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ORIGINAL ARTICLE

Short-term outcome in living donors for lung transplantation: the role of preoperative computer tomographic evaluations of fissures and vascular anatomy

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Summary

Successful living-donor lobar lung transplantation (LDLLT) largely depends on donor outcome. We reviewed our experiences with LDLLT and focused on preoperative computed tomographic evaluations of donors. Twenty-five LDLLTs were performed in Kyoto University. As a routine preoperative assessment, high-resolution chest computed tomography (CT), and three-dimensional (3D)-CT angiography were performed. Preoperative evaluations, surgical procedures, and early postoperative outcomes were reviewed in 43 consecutive LDLLT donors. All donors were discharged home after the donor lobectomies. Severely incomplete fissures were intraoperatively identified in two donors, whose interlobar fissures were mostly not identified by high resolution CT preoperatively. Preoperative 3D-CT angiography was effective for the identification of the branches of the pulmonary artery and vein. Pulmonary arterioplasties were performed with auto pericardial patches in three left donors. The bilateral donors had to be exchanged because of an anomaly of the pulmonary veins in one donor. Small pulmonary arterial branches to the remaining lobes were to be sacrificed in 23 donors (53%). Early postoperative complications were ascertained in seven donors, and five of them presented air leak-related complications. Living donor lobectomies were safely performed with low morbidities in our institution. Preoperative computer tomographic evaluations might be useful in donor lobectomies.

Introduction

In order to save the life of a rapidly deteriorating and critically ill patient with end-stage lung disease, living-donor lobar lung transplantation (LDLLT) has been developed by Dr. Starnes and his colleagues with satisfactory intermediate survival and functional results [1]. As a result of the severe donor shortage, particularly in Japan, LDLLT has been one of the last options used to save critically ill patients with a wide range of pathophysiologies [2]. In LDLLT, two separate donors are usually required for each individual recipient. In brief, the recipient undergoes a bilateral pneumonectomy, which is followed by implantation of a right lower lobe from one donor and a left lower lobe from the second donor during the same procedure. Therefore, the success of LDLLT is largely dependent upon donor outcome. Although several studies have described the preoperative and perioperative characteristics and assessed the outcomes of living lobar lung donors [1–6], there are not enough updated and recent studies on preoperative evaluations of the donors and their outcomes after donor lobectomy. The purpose of this study was to retrospectively assess preoperative computed tomographic (CT) evaluations, surgical procedures, and early postoperative outcomes in LDLLT donors in our institution.

Patients and methods

From June 2008 to November 2011, 43 donor lobectomies were conducted at Kyoto University Hospital for 25 consecutive LDLLT procedures (18 bilateral and 7 unilateral). All donors had previously completed clinical evaluations that included blood studies, pulmonary function tests, and chest CT scans. High-resolution chest CT was conducted in order to understand the incompleteness of the fissures (Fig. 1). In addition, three-dimensional (3D) multidetector CT angiography was performed in order to display the complex pulmonary arterial and venous anatomy (Fig. 2). Donor selection criteria are outlined in Table 1. For size accommodation during the LDLLT, we used our previously proposed method that calculated forced vital capacity (FVC) by the number of segments [2,7–9]. Given that the right lower lobe consists of 5 segments, the left lower lobe consists of 4, and the whole lung consists of 19, we estimated the graft FVC with the following equation: Graft FVC = measured FVC of the right donor × 5/19 + measured FVC of the left donor × 4/19. When the graft FVC was larger than 45% of the predicted FVC of the recipient (calculated according to height, age, and sex), we accepted the size disparity regardless of the recipient's diagnosis. The 43 patients constituted the cohort of patients for this outcome analysis. This study was approved by the Institutional Review Board of Kyoto University.

