Successful Surgical Intervention in Severe Chronic Thromboembolic Pulmonary Hypertension

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A 69-year-old man, in whom extensive embolic obstruction of the pulmonary arteries had likely been present for ten years, and who exhibited marked pulmonary hypertension and compromise of right ventricular function, was submitted to thromboendarterectomy. The course after surgery included extensive hemorrhagic infiltration of the reperused lung zones (predicted before operation), which required special management. Four months after surgery, reduction in pulmonary vascular resistance of almost 50 percent was demonstrated. The patient is improved and maintains normal activity more than two years after surgery. The patient demonstrates that, despite several negative features before operation, successful thromboendarterectomy is possible, if recent technical and conceptual advances are applied in a coordinated manner during all phases of management.

The era of heroic acute pulmonary embolectomy has essentially ended, phased out because of its unacceptable mortality and by demonstration that most pulmonary emboli resolve spontaneously.1-6 However, on occasion, emboli do not resolve. Rather, they are converted into amorphous or fibrotic deposits, which chronically obstruct pulmonary arteries. Why some emboli remain in situ instead of resolving is unclear; but the potential consequences are evident. If a sufficient portion of the pulmonary arterial cross-sectional area is obstructed, pulmonary hypertension and right ventricular failure will occur. In such patients, embolectomy (perhaps better termed “thromboendarterectomy”) is a potentially curative procedure.

Experience has indicated that the duration of the interval between embolic event and surgery does not condition success.7-12 One patient has been reported7 who was successfully operated on 15 months after the embolic episode, and others8-12 have reported similar results up to one year following embolism. However, previous experience did suggest that the presence of severe, sustained pulmonary hypertension was a relative contraindication to surgical intervention.12

This report describes a 69-year-old man in whom embolic obstruction had likely been present for ten years and who exhibited marked pulmonary hypertension and compromise of right ventricular function. Despite these negative features before surgery, thromboendarterectomy was successfully performed. The course after operation included extensive hemorrhagic infiltration of the reperused lung zones which was predicted before operation and required special management. The patient’s health is improved, and he maintains normal activity two years after surgery. The diagnostic, surgical and postsurgical problems encountered in this patient, and the approaches to them, may provide useful guidelines to others concerned with this difficult cardiopulmonary problem.

Case Report

The patient, a 67-year-old white man, was admitted to the University Hospital of San Diego County July 9, 1970. His

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Table 1—Arterial Blood Gas Values in Patient with Chronic Thromboembolic Pulmonary Hypertension*

<table>
<thead>
<tr>
<th></th>
<th>Before Operation</th>
<th>After Operation</th>
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<tbody>
<tr>
<td></td>
<td>3/69 Rest Exercise** 100% O2†</td>
<td>4/70 Rest Exercise** 100% O2†</td>
</tr>
<tr>
<td>Pao₂</td>
<td>62 56 412</td>
<td>59 54 320</td>
</tr>
<tr>
<td>Paco₂</td>
<td>34 32 37</td>
<td>32 32 34</td>
</tr>
<tr>
<td>pH</td>
<td>7.45 7.44 7.63</td>
<td>7.46 7.45 7.44</td>
</tr>
<tr>
<td>A-aDO₂</td>
<td>45 62 264</td>
<td>51 54 339</td>
</tr>
</tbody>
</table>

*Arterial oxygen tension (Pao₂), carbon dioxide tension (Paco₂) and alveoloarterial oxygen tension gradient (A-aDO₂) in mm Hg; pH in unit;
**no load** (leg raising exercise); ††10 minutes of bicycle ergometer exercise at 50 watt work load; values after 10 minutes of 100% oxygen breathing via mouthpiece with noseclip in place.

history dated to 1943 when “aching in the calves” during exercise first occurred, and bilateral varicose veins were noted. Over the next 11 years, he had multiple bilateral episodes of superficial phlebitis, for which he was treated with several sodium morrhuate injections.

