Anastomotic pitfalls in lung transplantation

Although airway, arterial, and venous connections required for lung transplantation appear simple, in practice we have encountered morbid early stenosis and obstructions, which are now avoided by technical modifications gradually made since 1985 in 134 cases (60 single lung and 74 double lung). Our initial eight double lung transplant procedures were done with tracheal anastomoses and omental wraps, but ischemic disruption, with a 75 % (6 of 8) rate of complications, resulted in the subsequent use of bibronchial connections. A total of 192 bronchial anastomoses were reviewed (60 single lung, 66 double lung). Although all anastomoses were constructed between the donor trimmed to one to two rings above the upper lobe origin and the host divided at its emergence from the mediastinum, the suture technique has evolved. Nine (32 %) of 28 cases with early bronchial anastomoses with end-to-end suture and intercostal muscle wrap had ischemic or stenotic complications, but the telescoping technique without wrap in 164 bronchial anastomoses reduced the problem to 12 % (19 of 164). Twelve anastomoses required temporary intraluminal stenting. Vascular anastomotic obstructions occurred in five arterial (excessive length 2, short allograft artery 1, restrictive suture or clot 2) and two venous (excessive length 1, restrictive suture or clot 1) connections. Suspicion of arterial obstruction was prompted by persisting pulmonary hypertension and reduced flow to the allograft measured by post-operative nuclear scan and hypoxia. Venous obstructions were suggested by persisting radiographic and clinical pulmonary edema. Modifications of earlier techniques have improved our early success in lung transplantation and might be considered by others entering this demanding field. (J THORAC CARDIOVASC SURG 1994;107:743-54)

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Lung transplantation has gained increased acceptance as a therapy for end-stage lung disease and, when associated with cardiac repair, for simple forms of Eisen-

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menger's syndrome.¹ In Pittsburgh our experience as of April 1993 with 81 single and 90 bilateral lung transplant procedures has made us aware of the potential for anastomosis-related stenoses of the airways, arteries, and veins.² The purpose of this communication is to review the prevalence, presentation, diagnosis, and treatment of these problems and to emphasize the current techniques that might reduce their occurrence.

Patients and methods

Anastomotic obstructions. We reviewed the cases of 60 single and 74 double lung transplant recipients who were operative survivors between 1985 and October 1992. Ischemia, partial or

Fig. 1. Right donor lung is prepared for implantation by division of airway, artery, and venous cuff close to their respective branch points.

complete dehiscence, and stenosis of the airway anastomosis were diagnosed by surveillance and therapeutic use of a flexible bronchoscope. Obstruction or dehiscence, reduced air flow, clearance of secretions, and postobstructive pneumonia were considered significant and generally were treated by placement of an endobronchial flanged silicone rubber stent (E. Benson Hood Laboratories, Pembroke, Mass.). The prostheses were slipped into position over a rigid bronchoscope and extracted by grasping forceps.³ The intent was to leave these stents in place for 3 to 6 months unless an earlier trial of removal was prompted by their dislodgment. Pulmonary arterial obstruction was suspected when systemic hypoxia was associated with a clear chest radiograph. Persistent pulmonary hypertension also raised concern when single lung transplantation was done for pulmonary vascular disease. Recently, portable nuclear perfusion scans have been obtained immediately after operation and arterial obstruction considered, in single lung transplantation, when the majority of flow was to the native lung or, after bilateral lung transplantation, when there was significant asymmetry. Obstructions were operatively revised when they were judged to significantly limit the potential physiologic benefit of the allograft, including perfusion less than 50% of total and arterial oxygen saturation less than 90% at rest or with exercise. Stenotic anastomoses were revised with spatulating techniques, with

homograft patch angioplasty, or with both techniques, and distortions caused by excessive lengths were improved by tapering and shortening of the arterial segments. Pulmonary venous obstruction was considered when diffuse interstitial edema appeared on chest radiograph and was distinguished from primary dysfunction of the lung or preservation injury when obstructed and/or significantly abnormal flow patterns were detected in the allograft veins at their junction with the recipient's atrium by transesophageal echography. When pulmonary venous obstruction was detected, emergency reoperation and revision were done. Currently transesophageal echograms are obtained intraoperatively with special attention to the pulmonary venous and arterial patterns of flow.

