

Surgical treatment of chronic thromboembolic pulmonary hypertension

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BACKGROUND: There are only limited treatment options for patients with chronic thromboembolic pulmonary hypertension in Canada.

OBJECTIVE: To conduct a case-series study to assess the effectiveness of surgical endarterectomy of the pulmonary artery.

DESIGN AND SETTING: Twenty-one patients with chronic thromboembolic pulmonary hypertension were admitted for surgery between July 1995 and October 1999. Clinical, laboratory and radiological data were collected for all patients who then underwent pulmonary thromboendarterectomy.

MAIN RESULTS: Thirteen men and eight women between 22 and 71 years of age underwent surgery. The main presenting complaint was dyspnea on exertion. Pulmonary vascular resistance ranged from 382 to 1694 dynes·s·cm⁻⁵ with a mean of 765±372 dynes·s·cm⁻⁵ (normal is less than 180 dynes·s·cm⁻⁵) with a mean cardiac index of 2.2±0.9 L/min/m².

Two patients had concomitant tricuspid valve replacement and one patient had coronary bypass grafting. In three cases, the surgery involved a repeat sternotomy. After surgery, there was a significant drop in the pulmonary vascular resistance (208±92 dynes·s·cm⁻⁵, P<0.05) and a concomitant rise in the cardiac index to a mean of 3.1±0.6 L/min/m² (P<0.05). There was one death in a patient who also had severe chronic obstructive pulmonary disease. Of the remaining patients, all but two showed significant clinical improvement. Spiral computed tomography postsurgery demonstrated improvement in pulmonary perfusion with either complete clearing or significant improvement in the mosaic perfusion pattern. Right ventricular function and pressure on echocardiogram improved in all but two patients.

CONCLUSIONS: Pulmonary thromboendarterectomy provides effective treatment for chronic thromboembolic pulmonary hypertension.

Key Words: *Chronic thromboembolic pulmonary; Hypertension; Pulmonary hypertension; Pulmonary thromboendarterectomy*

Pour le résumé, voir page suivante

Chronic thromboembolic pulmonary hypertension (CTEPH) is a rare complication of pulmonary embolus that occurs when acute emboli fail to dissolve, leading to the chronic obstruction of right ventricular outflow (1). Although initial estimates of this complication after pulmonary

embolus is 0.1% to 0.5% (2,3), it may be more common than initially thought. In a study by Remy-Jardin et al (4), using spiral computed tomography (CT) to follow patients after acute pulmonary embolus, 52% of patients showed persistent endovascular abnormalities at a mean of 10.5 months. Thus,

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Traitement chirurgical de l'hypertension pulmonaire thromboembolique chronique

HISTORIQUE : Au Canada, les options thérapeutiques à l'intention des patients souffrant d'hypertension pulmonaire thromboembolique chronique sont limitées.

OBJECTIF : Procéder à l'étude d'une série de cas pour vérifier l'efficacité de l'endartériectomie chirurgicale de l'artère pulmonaire.

MODÈLE ET CONTEXTE : Vingt-et-un patients atteints d'hypertension pulmonaire thromboembolique chronique ont été admis pour une chirurgie entre juillet 1995 et octobre 1999. Les résultats des examens cliniques et radiologiques et des analyses de laboratoire ont été recueillis pour tous les patients devant subir une thromboendartériectomie pulmonaire.

PRINCIPAUX RÉSULTATS : Treize hommes et huit femmes de 22 à 71 ans ont subi la chirurgie. Le principal symptôme était la dyspnée d'effort. La résistance vasculaire pulmonaire variait de 382 à 1694 dynes·s·cm⁻⁵ avec une moyenne à 765 ± 372 dynes·s·cm⁻⁵ (la normale se situe sous les

180 dynes·s·cm⁻⁵), et un index cardiaque moyenne à 2,2 ± 0,9 L/min/m². Deux patients ont subi concomitamment un remplacement de la tricuspide et un patient a subi un pontage. Dans les trois cas, la chirurgie supposait une reprise de la sternotomie. Après la chirurgie, on a noté une baisse significative de la résistance vasculaire pulmonaire (208 ± 92 dynes·s·cm⁻⁵, P < 0,05) et une élévation simultanée de l'index cardiaque, en moyenne jusqu'à 3,1 ± 0,6 L/min/m² (P < 0,05). Un patient atteint d'hypertension pulmonaire thromboembolique chronique avancée est décédé. Parmi les autres patients, tous sauf deux ont connu une amélioration significative de leur état clinique. La tomographie spirale postchirurgicale a fait état d'une amélioration de la perfusion pulmonaire, accompagnée d'un dégagement total ou d'une nette recrudescence du mode de perfusion en mosaïque. La fonction et la pression ventriculaires droites à l'échocardiographie se sont toutes deux améliorées chez tous les patients sauf deux.

