



# Technical Aspects of Lung Transplantation: Adverse Events and Circumstances

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Adverse events or emergency situations that are unacceptable in the context of lung transplantation may occur during the procedure. These adverse events and circumstances are not problems that are caused by insufficient experience or can be solved by increasing surgical experience. The purpose of this review is to describe the adverse events and circumstances that occur during lung transplantation and to identify an appropriate surgical approach through an analysis of case reports in the global literature.

**Keywords:** Lung transplantation, Adverse event, Partial anomalous pulmonary venous return, Trachea bronchus

## Introduction

Since the bilateral sequential long transplant technique was developed and standardized by the Toronto group, most lung transplant centers perform transplantation without any major complications [1]. However, standard techniques may be inadequate when adverse events or circumstances occur, such as technical failure or the presence of anatomical anomalies in the donor or recipient. In this literature review, we describe technical approaches to address the challenges that can arise during lung transplantation.

## Inadequate left atrial cuff on the recipient side

During lung transplantation, an inadequate atrial cuff may result from inadequate atrial clamping or slippage of the clamp. This is most likely to occur in patients with a small left atrium, obesity (body mass index  $>30$  kg/m<sup>2</sup>), or idiopathic pulmonary fibrosis. If an inadequate left atrial cuff hinders anastomosis, cardiopulmonary bypass (CPB) or re-clamping at a more proximal site can be performed. The first option is relatively safe, but increases the risk of bleeding and the warm ischemic time; the second option poses a risk of left atrial rupture. Given these limitations, a

more reasonable approach to an inadequate cuff is needed to avoid complications [2].

Robert et al. [3] proposed the use of a neo-cuff, created through a split incision and reunion of the pulmonary vein when the left atrial clamp slips toward the pulmonary vein. The extended neo-cuff facilitates left atrium anastomosis. However, creating a neo-cuff by splitting the inner side of the bilateral vein requires sophisticated surgical skills and takes 2–3 times longer than normal atrial cuff anastomosis. Moreover, it is particularly challenging in cases of left lung transplantation. In addition, because the size of the pulmonary vein decreases due to vessel contraction after clamping, application of a neo-atrial cuff may be difficult. Furthermore, the chamber created by a neo-cuff can cause “return flow turbulence” and associated complications if the shape is distorted and the cuff is too large.

To overcome these disadvantages, novel techniques to obtain a neo-cuff have been proposed. Bhamra et al. [2] described a simple technique to reconstruct the recipient's left atrium without CPB or additional re-clamping, by suturing the cut ends of the pulmonary veins together starting from the confluence close to the clamp. This method can be used when suturing of the pulmonary veins is complicated by clamp slippage during pulmonary vein anastomosis. For the same reason, we also modified the neo-cuff

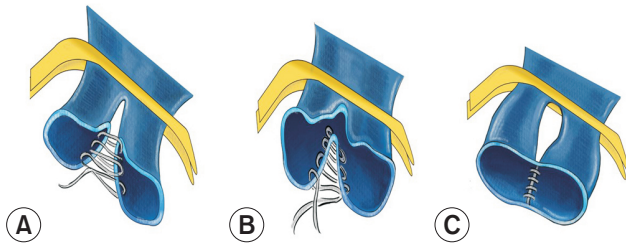


technique by suturing the inner side of the 2 blood vessels to create a wide septum, resulting in an oval-shaped cuff. The recipient and donor left atrial cuffs are then anastomosed. This method is similar to airway reconstruction