In 1954 he had an episode of sudden, severe dyspnea with a diagnosis of a “slight heart attack.” Thereafter, he had significant dyspnea on exertion. In 1958, he was begun on warfarin therapy for venous thrombosis and remained on it thereafter, except for brief interruptions because of rectal bleeding. In 1960, he had an episode of left-sided “fibronous pleurisy,” etiology undetermined. Thereafter, he noted more severe dyspnea on exertion. In April, 1967, because of persistent dyspnea, a perfusion lung scan was performed which showed “markedly decreased perfusion in the right lower, right middle and left upper lung zones compatible with pulmonary embolism.” A chest x-ray film at this time disclosed “clear lung fields” and a “heart size at the upper limits of normal.” Results of spirometric studies in late 1967 were “normal.” An electrocardiogram showed “right axis deviation.” Because of severe exertional dyspnea, spirometric studies were repeated in March, 1969, and results were again normal. Arterial blood gas studies at this time revealed mild resting hypoxemia with a wide A-aO₂ gradient, which widened further during minimal exercise (Table 1). Electrocardiogram showed right axis deviation and right ventricular hypertrophy. Chest x-ray film disclosed cardiomegaly due to right atrial and ventricular enlargement; hyperperfusion of the right upper lobe with decreased vascular markings elsewhere in the right lung; large central pulmonary arterial shadows on the left, with decreased vascularity in the apical and basilar areas of the left lung. A perfusion lung scan (Fig 1) showed marked bilateral abnormalities similar to those reported in the 1967 scan.

His dyspnea continued to worsen. However, another lung scan in September, 1969, showed no change, nor did a chest roentgenogram in November (Fig 2). In April, 1970, his condition was evaluated at another hospital. Physical examination disclosed a well-developed man who was neither cyanotic nor dyspneic at rest but became quite dyspneic with minimal exertion. The blood pressure was 130/80 mm Hg; pulse rate, 92; respirations, 16. There was no clubbing. The jugular veins were dilated at 45° elevation and displayed prominent “a” waves. The chest expanded well and was clear to percussion and auscultation. A right ventricular lift and pulmonic valve closure were both palpable. There was wide, fixed splitting of the second sound, very loud pulmonic closure, and a fourth sound over the lower left precordium and xiphoid areas. There were no murmurs. Both lower extremities showed marked “brawny edema” and venous stasis changes below the knees.

A carefully taken history disclosed that, over the last several years, he had modified his activities to minimize symptoms, and that his symptoms had increased significantly during the prior year. Any brief period of exertion, even level walking, rapidly induced severe dyspnea and dizziness.

Another perfusion scan, chest x-ray film and electrocardiogram showed no interval change. Right and left heart catheterization disclosed a pulmonary arterial pressure of 115/35 (mean 56 mm Hg); mean right atrial pressure of 12 with an “a” wave of 19 mm Hg; right ventricular pressure of 113/16; normal “wedge” pressure (5 mm Hg); normal left ventricu-
lar end-diastolic pressure and a cardiac output of 3.7 liters/min. Calculated total pulmonary vascular resistance was 1206 dynes-seconds cm⁻⁵. Breathing 100 percent oxygen did not significantly alter these values.

Spirometric and arterial blood gas data were essentially unchanged from those of 1969 (Table 1). A pulmonary angiogram (Fig 3) was interpreted as showing massive dilatation of the left main pulmonary artery, with marked narrowing of the right main pulmonary artery believed due to thrombus lining the arterial wall. This thrombus appeared to extend into the sharply narrowed lower branch of the right pulmonary artery. The branch to the right upper lobe was markedly dilated and this lobe was hyperperfused. On the left there was virtually no flow to the upper lobe and flow to the lower lobe was decreased.

The patient was transferred to University Hospital for further evaluation and surgery. Ventilation/perfusion scintigraphy showed the pattern of pulmonary vascular obstruction, (ventilation without perfusion) to the right middle and lower lobes and left upper lobe. The left lung received slightly more than 60 percent of total pulmonary blood flow.