Single lung transplantation. The pulmonary artery is circumferentially freed from the pericardium and divided distally between staples beyond the apical or upper lobe branches. The main-stem branch is transected just proximal to its upper lobe branch. Bronchial arteries are divided between surgical clips with minimal proximal dissection. The superior and inferior veins are divided and retracted laterally, and the pericardium is circumferentially incised to access the left atrium. The donor lung is prepared with transection of the main-stem bronchus within one or two cartilaginous rings above the upper lobe origin, of the pulmonary artery 1 cm proximal to its first upper lobe branch, and of the left atrial cuff to a 5.0 mm rim of muscle (Fig. 1). We use 3-0 nonabsorbable monofilament sutures to join the membranous portions of the bronchi by continuous suture that includes generous bites of tissue. Early in our experience, the anterior cartilaginous portion of the anastomosis had been completed with an interrupted end-to-end simple suture technique with a wrap of intercostal muscle, but our method now is based on horizontal mattress sutures that telescope the smaller airway into the larger.² This suture is begun on the outside of the larger airway and passes from inside to outside and back inside the smaller lumen before returning inside to outside through the larger airway. This method invaginates and secures the anastomosis but has occasionally been associated with an anterior flange of invaginated cartilage that obstructs the lumen proximal to the mattress suture. During the past year we have modified the dual mattress technique by substituting a vertical over-and-over suture for the smaller airway to more closely hold the proximal rings to the mucosal surface of the larger airway (Fig. 2). This technique requires the suture to pass outside to inside the large airway and then outside to inside the smaller airway twice before returning inside to outside the larger airway. We no longer wrap the anastomosis.

The anastomosis between pulmonary arteries is completed with running 5-0 monofilament sutures. Initially, this anastomosis was done just distal to the recipient's right upper lobe branch. Because problems occurred from distortion of the long artery segment and restrictive anastomoses to smaller distal arteries, we now divide the pulmonary artery proximal to its first branch in all cases except those associated with pulmonary hypertension and dilated arteries. A pursestringing of the continuous vertical mattress suture must be carefully avoided, and, when the arteries are small, the recipient's artery is spatulated inferiorly and the donor artery anteriorly to provide a larger, nonstenotic anastomosis.

In preparation for the venous anastomosis, a Satinsky-type clamp is placed deep within the host's atrium to access at least 5 to 10 mm of atrial cuff. The transected veins are connected by an incision through the intervening atrial muscle. A continuous

vertical 4-0 nonabsorbable monofilament suture is placed to encourage endothelium-to-endothelium contact in periatrial fat, and muscle is occluded from the blood-contacting surfaces when possible. Although initially we favored a luxurious amount of donor atrial cuff that facilitated the technical aspects of the pulmonary venous anastomosis, we now trim the pulmonary venous cuff so as to exclude all but a few millimeters of donor atrial muscle. With completion of the final anastomosis, the lung is revascularized and ventilated. The bronchial anastomosis is inspected with a flexible bronchoscope to exclude technical error. Transesophageal echography has become a standard to check the venous and pulmonary arterial anastomoses for patency and patterns of flow. This technique plus direct observation of the arteries and veins for distortion or anastomotic narrowing reduces the likelihood of an undetected obstruction.

Double lung transplantation. Initially, double lung transplantation was done en bloc with a supracarinal anastomosis and vascular anastomoses to the donor pulmonary arteries and posterior atrial cuff containing the left and right pulmonary veins.⁴ This procedure has undergone a number of modifications, beginning with the elimination of the tracheal anastomosis because of a high incidence of ischemia-related complications.⁵ The midline sternotomy with en bloc implantation has given way to a transverse sternotomy done through the fourth intercostal space with extended bilateral thoracotomy, which provides excellent exposure for sequential single lung transplantation.⁶ Currently anastomoses are done to main-stem bronchi, left and right pulmonary arteries, and donor veins to respective left cuffs of atrium. Cardiopulmonary bypass, when required, is initiated between the ascending aorta and the right atrium.

Results

Airway anastomoses. Our initial eight double lung transplant procedures were done with tracheal anastomoses and omental wraps, but ischemia in six patients, which resulted in complete dehiscence of the suture lines in three patients, prompted our subsequent use of bibronchial connections (Table I). We reviewed 192 bronchial anastomoses from 60 single and 66 double lung procedures. Nine of 28 early bronchial anastomoses with end-to-end suture and an intercostal muscle wrap resulted in ischemic or stenotic complications, but the subsequent use of the telescoping technique in 164 anastomoses reduced the problem to 12% (19 of 164). Complications did not correlate to number of episodes of rejection, ischemic time of the allograft, or the presence of diffuse alveolar damage.