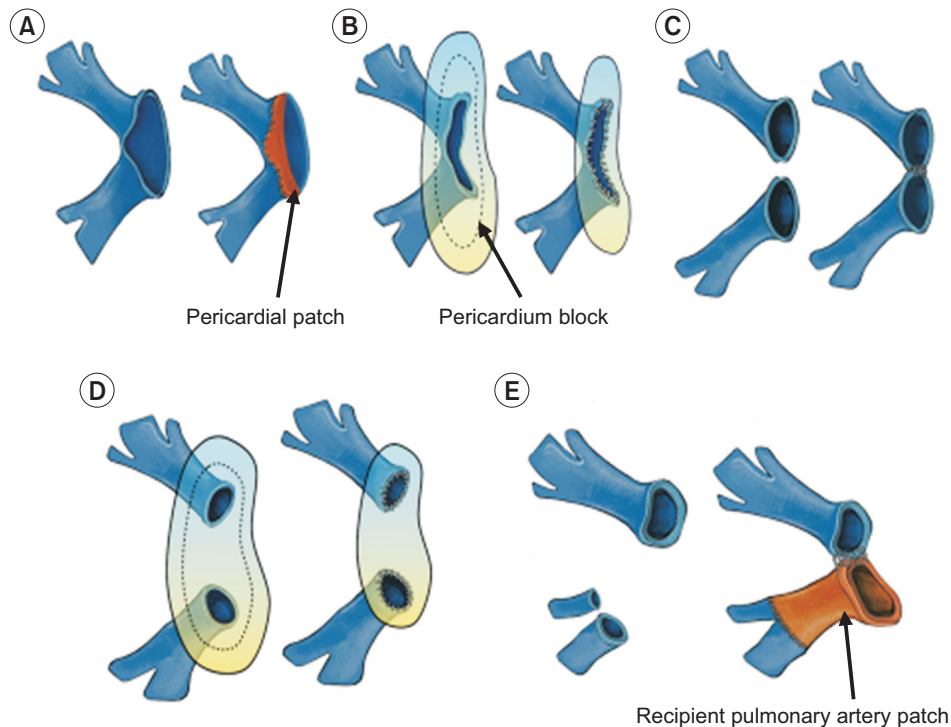
after trachea carina resection. Because the area of cuff anastomosis is close to the operator, there is no need for excessive heart retraction in patients with cardiomegaly (Fig. 1A–C).

### Inadequate or damaged left atrial cuff on the donor side

Anatomical abnormalities in donor pulmonary vessels or technical problems during procurement may damage the left atrial cuff. This frequently occurs in the right inferior pulmonary vein during division of the inferior vena cava or left atrium. A damaged atrial cuff can be repaired in various ways. Donor pericardium, the pulmonary artery, the superior vena cava (SVC), and the posterior left atrium can serve as reconstruction materials. Simple reconstruction can be performed intraoperatively, but back-table reconstruction is recommended if complex repair is required to reduce the warm ischemia time [4] (Fig. 2A–E).



**Fig. 1.** Techniques for the creation of a neo-atrial cuff. (A) Splitting incisions are made in the area facing the branch, with the facing veins combined to create a neo-atrial cuff. (B) The medial site of each vein is sutured without splitting incisions. (C) Suturing the cut ends of the pulmonary veins together, starting from the confluence close to the clamp.



**Fig. 2.** Creation of a neo-atrial cuff in the absence of an adequate left atrial cuff. (A) If the anterior portion of the left atrial cuff is damaged, partial patch repair using donor pericardium is performed (arrow). (B) If the anterior and posterior portions of the atrial cuff are injured, the inadequate cuff is circumferentially sutured to fix it to the pericardium, which is then trimmed to make an appropriate atrial cuff (arrow). (C) When the superior and inferior pulmonary veins are separated but suturing between them is possible, their medial portions are directly anastomosed to make a neo-atrial septum. (D) If the distance between the two separated pulmonary veins is too large to form a septum through direct suture, the veins can be fixed to the pericardium by suturing, after which the pericardium is trimmed to an appropriate size to form a neo-atrial cuff. (E) If the inferior pulmonary vein is injured up to the segmental artery level, angioplasty is performed using the recipient pulmonary artery to create a neo-inferior pulmonary vein, with the neo-atrial cuff then created by connecting the newly created vein to the normal superior pulmonary vein (arrow).

## Partial anomalous pulmonary venous return

In partial anomalous pulmonary venous return (PAPVR), not all of the pulmonary venous return enters the left atrium. This condition may be due to a defect arising during fetal development. The prevalence of fetal PAPVR is 0.1%–0.2%. While PAPVR can occur on both sides, the left side is more frequently affected than the right. Since most lung transplant patients with PAPVR have no symptoms, it is typically diagnosed during transplant evaluation and, in donors, procurement. When the left side is involved, the innominate vein is drained, and when the right side is involved, drainage occurs through the SVC and right atrium.