Procedures of donor lobectomies were described as follows [2,10]: epidural catheters for postoperative analgesia were routinely placed the day before the surgery. After the induction of general anesthesia, donors were intubated with a left-sided double lumen endotracheal tube. The donors were then placed in a lateral decubitus position, and a posterolateral thoracotomy was performed through the fifth intercostal space. Fissures were developed with linear stapling devices. Completeness of interlobar fissures were intraoperatively assessed as follows: complete (complete or almost complete fissures), mildly to moderately incomplete (interlobar fissures identifiable from outside), and severely incomplete (large part of the fissures unidentifiable from outside), and complete incompleteness (no interlobar fissures). The pericardium surrounding the inferior pulmonary vein was opened circumferentially. Dissection in the fissure was conducted to isolate the pulmonary artery to the lower lobe and to define the anatomy of the pulmonary arteries to the middle lobe and to the lingular segment in the right and left side of the donor. If the branches of the middle lobe artery and lingular artery were small, they were sacrificed by ligation and division. After the administration of intravenous prostaglandin E1, heparin (100 IU/kg) and 500 mg of methylprednisolone were administered intravenously.

(a)

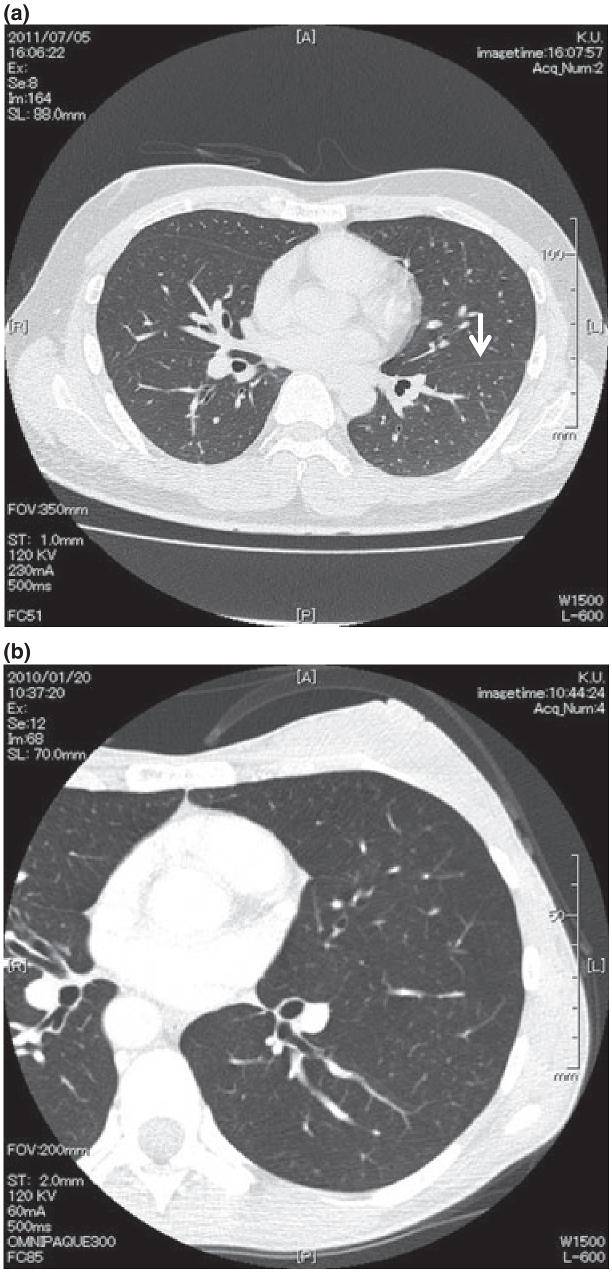

Figure 1 High-resolution chest computed tomography (CT). Interlobar fissures (arrow) were apparent in most donors (a). However, interlobar fissures were hard to identify even with 1-mm sliced high-resolution CT in some donors (b).

After placing vascular clamps in the appropriate positions, the division of the pulmonary vein, pulmonary artery, and bronchus were carried out in that order. Then, the lower lobes were extracted from the donor, and their pulmonary vasculature was flushed anterogradely and retrogradely with 1 l each of 4 °C extracellular-type (ET) trehalose-containing Kyoto solution supplemented with