Eleven anastomoses in nine recipients (7%) required intraluminal stenting with a flanged silicone rubber prosthesis (E. Benson Hood Labs., Pembroke, Mass.). Seven of the patients underwent bilateral lung transplantation, and two received single lung allografts (Table II). Stents were not more common in patients who required prolonged mechanical ventilation of the lungs. Three recipients were treated for cystic fibrosis, two for chronic obstructive lung disease, two for Eisenmenger's syn-

Fig. 2. Modified horizontal mattress suture technique that avoids potential for obstructing flange of invaginated cartilage.

drome, and one each for primary pulmonary hypertension and lymphangiomyomatosis. The most common clinical symptoms included dyspnea (4), retained secretions (3), and pneumonia (2). Endobronchial stents were required more commonly on the left (8) than on the right (3). Two of the recipients with right-sided lesions had bilateral stenoses. Endoscopic diagnosis confirmed stenosis of the suture line, usually associated with edema and granulation tissue (6 patients) and partial dehiscence of the suture line (3). Although stenosis occurred as early as 8 days after operation, the median was 38 days and the longest period after transplantation before development of a stenosis was 185 days. One patient with a functional stent died of systemic infection, but seven others had stable airways without stenosis after removal of the stent an average of 163 days (7 to 261) after insertion. Stenosis recurred in two recipients and stents were reinserted at 25 and 98 days. One patient with a functional stent died of systemic fungemia and diffuse alveolar damage. The other patient with restenosis required a second stent for 25 days and remains in stable condition without the endobronchial prosthesis. Somewhat surprisingly, bronchial airway problems, while causing some morbidity, were well-tolerated. Deaths in two of nine patients were not directly related to bronchial anastomotic problems.

Pulmonary arterial obstructions. Pulmonary arterial obstructions occurred in 5 of 60 single-lung recipients and were not recognized in any of the double-lung recipients (Table III). The anastomosis was distorted in two patients because the donor and recipient segments were too long (Fig. 3), and in another distortion occurred at the

Table I. Airway anastomoses

	n	No. with complications (%)			Total
		Ischemia	Dehiscence	Stenosis	
Tracheal					
End-to-end	8	3(47)	3 (47)	0	6 (75)
Bronchial					
End-to-end	28	4 (13)	4 (13)	1 (4)	9 (32)
Telescoping	164	11 (7)	0	8 (5)	19 (12)

Table II. Endobronchial stents in lung transplantation

Patient	Disease	Transplant	Presenting symptoms	Days postop.	Diagnosis	Treatment	Outcome
1	CF	BLT	Dyspnea	76	Bilateral dehiscence	L stent 7 days, R stent 15 days	Stable w/o stent ×2
2	COPD	LSLT	Retained secretions	35	L stenosis	L stent 275 days (reposition ×2)	Stable w/o stent
3	CF	BLT	Retained secretions	17	Bilateral dehiscence	L stent 476 days, R stent 507 days, laser debridement ×3	Stable w/o stent ×2
4	Eisen/ASD	BLT	Retained secretions	49	L stenosis	L stent 27 days (removed when dislodged)	Died, stable w/o stent
5	PPH	BLT	Dyspnea	38	L dehiscence	L stent 160 days	Restenosis 98 days, redo stent
6	Eisen/ASD	BLT	Left lung pneumonia	62	L stenosis	L stent	Died with stent, infection
7	CF	BLT	Dyspnea	185	L stenosis	L stent 261 days	Stable w/o stent
8	LAM	LSLT	Dyspnea	8	L stenosis	L stent 14 days (reposition ×2)	Stable w/o stent
9	COPD	BLT	Pneumonia	73	R > L stenosis	R stent 33 days reposition ×2, R laser ×2	Restenosis 25 days, redo stent 25 dy, R laser ×6, L laser ×2, stable w/o stent

CF, Cystic fibrosis; BLT, bilateral lung transplant; L, left; R, right; w/o, without; COPD, chronic obstructive pulmonary disease; LSLT, left single lung transplant; Eisen/ASD, Eisenmenger's syndrome/atrial septal defect; PPH, primary pulmonary hypertension; LAM, lymphangioleiomyomatosis.

origin of the donor right upper lobe (Fig. 4). In this case the donor artery was divided too close to the upper lobe during harvesting, which resulted in a technically compromised anastomosis to the recipient artery. The anastomosis was narrowed in two patients, and in one of these it was associated with an intraluminal thrombus (Fig. 5). Suspicion of obstruction was initially raised by moderate pulmonary hypertension in one patient who received a single lung transplant for Eisenmenger's syndrome associated with an atrial septal defect, by hypoxia in two, and more recently by routine postoperative lung scans (2).