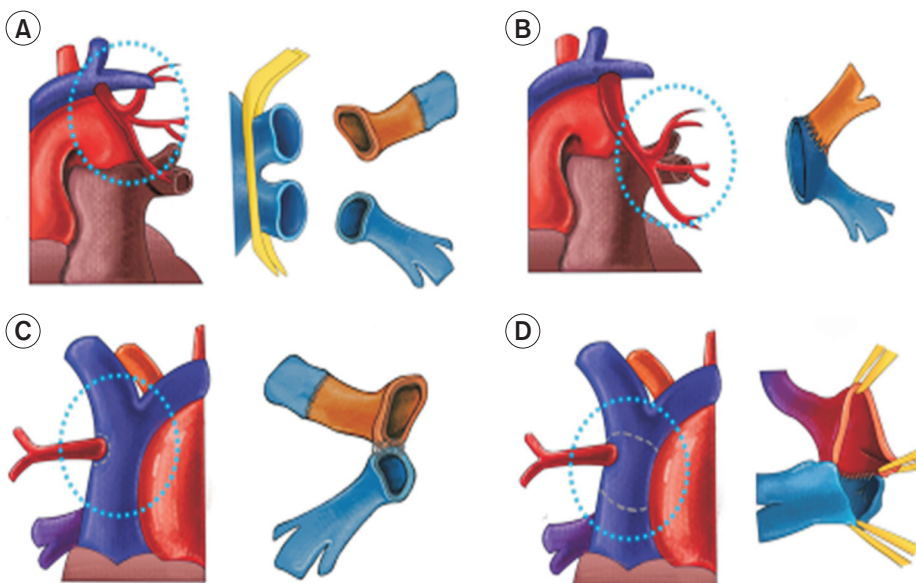
In recipient PAPVR, the left atrial cuff is made without the superior pulmonary vein, such that the cuff is small and has to be placed in a lower area. However, the resulting excessive tension increases the risk of stenosis at the anastomosis site. Cuff enlargement and a tension-free procedure are thus necessary. In the case of right-side involvement, the size and position of the left atrial cuff are not severely altered, such that an additional cuff enlargement procedure is not required. In cases with left-side involvement, the small left atrial cuff shows large mismatch with the cuff of the normal donor, which necessitates enlargement of the recipient cuff. Belli et al. [5] described a cuff enlargement method based on a modification of the neo-cuff technique. A neo-cuff is made by clamping the left atrium, including the left atrial appendage, and the inferior

pulmonary vein. An incision is made in the inferior pulmonary vein and left atrial appendage, and the neo-cuff is then created by re-suturing the split incision site. Separate pulmonary venous anastomoses using a left atrial appendage are an alternative option.

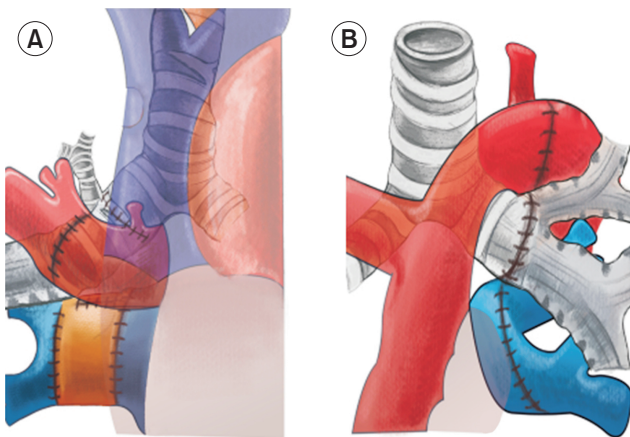
In cases of donor PAPVR, the major challenge is to connect the separated superior pulmonary vein of the donor to the donor's left atrial cuff. In most reported cases, the aberrant vein was connected to the lower left atrial cuff to create a new cuff. The native conduit is too short to directly connect to the cuff, because the aberrant vein drains via the innominate vein or SVC, both of which are located higher in the thoracic cavity. As alternatives, an autologous pericardial conduit, donor iliac vein or extracellular matrix conduit, bovine pericardium, and an SVC Carrel patch have been suggested [6-10] (Fig. 3A–D).