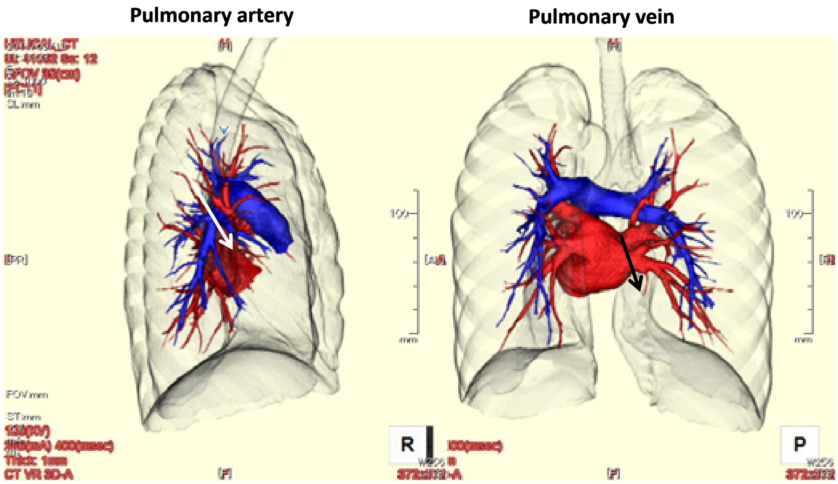

Figure 2 Three-dimensional computed tomography angiography for the confirmation of the pulmonary arterial (Right) and venous (Left) anatomy in a typical right donor. The white and black arrows showed the planned cutting line of the pulmonary artery and vein, respectively.

Table 1. Donor selection criteria for living donor lobar lung transplantation.

Relatives within the third degree or a spouse
20 ≤ age ≤60 years
ABO blood type identical or compatible
No significant medical history or active medical problems
No recent viral infections
No abnormalities on the electrocardiograph and echocardiogram
No significant pulmonary pathology on computed tomography on donor side
Arterial oxygen tension ≥80 Torr
Forced vital capacity and forced expiratory volume in 1 second ≥85% of predicted
No previous thoracic operation on the side to be donated
Nonsmoker (If current smoker, cessation of smoking is required at the time of the offer for donation and continuous cessation is required after donor lobectomy)
Absence of coercion
Satisfactory psychosocial evaluation

nitroglycerin and dibutyryl cAMP [11–13]. Vascular stumps were oversewn with 5-0 Prolene continuous sutures (Ethicon, Inc, Tokyo, Japan). An auto pericardial patch was used if necessary. Heparinization was reversed by the administration of protamine. The bronchial stump was closed with 4-0 polydioxanone suture (PDS) II interrupted sutures (Ethicon, Inc). Each bronchial closure was then covered with pedicled pericardial fat tissue. The thoracotomy was closed in a standard manner after the placement of one or two chest tubes. The patient was extubated in the operating room.

The chest tubes were removed when no air leaks were seen in the most recent 24 h and the chest tube drainage was less than 200 ml/day. Then the patients were discharged home when they did not show any significant concerns of complications.

For all donors, their inpatient and outpatient medical records, pulmonary function test results, and chest X-ray and CT films were reviewed.

Statistical analysis

Statistical analyses were performed using the StatView (version 4.5) software package (Abacus Concepts, Berkeley, CA, USA). All values were expressed as means ± standard deviation. The data were evaluated by Student's *t*-tests and Fisher's exact tests for two-group analyses. *P* values less than 0.05 were considered statistically significant.

Results

The current study included 28 female and 15 male healthy donors who fulfilled the donor inclusion criteria (Tables 1 and 2). Their ages were 40.2 ± 11.8 years with a range of 20–60 years. Donors were recipient's children (n = 14), parents (n = 13), siblings (n = 7), spouses (n = 7), or aunts/uncles (n = 2). Fifteen donors (35%) were ex-smokers or current smokers. All donors stopped smoking at least at the time of their offer to become donors. Twelve donors (28%) had comorbidities, but all of these comorbidities were well controlled or treated before the donor lobectomy. According to results from the preoperative evaluations, the FVC was 114.7% ± 12.5% of the predicted value, and the forced expiratory volume in 1 s (FEV1) was 104.2% ± 10.8% of the predicted value.

Chest CTs, including high-resolution CT, did not show any pathological findings in any of the donors. Prior to donor lobectomies, high-resolution chest CT was checked by surgeons in all cases. Interlobar fissures were mostly identified by high-resolution chest CT in 41 donors (Fig. 1A), while a large part of the interlobar fissures were

Table 2. Preoperative donor characteristics.