Three of the five patients underwent reoperation whereas two were observed. Both patients with anastomotic stenosis and one of the two with distortion from

extra length underwent revision of the anastomoses by spatulation or homograft patch, or both techniques. One patient with distortion of the connection because of excessive length underwent reoperation because of severe reduction of flow to the allograft. In the other with arterial distortion but with 80% flow to the allograft, pulmonary arterial pressure lowered in time from 70/22 to 48/15 mm Hg. Because the other recipient with reduced flow to the allograft would have required a complicated revision of the right upper lobe and main pulmonary artery, she too was observed. Somewhat unexpectedly, flow to the allograft in this patient and to the narrowed right upper lobe has significantly increased. The perfusion scans that demonstrated significant reduction of flow to

Fig. 3. Pulmonary arterial anastomosis distorted as result of excessive lengths of donor and recipient right pulmonary artery cuff.

Table III. Pulmonary artery obstruction in lung transplantation

Disease/transplant	Presentation	Findings	Treatment/outcome
CHD(ASD)/RSL	PA pressure 70/22 mm Hg	Excessive length donor & recipient PA	Observe/PA pressure 48/15 mm Hg
PPH/RSL	Q Tx 22% (minimal flow RUL)	Donor PA short, harvest injury	Observe/PA pressure 50/20 mm Hg
COPD/RSL	Q Tx 15%	Stenosis + distortion of anastomosis	Revision/Q Tx 66%
LAM/LSL (repeat)	Hypoxemia, PA pressure 60/30 mm Hg, Q Tx 22%	Excessive length donor PA	Revision PA pressure 40/22 mm Hg/Q Tx 70% + infection
LAM/LSL	Hypoxemia, PA pressure 40/16 mm Hg	Stenotic anastomosis	Homograft revision/PA pressure 27/13 mm Hg

CHD(ASD), Chronic heart disease/atrial septal defect; RSL, right single lung; PA, pulmonary artery; PPH, primary pulmonary hypertension; Q Tx, flow to transplanted lung; RUL, right upper lobe; COPD, chronic obstructive pulmonary disease; LAM, lymphangioleiomyomatosis; LSL, left single lung.

Table IV. Pulmonary venous obstruction in lung transplantation

Disease/transplant	Presentation	Findings	Treatment
COPD/LSL	POD 1: Diffuse ABN CXR, ABN ECHO	Excessive length donor vein cuff	Shorten donor cuff, slow improvement (3 mo)
CF/BSL	POD 2: R lung diffuse CXR, ABN ECHO	Partial thrombosis R vein anastomosis	Thrombectomy, revise anastomosis

COPD, Chronic obstructive pulmonary disease; LSL, left single lung; POD, postoperative day; ABN, abnormal; CXR, Chest radiograph; ECHO, echogram; CF, cystic fibrosis; BSL, bilateral single lung; R, right.

the transplanted lung (15% to 22%) showed improvement after reimplantation or after a period of observation (Table III, Fig. 6). Review of the perfusion scans in seven patients with no complications, who received single lung transplants for conditions associated with pulmonary hypertension, demonstrated that 90% of the pulmonary blood flow was directed toward the allograft. The flow to the allograft in 14 recipients without pulmonary hypertension who were treated for obstructive lung disease was more than 50%.