CONCLUSIONS : La thromboendartériectomie pulmonaire offre un traitement efficace pour l'hypertension pulmonaire thromboembolique chronique.

although the true incidence of CTEPH remains unknown (5), a conservative estimate is that this disorder affects 50 to 250 people in Canada per year.

There is no medical therapy for CTEPH. The natural history of the disease is increasing pulmonary artery pressure leading to progressive impairment of right ventricular function and death. Riedel et al (6) reviewed 147 patients with CTEPH who underwent serial right heart studies and pulmonary angiograms, and found that patients with mean pulmonary artery pressures over 40 mmHg had a 30% five-year survival rate, whereas patients with pressures over 50 mmHg had a 10% survival rate.

Surgical treatment has been the only therapeutic option and until recently, the results were disappointing. The first pulmonary endarterectomy for chronic thromboembolic disease was performed in 1958 by blocking the inflow to the pulmonary artery, but this procedure has had a high mortality rate (7). With advances in preoperative assessment, surgical technique including the use of cardiopulmonary bypass and postoperative management, the degree of success obtained with this surgery has improved steadily. Pulmonary thromboendarterectomy is now performed successfully in several centres around the world. The clinical team at the University of California in San Diego, California has been a pioneer in this procedure. The team has reported a perioperative mortality of 9% for the past 20 years (2,5,8,9), but it has fallen to 4% more recently (1,10). This is similar to that reported by other centres (11,12).

The functional improvement of patients treated surgically for CTEPH is dramatic. The majority of patients improve from preoperative New York Heart Association (NYHA) class III or IV to postoperative NYHA class I (10,13). This correlates well with the documented acute postoperative decrease of pulmonary artery pressures and pulmonary vascular resistance, and the anticipated rise in the cardiac output (2,14,15). A further improvement in pulmonary hemody-

namic indexes within the first year after the operation has also been reported (11,13).

A program for surgery for chronic thromboembolic pulmonary hypertension was started at the University of Ottawa Heart Institute, Ottawa, Ontario in 1995. This study reports the preoperative clinical findings, surgical procedure and follow-up on the first 21 patients, and then offers a clinically relevant review of this condition.

PATIENTS AND METHODS

Twenty-one patients with CTEPH were admitted to the University of Ottawa Heart Institute Department of Cardiac Surgery, Ottawa, Ontario from October 1995 to October 1999. Presenting symptoms, baseline pulmonary function tests, ventilation and/or perfusion scan results, and the results of echocardiography were collected. All patients then underwent a spiral CT scan, pulmonary angiography and right heart catheterization. If indicated, a coronary catheterization was also completed. In all but two patients, an inferior vena cava filter was inserted. The thromboembolic disease in the two cases was related to endocarditis of the tricuspid valve that had been excised previously.

The standard approach for pulmonary thromboendarterectomy involves a concerted, organized strategy among the anesthetist, the perfusionist and the surgeon. The intraoperative procedure includes cardiopulmonary bypass with profound hypothermia and intermittent circulatory arrest. A brief description follows, although a more detailed description is available elsewhere (15). After routine induction, the sternum is opened and the patient is heparinized. Cannulae are placed into the superior and inferior vena cava, and another is placed high into the ascending aorta. After cardiopulmonary bypass has commenced, cooling is initiated to allow for intermittent and controlled cardiac and circulatory arrest. During cooling, the superior vena cava is extensively dissected up to the brachiocephalic vein. Before initiating circu-

latory arrest, the patient is treated with phenytoin (15 mg/kg) and thiopental (20 mg/kg) to aid in cerebral protection. When the patient's nasopharyngeal temperature has reached 17°C and the electroencephalograph has been isoelectric for 3 mins, the circulation is stopped. The right pulmonary artery is exposed between the aorta and the superior vena cava, and then opened through the anterior wall. An endarterectomy dissection plane is created on the posterior wall. The plaque is lifted circumferentially, and through a combination of retraction and lateral dissection of the wall, a specimen can be removed up to the level of the subsegmental vessels. Once the specimen is removed, the arteriotomy is repaired. A similar approach is used for the left pulmonary artery, with particular care given to the left lower lobe specimen because of its course near the left lower lobe bronchus. The periods of circulatory arrest are limited to 20-min intervals, with extensive reperfusion of a minimum of 10 mins between each arrest.