Preoperative variables	
Age	40.2 ± 11.8 years
(range)	20–60 years
Gender	
Male:Female	15:28
Relations to the recipient	
Children	14
Parents	13
Siblings	7
Spouses	7
Aunts/uncles	2
%FVC	114.7% ± 12.5%
%FEV1	104.2% ± 10.8%
Smoking history	
Yes:No	15:28
Comorbidity	
Yes:No	12:31

FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity.

not identified by high-resolution chest CT only in two donors (Fig. 1B). At the time of donor lobectomies, complete fissures were seen in seven donors, mild to moderate fissures were seen in 34 donors, and severely incomplete fissures were found only in two donors. Interestingly, these two incomplete cases were all left donors and they were preoperatively detected as donors whose interlobar fissures were mostly not identified by high-resolution chest CT. However, the fissures were carefully divided by the multiple uses of staplers in order not to create air leakage. In mild to moderately incomplete fissures, 1.7 ± 0.7 staplers (range, 1–3 staplers) were used, whereas 5.0 ± 2.8 staplers (range, 3–7 staplers) were used in severely incomplete fissures ($P < 0.0001$).

Preoperative 3D-CT angiography presumed the possible requirement of pulmonary arterioplasty after the donor lobectomy in some donors, and, in effect, pulmonary arterioplasties were performed with auto pericardial patches in three left donors (Fig. 3). The bilateral donors had to be exchanged because of an anomaly of the pulmonary veins in only 1 (6%) of the 18 bilateral LDLLT cases (Fig. 4).

Right lower lobectomies were performed in 25 donors, while left lower lobectomies were performed in 18 (Table 3). In 23 donors (53%), small branches of the pulmonary artery were sacrificed in order to obtain an adequate arterial cuff for safe implantation. In brief, small pulmonary arterial branches were sacrificed in 12 of the 25 right lobectomies and in 11 of the 18 left lobectomies ($P = 0.54$). In right donors, small branches to the middle lobe were sacrificed in 10 donors (84%), a small branch to the upper lobe was sacrificed in one donor, and small branches to both the upper and middle lobes were sacrificed in one donor (Fig. 5). By contrast, small branches to the lingular lobe were sacrificed in all left donors. No challenging procedures were required for the pulmonary veins. Regarding the bronchial procedures, a sleeve right lower lobectomy was finally required in one case (2%) because direct closure of the bronchial stump made the middle lobe bronchus narrow. In that case, middle lobe was spared by a bronchoplastic procedure. Bleeding

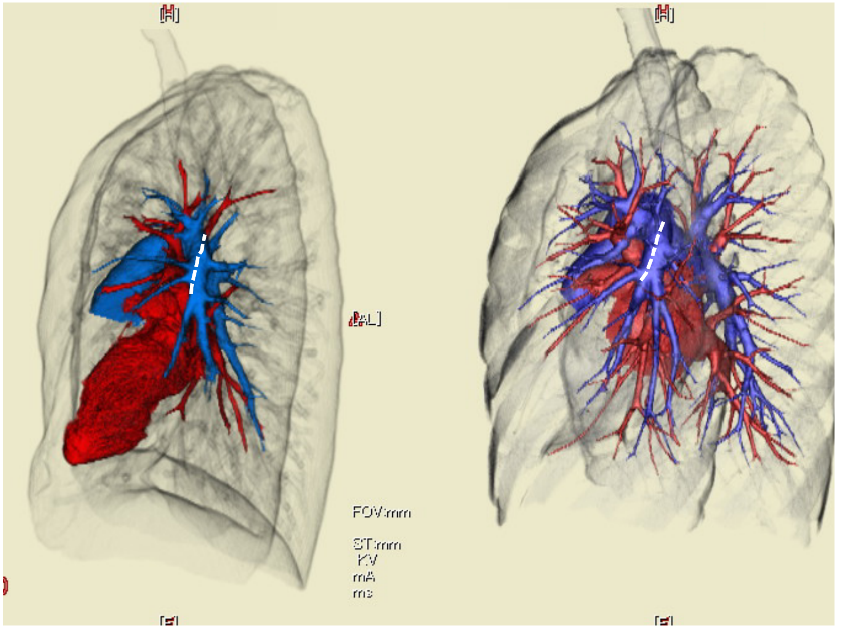

Figure 3 Preoperative three-dimensional computed tomography angiography in two left donors. Pulmonary arterioplasty was performed with an auto pericardial patch. The dotted white line shows the planned dividing line of the pulmonary artery.