Pulmonary venous obstruction. Pulmonary venous obstruction was detected in 1 of 60 single-lung recipients

and unilaterally in 1 of 74 double-lung recipients (Table IV). In the single-lung recipient, shortly after revascularization of the allograft, unilateral frothy pulmonary edema was noted from the transplanted lung, and the radiograph confirmed a pattern of diffuse interstitial edema throughout the transplanted lung (Fig. 7, A). The surgeon did not diagnose a venous obstruction and relied on his clinical impression of a nonobstructive pulmonary venous connection made between the usual recipient left atrium and an especially large donor left atrial cuff. Because of the persistence of pulmonary edema and the knowledge that the contralateral lung from the donor also trans-

Fig. 4. Right pulmonary angiogram showing narrowed origin of branch to right upper lobe.

planted had functioned flawlessly, transesophageal echography was done in the intensive care unit and documented near total obstruction of pulmonary venous flow uniformly at the level of the pulmonary venous anastomosis. At reoperation, an excessive length of donor atrium was noted to have obstructed flow by enfolding into the lumen (Fig. 8). This obstruction was more apparent when the chest was closed and the lung confined within a mildly restricted pleural space. Revision of the anastomosis with resection of the donor atrial muscle to within 3.0 mm of the pulmonary veins resulted in normal flow pattern, but the patient required prolonged intubation, and the allograft slowly recovered over 3 months (Fig. 7, *B*).

The other patient with venous obstruction received a sequential bilateral lung transplant for cystic fibrosis but progressive right-sided radiographic opacification developed on the second postoperative day. Prompt transesophageal echography demonstrated a large thrombus on the suture line on the left of the right pulmonary venous cuff (Fig. 9, *A*) and a near continuous wave Doppler pulse implying reduced and obstructed flow (Fig. 9, *B*). At urgent reoperation the thrombus was removed and the anastomosis reformed. Somewhat disturbingly, the original anastomosis looked to be flawless with appropriate endothelium-to-endothelium position. The patient was treated with heparin, and the thrombosis did not recur.

Discussion

We have discussed operative techniques in this series of 60 single-lung and 74 double-lung transplant recipients and emphasized anastomotic pitfalls. We have learned that, although the connections between airways, pulmonary arteries, and pulmonary veins appear technically uncomplicated, methods such as telescoping the closure of the bronchi, which minimizes length of connections and maximizes anastomotic circumferences, are necessary to achieve consistent technical success. Since bilateral single lung transplantation⁶ was introduced as an improved alternative to en bloc double lung transplantation,^{4,7} we now approach cases of single- and double-lung transplantation with the same simplified techniques of implantation.

Unlike heart and lung transplantation in which pericardial collateral vessels from the coronary and pulmonary arterial system nourish the donor airway, the collateral supply available to the bronchus of the single lung allograft is limited. Problems of necrosis and dehiscence of bronchial anastomoses were responsible for many of the deaths in the early attempts of clinical lung transplantation.⁸ Before their reintroduction of single lung transplantation, Cooper's group demonstrated the benefits in the dog of avoiding steroids and of the use of a bronchial omentopexy.^{9,10} Those techniques combined with advances in preservation and cyclosporine-based immunosuppression reduced the prevalence of major bronchial anastomotic complications to 10%.^{5,8,11,12} The success of the San Antonio, Texas, group in limiting problems by use of a telescoping suture technique for bronchial anastomoses without a tissue wrap resulted in the general abandonment of the time-consuming, potentially morbid omentopexy.¹³ We adopted the horizontal mattress telescoping technique suggested by Patterson⁸ because we were unhappy with results from the wrapped end-to-end technique and found the figure-of-eight telescoping technique less secure in our hands. Subsequently we modified the horizontal mattress technique to include an over-and-over suture on the smaller invaginated airway because a flange of interior cartilage partially obstructed our telescoped anastomoses in a number of cases (Fig. 2). This change has provided a secure and technically sound closure.

The results in this series of airway ischemia and obstructions requiring stents compare favorably with reports from other series^{5,8,11,12} and confirm that although moderate morbidity is associated with a 10% prevalence of significant airway problems, death is infrequent. It is interesting to speculate that, on the basis of laboratory experience, improved ex vivo parenchymal preservation might provide for a more luxurious micro-

Fig. 5. Stenotic left pulmonary artery anastomosis.

