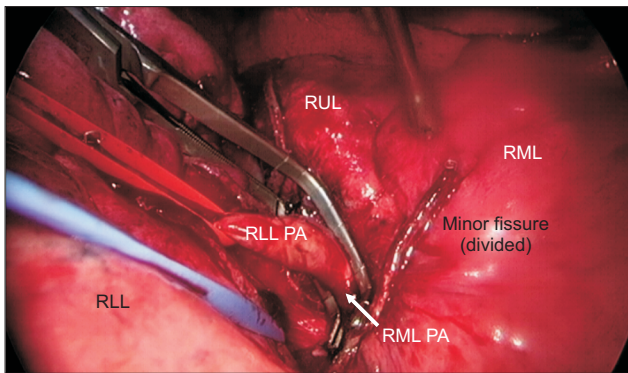


Fig. 8. Pulmonary artery (PA) division in living-donor lobar lung transplantation. The partially incomplete major and minor fissure is safely divided using a stapler, and the perivascular tissue is dissected from the interlobar PA. To preserve enough of the right lower lobe (RLL) PA stump for lobar lung anastomosis, a vascular clamp is placed just below the right middle lobe (RML) PA bifurcation. RUL, right upper lobe.

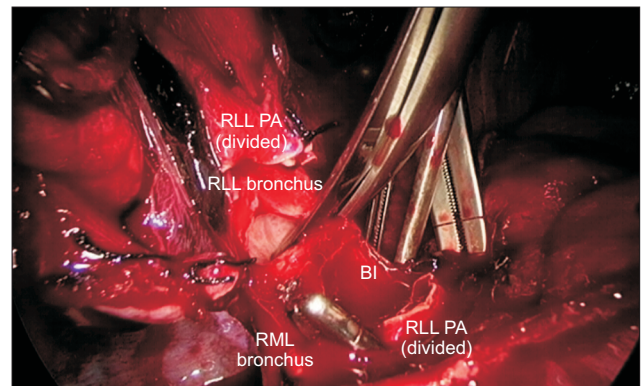


Fig. 9. Bronchus division in living-donor lobar lung transplantation donor lung procurement. The right lower lobe (RLL) bronchus is made visible after the pulmonary artery (PA) is divided. In order to maintain peribronchial blood flow after lung transplantation, the dissection around the bronchus should be kept to a minimum. The oblique incision between the bronchus intermedius (BI) and RLL bronchus must be made carefully to prevent stenosis of the right middle lobe (RML) bronchus after primary repair of the bronchial opening, while the RLL bronchial cuff is preserved for secure lobar anastomosis. A 5-0 polypropylene suture is used to close an opened donor PA, while a 4-0 absorbable multifilament suture is used to close an open bronchus. Viable flaps can be used to cover the suture lines; my preference is a pericardial fat pad.

Comments

Size mismatch problems in pediatric lung transplantation

Long-term research has been done on the size mismatch problem, and the solutions offered are generally the same. Based on the expected total lung capacity (TLC), the vol-

ume of the lobes is roughly calculated as follows: right lower lobe, 25% of TLC; right middle lobe, 15%; and the other lobes, 20% each. All minor differences (<15%) are adjusted

by wedge resections; however, if the difference is more than 15%, anatomical resection of lobes is performed. Bilateral lobar lung transplantation is recommended if the TLC mismatch is 100% [3,8]. In cases of living donor lung transplantation, Date et al. [9] proposed the following formula for calculating the total forced vital capacity (FVC) of both donor grafts: total FVC of the 2 donor grafts=measured FVC of the right donor \times 5/19+measured FVC of the left donor \times 4/19. If the total FVC of the 2 donor grafts was greater than 50% of the predicted FVC of the recipient, they defined the donors as suitable [9]. In our first LDLLT case, the father's height and FVC were 170 cm and 4.17 L, respectively; the mother's were 163 cm and 3.68 L, and the recipient's height was 157 cm and predicted FVC was 3.16 L. According to Date's calculation, the total FVC was 59.1% for the recipient's predicted FVC, which was suitable for LDLLT. The predicted TLC (pTLC) may be easily calculated based on height and sex [10,11]; however, the pTLC is not available in very young patients, and there do not exist strong suggestions regarding the mean value of the pTLC in the Korean population. Our approach to solve size mismatch is that we prefer left side lobar transplantation and right whole lung transplantation if the pTLC ratio is about 1.5. We perform bilateral lower lobar transplantation if the pTLC ratio is about 2. We define donors as not adequate for a pediatric recipient if the pTLC ratio is 2.5 or above. Since the patient needs lung parenchyma for gas exchange and the airway offers a dead space for ventilation, we often do not perform wide wedge resection for size reduction. When wedge resection is required, it usually means that the donor lungs are larger than the recipient's thorax. Frequently, wedge resection is insufficient to effectively reduce lung volume, and even after wedge resection, there may still be postoperative atelectasis, which worsens gas exchange and CO₂ retention by creating a shunt.

Bronchial anastomosis to reduce ischemia

In general, bronchus division at the level of 2 cartilaginous rings above the upper lobar bronchus bifurcation is recommended. However, some authors have argued that the division line should be made as close as possible to the upper lobar bronchus bifurcation, with special caution to keep the peribronchial tissues preserved to reduce the risk zone for bronchial ischemia and stenosis [12,13]. I agree with the opinion that it is necessary to shorten the donor bronchus as closely as possible to the lobar carina, which includes the lower and upper lobar bronchus or bronchus intermedius [13]. Because the blood supply to the margin

of donor bronchus is significantly compromised and entirely dependent on the backflow from the transplanted lungs, that area is susceptible to ischemic injuries and delayed stenosis. Many techniques and modifications have been suggested for bronchial anastomosis [14]. I prefer a single continuous running suture for the anterior cartilaginous region of the bronchus, as well as the posterior membranous portion. A single running suture is easy, fast, and presents a very low risk for anastomotic complications [13]. Additionally, telescoping can usually be achieved with the single running suture technique in most cases by adjusting the size of the opening of donor and recipient's bronchus during the trimming procedure. I use a 5-0 polydioxanone absorbable monofilament suture for PLT if the patient's height is less than 100 cm or the weight is less than 20 kg.

Conclusion

Every candidate for PLT is in a different scenario in terms of age, height and weight, the size of the structures, indications for PLT, the concomitant presence of a cardiac anomaly, and other individual-specific factors; thus, a thorough understanding of pediatric patients' medical problems is essential. LDLLT has only been performed once in Korea to date. However, since each step in LDLLT is a well-established procedure, including intrapericardial lobectomy, lung procurement, and lobar lung transplantation, qualified surgeons and lung transplantation teams are competent to perform LDLLT in clinically necessary situations.

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Author contributions

All work was done by Sehoon Choi.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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