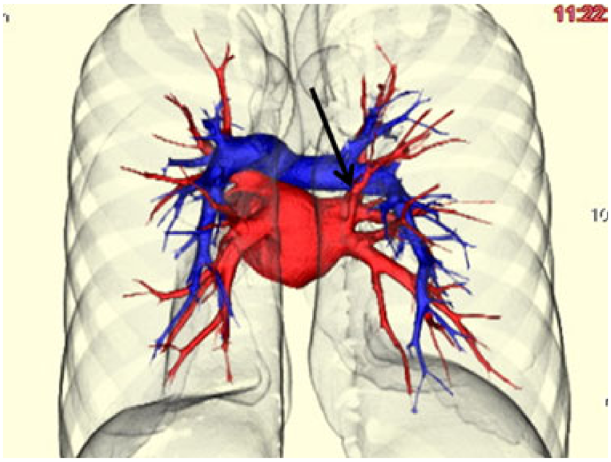

Figure 4 Preoperative three-dimensional computed tomography angiography. Bilateral donors were exchanged because of the anomaly of the pulmonary veins (arrow).

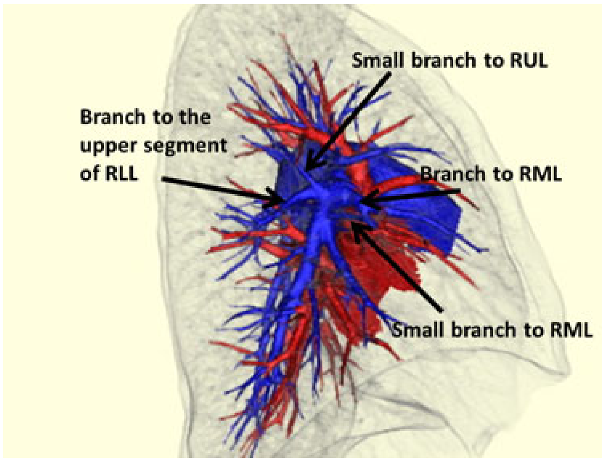

Figure 5 A case of right donors with an anomaly of pulmonary artery. Arrows showed several branches of pulmonary artery. RLL, right lower lobe; RML, right middle lobe.

Table 3. Operative characteristics of the donors.

Intraoperative variables	
Surgical procedures	
RLL:LLL	25:18
State of interlobar fissures	
Complete	7
Mild to moderately incomplete	34
Severely incomplete	2
Completely incomplete	0
Sacrifice of PA branches	23 donors (28 branches)
Right	12 donors (14 branches)
Left	11 donors (14 branches)
Additional PA procedures	3
Additional PV procedures	0
Additional bronchial procedure	
Right sleeve lower lobectomy	1
Operation time	245 ± 45 min
Bleeding	139 ± 73 ml
Ischemic time	
1st lung	119.8 ± 28.2 min
2nd lung	176.4 ± 26.0 min

LLL, left lower lobectomy; PA, pulmonary artery; PV, pulmonary vein; RLL, right lower lobectomy.

Table 4. Postoperative data in donors.

Postoperative variables	
Duration of chest tube placement	4.0 ± 1.9 days
(range)	2–10 days
Early postoperative complications	7
Prolonged air leakage (≥7 days)	3
Pneumothorax after chest tube removal	2
Re-accumulation of pleural effusion	1
Bleeding from the lung parenchyma	1

volume was 137 ± 87 ml, and no blood transfusions were required. The graft ischemic time was 119.8 ± 28.2 min for the first lung and 176.4 ± 26.0 min for the second lung in the LDLLT procedures.