Other cardiac procedures that are deemed necessary, such as coronary bypass, are completed during the rewarming phase. Usually the tricuspid valve is not repaired, even in the presence of moderate to severe tricuspid insufficiency, because it has been demonstrated that right ventricular remodeling occurs within a couple of days of the procedure, with return of tricuspid competence (16). During the rewarming phase, methylprednisolone (30 mg/kg) is given intravenously to help prevent reperfusion pulmonary edema. After coming off bypass, all patients are treated with a low-dose infusion of prostaglandin E1 for the first 12 to 24 h to guard against immediate postprocedure pulmonary vasoconstriction and in situ thrombosis (15).

Postoperative follow-up: Patients are observed in the intensive care unit for a minimum of 48 h. Nitric oxide ventilation was used liberally in the intensive care unit in the presence of persistent pulmonary hypertension or hypoxemia requiring high fraction of inspired oxygen, to prevent toxicity from the latter. Supplemental oxygen is continued after extubation for a period of six weeks to aid in remodeling of the pulmonary vasculature. All patients undergo follow-up echocardiography and spiral CT within three months and then one year after surgery.

RESULTS

All patients presented with dyspnea at rest or with minimal exertion. Four had peripheral edema and two presented with chest pain. All patients showed definite areas of ventilation-perfusion mismatch. Nine patients presented with normal spirometry, three had restrictive defects, five had mild airflow obstruction and one had moderate airflow obstruction. One patient had combined restrictive and obstructive disease, and one patient had severe airflow obstruction. One patient had no preoperative pulmonary function testing. Most had impaired gas exchange as measured by the diffusing capacity. Three patients had had previous sternotomies and two patients were morbidly obese. Of the twenty who underwent echocardiogram, 19 had a dilated right ventricle; one patient had a normal result (Table 1). On spiral CT,

most patients showed evidence of chronic thrombi and the characteristic mosaic perfusion pattern.

In two cases, tricuspid valve replacement was completed because the native tricuspid valve had been previously excised because of endocarditis. Both had severe pulmonary embolic disease from mycotic lesions secondary to intravenous drug abuse. Three of the patients required temporary tracheostomy because of postoperative respiratory insufficiency. Three patients required early reoperation in the first 24 h, one because of tamponade, and the others as a consequence of myocardial edema. Two of these cases involved reoperations, and the third had severe right ventricular dysfunction and jaundice preoperatively contributing to coagulopathy. One patient developed late sternal dehiscence requiring rewiring.

The one death that occurred was secondary to multiorgan failure after prolonged ventilation. A spiral CT before death demonstrated normal pulmonary perfusion and there was no residual pulmonary artery obstruction at autopsy. One patient developed late tamponade requiring percutaneous pericardial drainage. In one patient, recombinant hirudin was used successfully for anticoagulation for cardiopulmonary bypass because of a previous history of heparin-induced thrombocytopenia. The average time of cardiopulmonary bypass for all of the patients was 237±83 mins. The cardiac anoxic time was 112±57 mins and the circulatory arrest time was 52±19 mins.

In follow-up, all but two of the remaining patients improved significantly both clinically and hemodynamically. The hemodynamic results early and late following surgery are demonstrated in Figure 1. The cardiac index increased by 70% after surgery. The pulmonary vascular resistance fell from a preoperative level of 765±372 dynes-s-cm⁻⁵ to 208±92 dynes-s-cm⁻⁵ at the time of removal of the Swan-Ganz catheter. The total hospital length of stay was 23.8±12.0 days and the time in the intensive care unit was 12.6±8.0 days. The average time on the ventilator was 9.4±7.9 days. In 13 patients, nitric oxide ventilation was used for an average of 4.4±6.0 days. Two patients had persistent pulmonary hypertension requiring continuous oxygen therapy. Follow-up angiograms demonstrated severe diffuse peripheral disease not amenable to surgery, and both of these patients are being considered for transplantation.