Fig. 6. Improved perfusion of left lung allograft after revision of stenotic anastomosis. *PRE*, Before revision; *POST*, after revision; *L*, left; *R*, right.

circulation of the airways.¹⁴ Additionally it has been proposed but not assured that routine use of perioperative corticosteroids might reduce allogenic reaction and inflammation at the suture line.¹⁵ Although we hoped that improvements in lung preservation and immunosuppression might reduce the occurrence of airway ischemia, we have not found significant correlation in this series with the occurrence of acute rejection or ischemic time, and we believe further improvements are likely only to come from direct bronchial revascularization. Currently, series are underway to test the benefit of a left mammary artery anastomosis to the left bronchial artery and of intercostobronchial artery reimplantation.^{16, 17}

Although the problems associated with the airways were known from both historical experience and contemporary series, difficulties arising from the anastomoses of the pulmonary arteries and veins were not anticipated.¹⁸ Although experienced in heart and lung transplantation, we drew heavily on our laboratory models of single lung transplantation in the canine and the clinical reports from

Toronto before beginning clinical lung transplantation. Our laboratory work had demonstrated the potential for thrombosis of the pulmonary venous connection and stressed the need for an exacting suture technique that would guarantee an endothelium-to-endothelium junction; however, the animal model did not lend itself to the human anatomy and the potential for excessive lengths of donor atrium or pulmonary arteries that could distort and obstruct anastomoses. In fact, the surgical technique for human lung transplantation successfully done by Cooper¹⁹ and Cooper and associates²⁰ suggested that pulmonary arterial anastomoses be made distally below the origin of the host's right upper lobe to minimally trimmed donor segments and also encouraged the routine use of large donor pulmonary venous cuffs. Although no doubt these techniques have been generally successful, our experience, which relied on them, demonstrates the potential problems caused by long connections. Despite our surgeons' opinions that a nonrestrictive anastomosis had been completed, the rare problem of stenosis of the

Fig. 7. **A,** Chest radiograph demonstrating unilateral pulmonary edema after left lung transplantation. **B,** Chest radiograph 3 months after revision of obstructing pulmonary venous atrial cuff.

pulmonary anastomotic suture line occurred. Our data suggest that 90% of the pulmonary blood flow should be diverted into the allograft for patients with primary pulmonary hypertension or Eisenmenger's syndrome who are treated with single lung transplantation and at least 50% for conditions without significant elevation of pulmonary vascular resistance, such as chronic obstructive

lung disease. The finding that perfusion to the transplanted lung rose from 15% to 22% to higher than 50% after successful revision in each instance is a further indication of the sensitivity of perfusion scans. We only recently have begun to scan routinely the patients having bilateral single lung transplantation. On the basis of single-lung experience, we likely have underdiagnosed a unilateral

Fig. 8. Left lung transplant with redundant donor pulmonary venous atrial cuff that obstructed venous flow from allograft.

Fig. 9. **A,** Transesophageal echogram of right-sided pulmonary venous anastomosis. Large thrombus (*T*) along atrial cuff and obstructed flow from right pulmonary vein (*RPV*) are noted. *LA*, Left atrium. **B,** Doppler waveform from transesophageal study in Fig. 7, *A*. Near uniform wave suggests abnormal obstructed flow from right-sided vein.

problem. Before the routine use of postoperative perfusion scans, the presenting clinical feature was hypoxia in patients with low pulmonary vascular resistance and continued moderate pulmonary hypertension in the patients treated with preoperative systemic levels of pulmonary pressure. The decision to revise the arterial anastomosis was based on the likelihood of technical success and the presence of significantly reduced perfusion of the allograft.

We elected to observe a patient with moderate pulmonary hypertension after single lung transplantation for Eisenmenger's syndrome associated with an atrial septal defect. Eighty percent of the pulmonary blood flow was directed to the transplanted lung, and the patient was clinically well with systolic pulmonary artery pressures reduced from 120 mm Hg measured to 70 mm Hg. In the other conservatively treated patient with obstruction caused by a shortened allograft artery, it was believed that restoration of flow to the right upper lobe would have been technically complicated. Somewhat surprisingly, pulmonary artery pressure has lowered in the first patient, and perfusion to the right upper lobe has significantly increased in the latter.

Our two instances of pulmonary venous stenosis were both heralded by diffuse unilateral interstitial edema on the radiograph, and in the patient with near total obstruction it was also associated with continuous frothy endobronchial edema. Because venous hypertension and obstruction can irreversibly injure an allograft, we consider the suggestion of pulmonary venous stenosis by transesophageal echography to be a surgical emergency. Before the routine use of transesophageal echography it is probable that other lungs might have been lost because of pulmonary venous obstruction when the presumptive diagnosis was that of primary lung dysfunction.