## “Left-inverted” to right transplantation or “right-inverted” to left lung transplantation

Single-inverted lung transplant is rarely performed, and only a few cases have been reported in the literature. However, it can be a useful surgical method if one-sided lung transplantation is needed and the contralateral lung is available. Once the need for single-inverted lung transplantation has been confirmed, a surgical plan should be made that takes into account the characteristics of the left and right anatomical structures. If the donor lung is counter-rotated, there will be changes in the positions of the

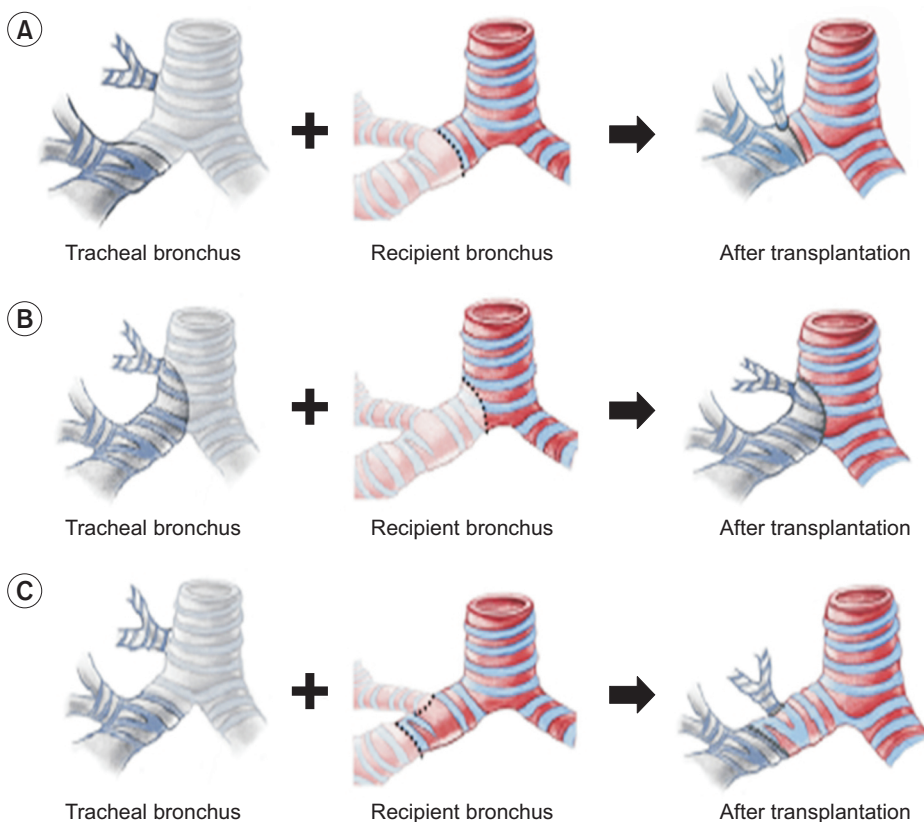


**Fig. 3.** Partial anomalous pulmonary venous return (PAPVR) in the donor. (A) If the left superior pulmonary vein is short, it must be extended using a conduit. (B) In left PAPVR, if the left superior pulmonary vein draining into the innominate vein is long, the neo-cuff is made at the donor atrial cuff. (C) In right PAPVR, a short right superior pulmonary vein drains into the superior vena cava (SVC) or right atrium and must be extended using a vascular conduit. (D) Carrel patches are made using the donor SVC into which the superior pulmonary vein drains. The Carrel patch and inferior pulmonary vein are combined to make a neo-atrial cuff.