There is one-year complete follow-up data on 10 patients (Table 1). The other 10 patients have not completed one year of follow-up. Pulmonary artery pressures and right ventricular function on echocardiogram returned to normal in all but one patient. Another patient had very little resectable thrombus found during surgery and has persistent pulmonary hypertension; however, the follow-up is less than six months. All cases demonstrated improvement in pulmonary perfusion and clearing or significant improvement in mosaic perfusion pattern on the CT. One patient with neuropsychiatric changes, possibly related to the circulatory arrest during surgery, continued to have short term memory loss and judgment difficulties.

TABLE 1
Pre and postoperative findings on echocardiogram and computed tomography of 21 patients who underwent endarterectomy for chronic thromboembolic pulmonary hypertension

Point	Echocardiogram		Computed tomography findings	
	Preoperative	Postoperative	Preoperative	Postoperative
1	Dilated PA and RV; patent foramen ovale; systolic pressure 90 mmHg	Normal RV size and pressure	Evidence chronic thrombi; bilateral mosaic perfusion	No residual clot; no mosaic perfusion
2	n/a	n/a	Evidence acute and chronic thrombi both lower lobes; extensive mosaic perfusion	No residual clot; partial resolution mosaic perfusion both lungs
3	Normal	Mild RV dilation	Large chronic thrombi, right larger than left ???; bilateral mosaic perfusion	Mild residual mosaic perfusion anterior RLL
4	Dilated hypokinetic RV; systolic pressure 56 mmHg; absent tricuspid valve	Normal RV	Large chronic thrombi, right larger than left; bilateral mosaic perfusion	Persistent thrombi lingula; significant improvement mosaic perfusion
5	Dilated hypokinetic RV; systolic pressure 68 mmHg	RV size upper limits normal; marked decrease in chamber size; systolic pressure 40 mmHg	Extensive chronic thrombi; bilateral mosaic perfusion	No residual clot; no mosaic perfusion
6	Severe RV dilation with systolic dysfunction; systolic pressure 108 mmHg	Normal RV	Bilateral mosaic perfusion; extensive chronic thrombi, right larger than left	No clot; significant improvement mosaic perfusion
7	Severe RV dilation; systolic pressure 86 mmHg	n/a	Bilateral mosaic perfusion; extensive chronic thrombi	n/a
8	Dilated RV; moderate impairment RV systolic function Systolic pressure 51 mmHg; severe TR	RV size normal; unable to calculate PA pressure	Bilateral mosaic perfusion; occluded right interlobar artery and left lower lobe; mild bilateral mosaic perfusion	Marked improvement in perfusion of lower lobes Significant improvement mosaic perfusion
9	Dilated RV	Mild RV dilation	Bilateral mosaic perfusion; bilateral extensive chronic thrombi	Small residual thrombus; superior segment; right lower lobe; significant improvement mosaic perfusion
10	Moderately dilated RV; moderate global hypokinesis RV	Marked reduction RV size; PA pressure 40 mmHg	Bilateral extensive chronic thrombi; bilateral mosaic perfusion	No clot; significant improvement mosaic perfusion
11	Moderate dilation RV; moderate global hypokinesis RV	Marked reduction RV size	Bilateral mosaic perfusion	n/a
12	Dilated RV; RV systolic pressure 112 mmHg	n/a	Emphysema; bilateral mosaic perfusion; extensive right-sided thrombus	n/a
13	Moderate dilation RV; moderate global hypokinesis RV	Normal RV; PA pressure 49 mmHg	Subtle mosaic perfusion; extensive right-sided thrombus	Marked improvement in perfusion right lung; small residual mosaic perfusion
14	Absent tricuspid valve previously excised for endocarditis; dilated RA and RV, severe hypokinesis RV	Moderate RV enlargement with mild RV dysfunction	Marked dilation of pulmonary arteries; patchy mosaic perfusion; abrupt occlusion lower lobe arteries	Marked improvement in perfusion of lower lobes

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Pre and postoperative findings on echocardiogram and computed tomography of 21 patients who underwent endarterectomy for chronic thromboembolic pulmonary hypertension