After the operation, one chest drain was placed in 40 donors, and two chest tubes were placed in three donors. Six patients showed a small amount of air leakage just after the operation. The drainage period was 4.0 ± 1.9 days after the lobectomy (Table 4). Only three patients required chest tube placement more than a week after the surgery because of a prolonged air leakage (8–10 days). One donor who showed a re-accumulation of pleural effusion after chest tube removal required a thoracentesis on postoperative day 10. Two donors who each developed a pneumothorax after chest tube removal required chest tube placement. The remaining one donor showed expectoration of hemosputum starting a week after surgery. Further investigation showed bleeding from the right middle lobe lung parenchyma, which stopped a week later. No donors were declined as a donor because of preoperative CT findings. There were no mortalities that were related to the donor lobectomies. All of the donors were discharged home without any significant complications.

Discussion

The use of living donor lung lobes for transplantation in children with end-stage lung disease was first described in 1992 [14]. Since then, LDLLT has been developed by Dr. Starnes and his colleagues and performed all over the world. However, as of now, LDLLT has been mostly performed, particularly in Japan, as a last option in the treatment of patients with terminal pulmonary diseases [2]. Usually, two healthy donors are needed for the LDLLT, and the safety of the donors should always be a primary concern. Each of the donor individuals undergoes a lobe resection in one of their lungs, resulting in some degree of permanent loss of lung function. However, there have only been a small number of studies that have examined the characteristics of the donors and their outcomes [1–6,10]. Thus, we decided to review the preoperative evaluations of the donors, particularly preoperative CT evaluations in this study. Furthermore, we also assessed the surgical procedures and early postoperative outcomes retrospectively in living lobar lung transplant donors in our institution.

A preoperative understanding of donor anatomy is very important for donor surgery. Most of the interlobar fissures were usually identified by high-resolution chest CT. When interlobar fissures are mostly not identified, severely or completely incomplete fissures might be presumed. In our series, high-resolution CT was very effective for the presumption of the severely incomplete fissures because all the severely incomplete fissures were detected by preoperative high-resolution CT. The state of interlobar fissures in donors would change the difficulty of the donor lobectomies; thus this information would be helpful for the surgeons if they are provided prior to donor lobectomies.

In addition, 3D-CT angiography has been reported to be useful for preoperative evaluations of the anatomy of pulmonary arteries and veins [15]. We also used 3D-CT angiography for a better understanding of the anatomy of pulmonary vessels of the donors. To date, we have encountered only one unacceptable and unusual anatomy of the donor vessels of a right donor. In fact, we have sacrificed, at most, only small branches to the lingular segment or the right middle or upper lobe. This information that was preoperatively obtained by 3D-CT angiography not only resulted in the safe explantation of the lower lobes from living donors, but also relieved surgeons from stress when performing surgeries on living donors to some extent. According to our results, there was no difference in terms of the number of donors with pulmonary arterial branches sacrificed between left lower lobe donors and right lower lobe donors.

Morbidity rates in living lung transplant donors varied from 20 to 60% in the previous reports [1–6], and this is probably because of the different definitions of complications from study to study. According to a report from an international forum on the care of a live organ donor that was conducted in 2005 [16], data on more than 500 live lung donors showed that 4% of live lung donors experienced an intraoperative complication and 5% of donors experienced complications that required surgical or bronchoscopic intervention. In our study, there were no intraoperative complications, while 7 of 43 (16%) demonstrated early postoperative complications. Five out of these seven donors (71%) presented air leak-related complications. In lobectomies that were performed for the use of the lobe in transplantation, the proximal dissection of the structures can often be the cause of the prolonged air leakage [3,6]. However, two donors with severely incomplete fissures showed neither any air leakage just after the operation or any air leak-related complications. In addition, two other donors who required chest tube re-insertion for minor air leakage after chest tube removal presented almost complete fissures at the time of the operation. These results imply that air leak-related complication might equally happen in all donors since the proximal dissection of the structures is potentially required in donor lobectomies. However, three patients who suffered from prolonged air leak more than a week showed air leakage just after the operation, remarking the importance of dealing with air leakage at the operation.

There are several limitations in this study. First, the sample size was relatively small. Secondly, a retrospective study was the most practical way to address our question because of the low incidence of LDLLT in a single surgical center, but the results should be interpreted carefully.

In conclusion, living donor lobectomies were safely performed with low morbidities in our institution. Preoperative computer tomographic evaluations might be useful in donor lobectomies.

Authorship

All authors took part in the design of the study, contributed to the data collection, participated in writing the manuscript, and agreed to accept equal responsibility for the accuracy of the content of the paper.

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