Much of the excitement in thoracic transplantation over the past few years has been related to the development of various forms of and techniques for pulmonary transplantation. It has been a challenge to be involved in most of these cases, which demand technical excellence and a keen diagnostic sense, not only when operations appear to have failed but also when they appear superficially to be adequate. Experience with the procedures, intraoperative and postoperative transesophageal echography, and perfusion scans has improved the likelihood of a favorable outcome for patients in desperate need of pulmonary transplantation.

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Discussion

Dr. J. Kent Trinkle (*San Antonio, Tex.*). It takes a lot of courage to discuss complications and I think we learn a lot from them. I would like to make one comment on the silicone rubber stent. If the authors would convert to the vascular-type wire mesh stent I believe they would be much happier with it than with the other. I have only used it three times because I do not have nearly as much experience as the authors with anastomotic problems, but the one we use is the Palmaz stent made by Johnson & Johnson (Johnson & Johnson Cardiovascular, King of Prussia, Pa.). The use of mucolytic agents is unnecessary and the stent is not nearly as obstructing as the silicone rubber stent.

Dr. G. Alec Patterson (*St. Louis, Mo.*). I myself have reported airway complications in the past so I thought I might make a few remarks on this important experience.

The authors have demonstrated a very low prevalence of bronchial anastomotic complications in a series of patients having single and bilateral lung transplantation. I cannot remember from the data whether the prevalence was higher in unilateral or bilateral transplantation. Graft for graft one could argue that in a bilateral transplant a higher prevalence of airway complications would be expected inasmuch as pulmonary artery flow is divided equally between both allografts.

The authors demonstrated that airway complications are associated with low morbidity. Furthermore, the stents they used were, for the most part, temporarily required and very well tolerated.

The authors mentioned that they do not wrap the bronchial anastomosis. I would like to ask Dr. Griffith whether they put any local nodal tissue on the anastomosis or if they just leave it telescoped and bare. I would also be interested in how the authors deal with a really small left main bronchial anastomosis. The distal left bronchus is always smaller than the proximal right. Dr. Griffith, do you avoid telescoping a small left bronchus? The other question I would ask is this: When is the earliest you have placed a stent? How soon can we put those stents in in airways that have gone bad?

Dr. Griffith. We have not used the Palmaz stent and are reasonably happy with the silicone rubber Cook prosthesis (Cook, Inc., Bloomington, Inc.).

Dr. Patterson, by and large, we do not wrap the bronchial anastomosis. Sometimes, however, adjoining donor and regional recipient tissue gets drawn in around the suture line. A small left main bronchus is a problem, and because a telescoping method might further restrict the lumen, we would consider an end-to-end suture and likely would wrap the anastomosis with an intercostal muscle.

The earliest that we have had to use a stent has been 7 days after operation, and we did so without too much trouble: there was a little bit of bleeding, but no apparent dehiscence.

Dr. Griffith. The decision whether to reoperate depends on the degree of reduced perfusion, the anatomy, and the clinical condition of the patient. Certainly in a single-lung recipient who

has only 20% of blood flow to the allograft, the physiologic bang benefit is quite reduced, and the decision to repair will be obvious. A patient with pulmonary hypertension with moderate elevation of pulmonary pressures after single lung transplantation and 60% to 80% of flow to the allograft, and who is otherwise doing well, would be observed. The clinical condition of the patient and whether or not the result can likely technically be improved on factor in the decision. In the one case described, we did not think we could improve on the narrowed right upper lobe. The patient's condition was stable and so we waited it out. The flow to the upper lobe and the anastomosis improved, thus we were pleased with waiting in that case, but whether this would happen in every case, I cannot tell.

Dr. Thomas M. Egan (*Chapel Hill, N. C.*). We began our program using the old sort of Toronto-style end-to-end anastomosis with omentopexy and then went to telescoping anastomoses. After four transplants, which gave us seven anastomoses to evaluate, we were impressed with how often we had severe problems: in fact, one of the patients without omentopexy died of an airway problem and one required a stent.

All of the rest of our anastomoses have been done with the old-fashioned end-to-end anastomosis and omentopexy, and we have had 33 double-lung recipients and 18 single-lung recipients to evaluate. Among all 84 anastomoses, we have had one dehiscence that healed without any further complications, one dehiscence that led to death, one dehiscence for which the patient underwent retransplantation, and one dehiscence for which the patient required a stent, for an overall serious complication rate of about 5%. Thus we are pretty satisfied with end-to-end anastomosis and omentopexy with a relatively low prevalence of morbidity.