Point	Echocardiogram		Computed tomographic findings	
	Preoperative	Postoperative	Preoperative	Postoperative
15	Severe RV enlargement; moderately hypokinetic RV	n/a	Large clot right pulmonary artery; mild emphysema; bilateral mosaic perfusion	Significant interval improvement; small residual clot right lateral basal segment
16	RV markedly dilated with mod-severe TR; RV pressure 94 mmHg	n/a	Occlusive clot RLL; patchy mosaic perfusion; dilated pulmonary arteries	n/a
17	RV markedly dilated with severe TR; RV pressure 62 mmHg	n/a	Abrupt tapering of vessels LLL; bilateral mosaic perfusion	n/a
18	RV moderate dilation and hypokinesis; RV pressure 82 mmHg	n/a	Bilateral mosaic perfusion	n/a
19	RV moderately dilated and hypokinetic; RV pressure 65 mmHg	n/a	Abrupt occlusion posterior basal segmental artery LLL and posterior basal artery on RLL; bilateral mosaic perfusion	n/a
20	RV mildly dilated and hypokinetic; RV pressure not estimated	n/a	Abrupt occlusion left pulmonary artery with tapered distal vessels	n/a
21	RV severely dilated and hypokinetic	n/a	n/a	

LLL Left lower lobe; n/a Not applicable; PA Pulmonary artery; RA right atrium; RLL Right lower lobe; RV right ventricle; TR Tricuspid regurgitation

DISCUSSION

The discovery that chronic mechanical obstruction because of chronic thromboembolic disease is a cause of pulmonary hypertension, and that this problem may be remedied surgically, has offered hope to patients with thromboembolic pulmonary hypertension. With new diagnostic techniques, such as spiral CT, refinements in surgical techniques and new forms of postoperative management of hypoxia with nitric oxide, the mortality rate is now comparable with other forms of open heart surgery. For clinicians to be able to diagnose this condition, a review of the pathophysiology, presenting symptoms, differential diagnosis and relevant diagnostic tests is indicated.

Pathophysiology: It is not known why most acute pulmonary emboli resolve and others do not. Although intuitively, abnormalities of the fibrinolytic system would be suspected as the cause, this theory remains controversial. One study found patients with persistent thrombus had decreased levels of plasminogen activators and increased concentrations of plasminogen activator inhibitors (17); however, in another study (18), the reverse was found. Other types of thrombophilias have been investigated as possible causes, including deficiencies of protein C, protein S and antithrombin III (10) as well as Factor V Leiden (19). Although these studies have

been small series, these conditions have not been found to be more prevalent in CTEPH patients.

The most common thrombophilic abnormality demonstrated in CTEPH is lupus anticoagulant, which is present in over 10% of patients (10). It is important to identify this subgroup, because over 50% of these patients will develop heparin-associated thrombocytopenia perioperatively (20). This condition will often necessitate modification of the surgical and postoperative management.

History and physical findings: Less than half the patients will have a history of either deep venous thrombosis or pulmonary embolism (5). Careful questioning of the patient may pick up suggestive events, such as a history of unexplained chest pain or a 'pulled muscle'. If there was a history of an acute pulmonary embolus, the patient may describe what is referred to as a 'honeymoon' period after the event, during which they were symptom-free for months to years. The etiology of the honeymoon period is not yet known; however, it is probably because of early changes in the small peripheral vascular bed of the perfused lung. It is only in later stages of the disease, when over 50% of the pulmonary vasculature has been occluded, that patients will develop symptoms (2,21,22).