On July 14, 1970, a pulmonary thromboendarterectomy was performed, using cardiopulmonary bypass. Venous drainage was achieved with separate plastic cannulae placed in the superior and inferior vena cava through the right atrium. Arterial return was via the femoral artery. The right main pulmonary artery was approached through a right lateral thoracotomy and exposed by dissecting posteriorly between the superior vena cava and aorta. Externally, the pulmonary artery at this site was enlarged to 1½ inches in diameter. The artery was incised longitudinally from its bifurcation to the takeoff of the apical anterior branch, and its lumen was completely occluded by grayish thrombotic deposit. This rather friable material in the right main pulmonary artery fragmented during its removal with forceps and embolectomy spoons. On removing the proximal deposit, it was evident that the distal pulmonary artery below the apical branch was also completely occluded by similar material. This was removed by repeatedly passing long forceps into the dilated right pulmonary artery distal to the arteriotomy.

Thrombotic deposit also extended across the bifurcation into the left pulmonary artery. This was removed using large

**Figure 3.** Pulmonary angiogram before operation. Note massive dilatation of left main pulmonary artery and marked narrowing of right main pulmonary artery and its lower branch. Right upper lobe is hyperperfused.

**Figure 4.** Chest roentgenogram day after surgery shows extensive infiltration of reperfused lung zones.

Gallstone forceps. Thereafter, a balloon catheter was passed distally in both directions to make certain that there were no residual deposits, and the pulmonary artery was flushed with saline. Good back bleeding was evident from both pulmonary arteries. The pulmonary arteriotomy was closed with continuous 4-0 Tefdek sutures and the patient was removed from cardiopulmonary bypass, with the aid of some vasopressor therapy. The chest was closed, and an elective tracheostomy was performed.

It had been predicted before surgery that restoration of blood flow to areas of vascular bed which had long been nonperfused might result in hemorrhagic pulmonary edema. This indeed did develop in the right middle and lower lobes within hours after surgery (Fig 4). Associated with this complication was a profound widening of the alveolo-arterial oxygen tension gradient so that, even with 100 percent oxygen via a volume ventilator, the Pao₂ hovered about 60 mm Hg. Two special maneuvers were adopted to deal with this problem. First, moderate end-expiratory pressure was maintained, which led to substantial elevations of Pao₂ at any given fraction of inspired concentration of oxygen (FIO₂) (4-5 cm end-expiratory pressure was ineffective, 8-9 cm, highly effective in improving arterial Pao₂). The other maneuver was to alter the patient’s position. The Pao₂ at any given FIO₂ improved dramatically when the left hemithorax was dependent; decreased with the patient in the supine position; and decreased further when the right hemithorax was dependent.

The maneuvers maintained Pao₂ above 50 mm Hg and by the fifth day after surgery, this Pao₂ could be achieved with FIO₂ of 40-50 percent. The Paco₂ consistently remained at 40 mm Hg or below. Attempts to interrupt assisted ventilation were unsuccessful, being associated not only with marked hypoxemia but also onset of supraventricular tachycardia which required cardioversion on three occasions. Heparin therapy was resumed on the fifth day after operation.

On July 31, 1970 (17 days after operation), while still on the ventilator, a perfusion lung scan was performed, which
showed good perfusion to the still heavily-infiltrated right middle and lower lung fields; decreased flow to the previously hyperperfused right upper lobe, and rather uniform perfusion throughout the left lung (Fig 5).