With respect to pulmonary artery anastomoses, we have had a couple of problems that necessitated reoperation. This has led us to measure gradient across the anastomosis intraoperatively, which is fairly easy to do. To our surprise we had to redo two anastomoses that looked good. Anastomoses in single-lung transplant recipients can be evaluated with a scan. Do you have any data on doing scans in double-lung transplant recipients after operation? How helpful is that in sorting out whether there is a vascular anastomotic problem?

Dr. Griffith. Dr. Egan, I would not quibble with your results: as usual they are excellent. We just do not find that the inconvenience of an omentopexy is worth the potential gain.

With respect to the flow scan and transesophageal echography, we use transesophageal echography intraoperatively to visualize vascular anastomoses and to evaluate flow patterns by Doppler ultrasonography. The postoperative pulmonary flow scan is useful after single and double lung transplantation. After single lung transplantation, less than 60% to 70% flow, or less than 85% in patients treated for pulmonary hypertension, would be cause for alarm, and a repeat scan would be obtained at 24 to 36 hours. If confirmatory, we would obtain a pulmonary arteriogram to evaluate the anatomy of the arterial anastomosis. Significant asymmetry after double lung transplantation would also be a cause for concern. We have recently noted small isolated perfusion defects consistent with pulmonary emboli likely arising within the donor.

Dr. Hans G. Borst (*Hannover, Germany*). I greatly enjoyed Dr. Griffith's presentation, which again reflects the high standard of lung transplantation attained at Pittsburgh. It confirms as correct our ideas about the bronchial anastomotic technique with the use of ultrashort stumps, both on the donor and the recipient side, and about not using omental wrapping. In fact,

I think that by having short stumps the anastomosis is wrapped automatically by the mediastinum. We are not so sure about the telescoping anastomosis because in our own experience with end-to-end anastomosis a similar dramatic decrease in bronchial complications occurred. In fact, in bronchial stumps of discrepant sizes, some anastomoses invaginate automatically.

I wanted to address briefly certain therapeutic alternatives. We have had 76 patients now who underwent 84 lung transplantations with 144 anastomoses at risk. In these patients we have seen 10 severe bronchial complications, especially early in our experience. In three of them we did sleeve resections and in one a lobectomy. Two patients underwent retransplantation and four received stents. There were no deaths except in one patient who received a stent who died late because of severe and recurrent rejection. It was rather interesting to note a luxuriant blood flow to the bronchi when sleeve resection or lobectomy was done 6 to 12 months after the transplantation. Bronchial anastomotic healing was perfect in these patients.

Dr. Griffith, have you had a similar experience and, if so, what would be your indications for doing such parenchyma-sparing operations?

Dr. Griffith. I think I would wait to review your experience and then make my decisions, but your experience with resection as a late rescue from bronchial complications is fabulous. Perhaps purposeful telescoping might reduce the need, but we have not faced the problem as yet.

Dr. Robert W. Emery (*Minneapolis, Minn.*). As you know, Dr. Griffith, we have a much more limited lung transplant experience than you. We are using Dr. Trinkle's telescoping technique along with wrapping the anastomosis with the pericardial fat pad, a ubiquitous structure in all patients except for those with cystic fibrosis in whom it is obliterated by infection. It is a fairly simple technique that presents a vascularized pedicle that can be used at the tracheal or bronchial level and that is bilateral (Emery RW, Arom KV, Von Rueden TJ, Copeland JG. Use of the pericardial fat pad in pulmonary transplantation. *J Cardiac Surg* 1990;5:145-8).

In this regard, do you believe that your anastomotic problems are ischemic or are a part of the healing process, necessary because of the construction of the anastomosis or because of damage during harvest or at the time of the construction?

Dr. Griffith. I do not know. The problems are occurring early as opposed to late. They do not appear to be suture-related scarring of an anastomosis inasmuch as the average time of the occurrence of problems was around a month. My guess is that the problems may be a natural consequence of suturing airways together with or without anastomotic blood flows, although I think the relative ischemia of the donor certainly exacerbates the problem. It would be interesting to evaluate the international results of direct bronchial artery anastomoses.