When patients become symptomatic, the most common

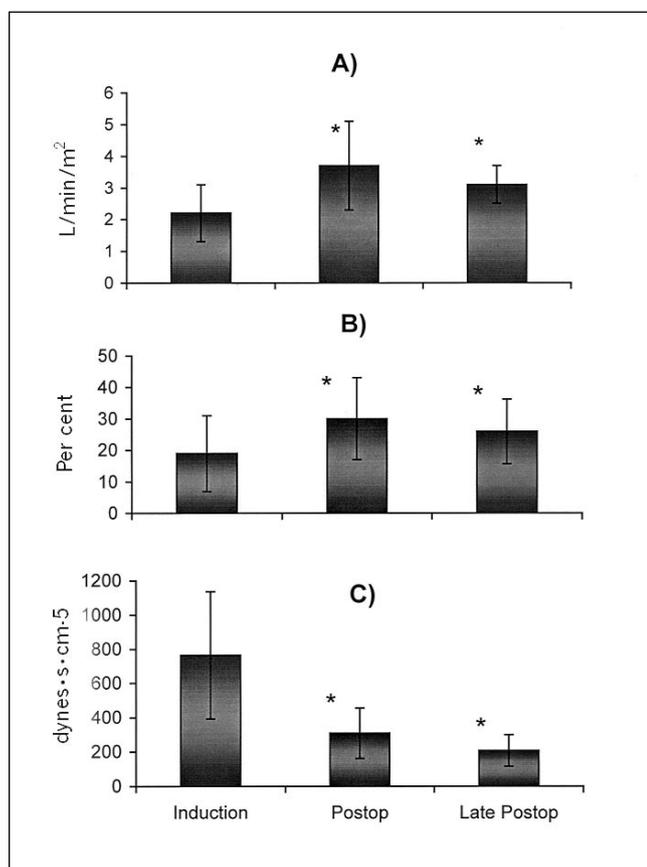


Figure 1 Cardiac index (A), right ventricular ejection fraction (B) and pulmonary vascular resistance (C) in patients undergoing pulmonary thromboendarterectomy for chronic thromboembolic pulmonary hypertension. Values collected at insertion of a Swan-Ganz catheter (Induction), before transfer to the intensive care unit postoperatively (Postop) and at the time of removal of the Swan-Ganz catheter in the intensive care unit (late postop). Values are mean \pm standard deviation; means in each group were compared using a two-tailed t-test to the baseline (Induction) mean. * $P < 0.05$

complaints are dyspnea and fatigue. Occasionally, patients may present with hemoptysis, cough, syncope and chest pain, with the latter because of outstripping of the blood supply by the hypertrophied right ventricle. The physical findings are typical of pulmonary hypertension from any cause, such as splitting of the second heart sound and accentuation of the pulmonary second sound. There may be signs of overt right ventricular failure, including right ventricular heave, a positive hepatojugular reflux, an elevated jugular venous pulse, prominent A and V waves, murmurs of tricuspid and pulmonic regurgitation, hepatomegaly, ascites and peripheral edema. A unique and characteristic physical finding of CTEPH (although not always present) is the presence of a flow murmur, particularly over the posterior lung fields (13). This is thought to be likely because of flow through stenotic pulmonary arteries or increased bronchial artery flow.

Differential diagnosis: Chronic thromboembolic pulmonary hypertension is a diagnostic challenge, because it must be differentiated from other causes of pulmonary

hypertension. A chest x-ray will help to identify chronic obstructive pulmonary disease and may suggest evidence of interstitial disease. In the early stage of CTEPH, the chest radiograph is often normal; later it shows an enlargement of the right ventricle and the pulmonary trunk. The electrocardiogram will help identify left ventricular disease. If pulmonary hypertension is the cause, the electrocardiogram may show evidence of right ventricular and atrial enlargement.

Pulmonary function tests will help distinguish CTEPH from respiratory causes. In CTEPH, the pulmonary function tests may show a slightly abnormal single-breath carbon monoxide diffusion capacity. A restrictive defect is seen in 20% of patients, and patients may have a mild obstructive defect on the basis of bronchial hyperemia. The resting arterial oxygen concentration (PO_2) is often normal, but significant desaturation with exercise is seen in virtually all patients. Finally, increased dead space ventilation with increased minute ventilation is seen, particularly in those with isolated unilateral pulmonary artery obstruction.

Echocardiography will not only identify cardiac disease, but is also an excellent noninvasive approach to assess pulmonary arterial disease. The presence of pulmonary hypertension is confirmed by using continuous wave Doppler to assess tricuspid regurgitation (23). Other findings may include right atrium and/or right ventricle enlargement (by M-mode) and flattening of the interventricular septum with possible paradoxical movement by two dimensional echocardiography. There may be visualization of the proximal thrombus in the main pulmonary artery or the right or left pulmonary artery. It was also demonstrated recently that an echocardiogram may be used to differentiate CTEPH from primary pulmonary hypertension (23). In CTEPH, the pulse pressure measured in the pulmonary artery is markedly greater than that found in primary pulmonary hypertension, consistent with the finding that the major occlusive site is more proximal than in primary pulmonary hypertension (24).

The most important test to differentiate patients with CTEPH from those with primary pulmonary hypertension is ventilation-perfusion scanning (25). In CTEPH, there are definite areas of ventilation-perfusion mismatch, whereas in primary pulmonary hypertension, the scan is either normal or there may be patchy or subsegmental changes.