**Fig. 4.** Inverted lung transplantation. (A) Left-inverted to right lung transplantation is performed in the following order: pulmonary vein cuff, bronchus, and pulmonary artery. In general, direct anastomosis may be difficult due to the distance between the donor and recipient cuffs. In this case, anastomosis can be performed after the left atrium is extended using donor pericardium. (B) In right-inverted to left lung transplantation, the downward-running donor pulmonary artery is located in the posterior part of the donor bronchus, and the recipient pulmonary artery is in the superior anterior recipient bronchus, thus requiring pulmonary artery interrupted anastomosis at the posterior portion of the bronchus. Bronchus and pulmonary vein anastomoses are then performed sequentially.

bronchial and pulmonary arteries and the veins of the donor lung. Left-inverted to right lung transplantation is performed in the following order: pulmonary vein cuff, bronchus, and pulmonary artery. Direct closure tends to be difficult due to the distance between the donor and recipient cuffs. In this case, anastomosis can be performed after back-table left atrial elongation using donor pericardium. After pulmonary vein anastomosis, anastomosis of the bronchus is performed. The recipient's bronchus is located at the back of the thoracic cavity, but the donor's bronchus is located in the front. The recipient's pulmonary artery is located in the front, and the donor's pulmonary artery is behind the recipient's hilum. These structural issues are the most important considerations in anastomosis. Bronchial anastomosis can be performed in the same way as in a general lung transplant. However, because inversion of the lung affects the back and front of the bronchus, the posterior membranous portion of the bronchus of the donor lung is in a forward position. Therefore, the cartilage of the donor bronchus and membrane part of the recipient bronchus are continuously anastomosed, while interrupted anastomosis is performed on the membrane part of the donor bronchus and cartilage part of the recipient bronchus.



**Fig. 5.** Surgical techniques for tracheal bronchus. (A) The tracheal bronchus variant is located in the upper portion of the lower trachea. After the tracheal and main bronchi have been resected, the tracheal bronchus is attached between the donor and recipient bronchi as a button shape. (B) The tracheal bronchus variant is located in the lower portion of the lower trachea. A wide pedicle is made and an end-to-end anastomosis in the carina is then performed. (C) A segment of the tracheal and main bronchi is connected to the orifice of the right upper lobe bronchus and intermediate bronchus, respectively.

Finally, pulmonary artery anastomosis is performed. In left-inverted to right lung transplantation, anastomosis does not present difficulties because the donor pulmonary artery is in the anterior superior part of the bronchus and runs downwards, as does the recipient's pulmonary artery. As the likelihood of kinking is high, shortening the donor pulmonary artery as much as possible is recommended, as is leaving the recipient pulmonary artery as long as possible [11].

In the case of right-inverted to left lung transplantation, the order of anastomosis is different. When the right donor is inverted, the downward-running donor pulmonary artery is located in the posterior part of the donor bronchus, and the recipient pulmonary artery is in the superior anterior recipient bronchus. It is thus necessary for the pulmonary anastomosis site to be located behind the bronchus site. Bronchus and pulmonary vein anastomoses are then performed sequentially. If the distance between the donor and recipient cuffs is long, cuff elongation may be necessary (Fig. 4A, B) [12].

## Tracheal bronchus

In this condition, also called pig bronchus, the orifice of the tracheal bronchus originates from the distal third of the trachea and is directed to the right upper lobe. The region in which the tracheal bronchus is distributed may include the entire upper lobe or only an apical segment. In general, if the region of distribution involves only segments rather than the entire upper lobe, only segmentectomy is required. However, if the distribution range of the tracheal bronchus includes the entire upper lobe, lung transplantation combined with bronchoplasty around the carina is required [13].

Surgical methods for lung transplantation vary. Schmidt et al. [9] performed bronchial anastomosis after resecting the tracheal bronchus, attaching the latter to the bronchus of the donor lung. Sekine et al. [14] performed end-to-end anastomosis of a widely exposed carina. Miyahara et al. [15] described a method to connect the tracheal bronchus to the main bronchus, and the upper lobe to the intermedium bronchus, by modifying right upper and middle bi-lobar lung transplantation techniques. If lung transplantation involves a tracheal bronchus donor, the choice among the above 3 methods will depend on the clinical situation (Fig. 5A–C).

## Conclusion

In conclusion, adverse events and circumstances that are unacceptable in the context of lung transplantation may occur during the procedure, even with increasing surgical experience. This review will help to solve the challenges that occur during lung transplantation.

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## Author contributions

All work was done by Do Hyung Kim.

## Conflict of interest

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

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