Spiral CT is a new modality with the advantage of making it possible to image the entire lung and mediastinum within one breath hold. This permits maximum enhancement of the pulmonary vessels for data acquisition and minimization of breathing artefacts. CT scans can confirm the presence of thrombus, demonstrate the degree of chronicity of the process and assess the operability of the patients with CTEPH (26,27). Figure 2 shows the utility of this technique in the preoperative assessment of chronic disease and for documentation of resolution of the thrombus.

Once the diagnosis of CTEPH is established, and the patient is medically stable, he or she can be referred for surgical assessment. Further studies are completed at that time to confirm that the thrombotic occlusion is proximal enough to access surgically. The gold standard to confirm the diagnosis

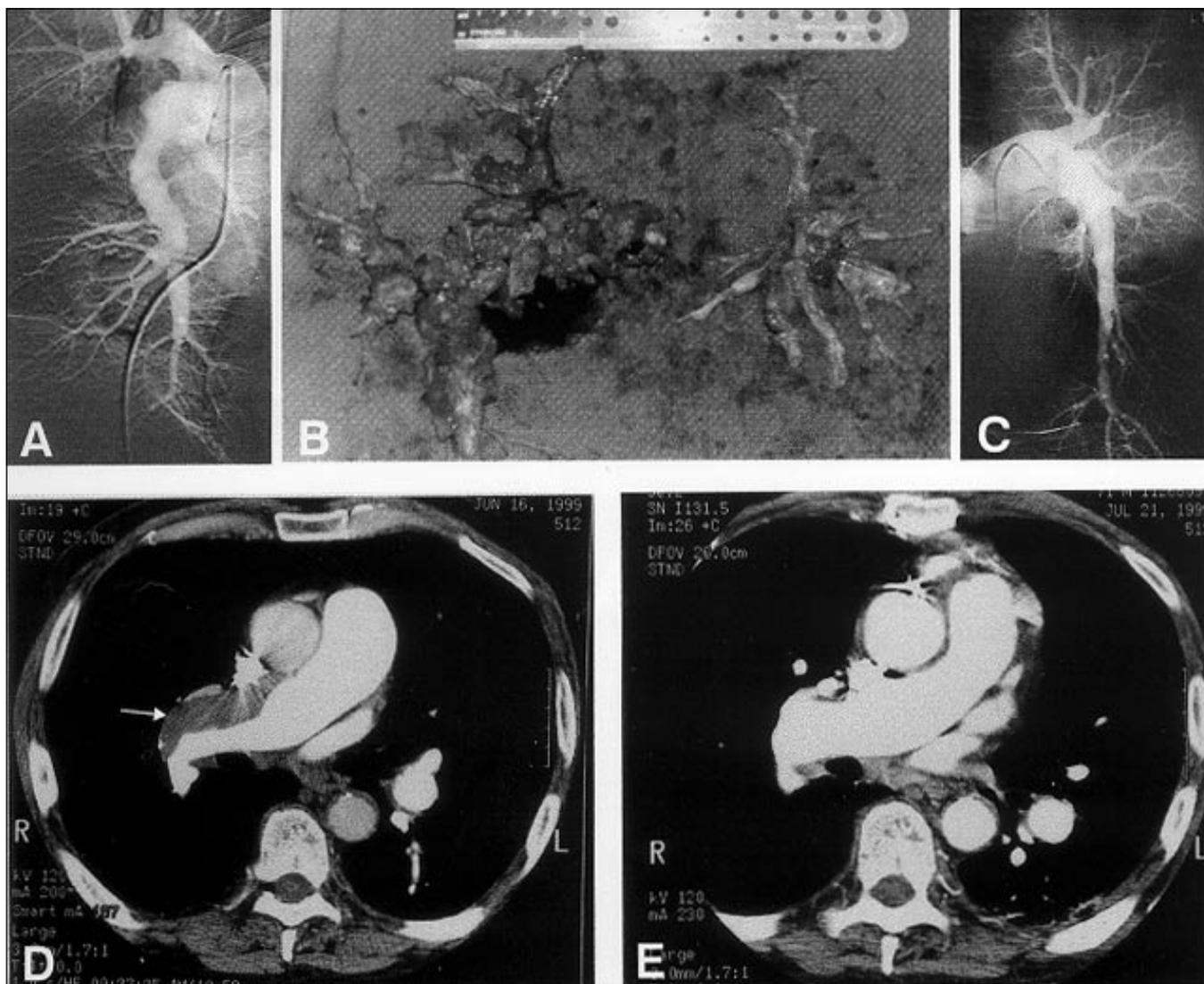


Figure 2) Radiological and pathological findings in a patient with chronic thromboembolic pulmonary hypertension. **A** Preoperative right pulmonary angiogram. **B** Resected surgical specimen. **C** Preoperative left pulmonary angiogram. **D** Preoperative spiral computed tomographic (CT) mediastinal windows demonstrating extensive intraluminal thrombus in the right main pulmonary artery (arrow). **E** Postoperative spiral CT mediastinal windows with normal right pulmonary artery

and to assess operability has been pulmonary angiography (21). A right heart catheterization is usually performed to confirm the diagnosis of pulmonary hypertension and to verify the level of the pulmonary vascular resistance. A pulmonary vascular resistance greater than 300 dynes-s-cm-5 usually confirms the indication for surgery. In patients who are candidates for surgical therapy are at risk for coronary artery disease, coronary angiography is also indicated.

Pulmonary thromboendarterectomy: The surgical procedure of pulmonary thromboendarterectomy is technically demanding. After surgery, the patients require intense monitoring for the early identification and prevention of complications. In our series, the perioperative mortality rate was comparable with that achieved in San Diego, the pioneer centre for this procedure (1,10). Nitric oxide was used liberally in our patients after surgery; this may have contributed to the positive results such as those documented by other groups

(28). Because of the small patient size and the nonrandomized nature of the use of this ventilation, we cannot confirm that this ventilation mode prevented mortality.

Reopening with delayed sternal closure occurred in three patients. We were not surprised by this outcome because two of these cases were reoperations with long operative times, and the other was a high risk case with preoperative jaundice and severe right heart failure. In each case, the hemodynamics of the patients were markedly aided by leaving the sternum open to minimize compression of the right ventricle, which was edematous and dysfunctional. All of these patients survived and their long term outcomes have been excellent.

Complications specifically associated with this procedure include postoperative pulmonary hypertension, reperfusion pulmonary edema, pulmonary artery steal and late cardiac tamponade (1,5). Pulmonary hypertension seemed to occur

to some degree in nearly all of the patients after surgery, and it is our impression that the degree of pulmonary hypertension was inversely related to the amount of chronic thromboembolus removed, an opinion shared by other authors (29). The pulmonary vascular resistance fell progressively after surgery, and follow-up echocardiograms at six to 12 months have demonstrated normalized pressures. Although radiological pulmonary edema was seen on the chest x-rays of some of the patients after surgery, it was not a major clinical problem except in the one patient who died. In this case, the respiratory insufficiency was irreversible and it cascaded into multiorgan failure.

Pulmonary arterial steal represents a postoperative redistribution of pulmonary arterial blood flow away from previously well-perfused segments and into the newly endarterectomized segments (30). This phenomenon is likely to be due to the development of a low resistance circuit in the endarterectomized bed and persistent high resistance in the nonoperated bed because of previous small vessel changes (1). In our series, we believe this factor was likely a more important contributor to the relatively long ventilatory times required, as opposed to the occurrence of reperfusion pulmonary edema.

Finally, only one patient developed a late tamponade. It is believed that the incidence of this complication has been limited by the use of routine prolonged pericardial drainage (1,5).

Other treatment options: Unlike many patients in end-stage heart failure, a heart transplant is not an option because the primary pathology rests in the pulmonary vasculature. Some authors believe that if the preoperative mean pulmonary artery pressure is too high (mean greater than 62.1 mmHg), these patients should undergo pulmonary transplantation (31). Heart-lung transplants are another option. However, the long term results with transplantation are poor because of the development of bronchiolitis obliterans in almost 50% of these patients after three years (32). Furthermore, the limited availability of donors and the extensive vascular intrapleural adhesions because of collateral flow to the lungs make transplantation an unattractive option.

CONCLUSIONS

Pulmonary thromboendarterectomy is not without risk; however, outcomes have improved markedly over the past two decades. The multidisciplinary program developed at the University of Ottawa has yielded excellent initial results; there has only been one death (4.8%) and most patients have experienced marked improvement in functional status. In patients with pulmonary hypertension because of CTEPH, careful diagnosis and appropriate surgical intervention will improve quality of life and it will avert premature mortality from this otherwise fatal disease.

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