On Aug 5, 1970, it was possible to remove the patient from the ventilator at intervals, using a bag-system which contained 100 percent oxygen and maintained an end-expiratory pressure of 6-9 cm H₂O. By Aug 16, 1970, he could sustain a Pao₂ >60 mm Hg with this maneuver for 45 minutes out of every two hours, and his chest x-ray film showed substantial clearing of the right lung infiltration. By Aug 27, 1970 (six weeks after surgery) it was possible to discontinue both assisted ventilation and positive end-expiratory pressure. On Aug 31, 1970, the tracheostomy was removed. The remainder of his hospital course was devoted to physical reconditioning and a transition from heparin to warfarin therapy. On Sept 16, 1970, the patient showed a Paco₂ (supine, room air) of 48 mm Hg; Paco₂, 35 mm Hg; pH, 7.48. Modest supine exercise for four minutes led to a Paco₂ of 43 mm Hg; Paco₂ of mm Hg 28; and pH of 7.48. At 2 liters/min of 100 percent O₂ at rest, the Pao₂ was 55 mm Hg. The patient was discharged on Sept 18, 1970, using an oxygen "walker" (2 liters/min at rest, 4 liters/min on exertion) and on digitalis and quinidine therapy. At discharge, fixed splitting of the second sound was absent, pulmonary closure was no longer palpable and "a" waves were no longer visible in the jugular venous pulse.

The histopathologic report revealed that the fragmented thrombus consisted chiefly of acellular material greatly resembling that seen in atherosclerosis of the large arteries (Fig 6). There was minimal evidence of organization. Sections of atrial appendage removed at operation showed organizing thrombosis.

After discharge, the patient's steady improvement continued. By Sept 28, 1970, supplementary oxygen at rest was discontinued. In late October, Pao₂ at rest on room air was 54 mm Hg and after 10 minutes of light exercise it was 51 mm Hg, with normal Paco₂. Administration of supplementary oxygen was entirely discontinued. He was able to carry on gardening and light repair work, which had not been possible before surgery.

In late November, 1970, he was admitted for re-evaluation. Examination disclosed clear lungs except for residual dullness and decreased breath sounds at the right base. Cardiac examination disclosed a barely palpable right ventricular lift. P$_2$ was not palpable and, on auscultation, P$_2$ was slightly accentuated. Cardiac catheterization disclosed a resting pulmonary arterial pressure of 83/29 mm Hg (mean 45), right ventricular pressure of 88/13 mm Hg, mean right atrial pressure of 10 mm Hg with a 13 mm "a" wave, a normal "wedge" pressure (11 mm Hg) and a cardiac output of 5.62 liters/mm. One hundred percent oxygen breathing did not significantly alter these values. Calculated total pulmonary vascular resistance was 640 dynes/sec cm$^{-5}$ during room air breathing: approximately half of the value before operation. Pulmonary angiography (Fig 7) disclosed that the distal right main pulmonary artery was patent, with good flow to all zones of the right lung. Flow to the left middle and lower lobes was excellent; that to the left upper lobe, decreased. Results of arterial blood gas studies disclosed moderate resting hypoxemia, which was slightly exaggerated during mild exercise. The Pao₂ rose to 351 mm Hg during 100 percent oxygen breathing. Ventilation/perfusion scintigraphy showed uniform ventilation and perfusion throughout both lung fields, except in the left upper lobe where perfusion remained decreased. Persistent elevation of the right hemidiaphragm accounted for a "small" right lung on both the V

Figure 7. Pulmonary angiogram four months after surgery. Note size of right main pulmonary artery and its branches as contrasted to Figure 3. Right hemidiaphragm is still elevated.

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Figure 8. Anterior ventilation and perfusion scintiphotographs 22 months after surgery. Right lung now appears normally perfused. Left upper lobe remains poorly perfused, as before surgery.

and Q scans.

The patient’s progress since that time has been excellent. During 1971, he resumed full activity, limited only by leg pain due to venous insufficiency. In May, 1972, his ECG showed rotation of the QRS axis to a vertical position; his V/Q scintiphotography showed uniform distribution of perfusion to all lung zones except the left upper lobe which remained, as before surgery, essentially nonperfused (Fig 8). The arterial blood gas levels (Table 1) showed significantly less hypoxemia during a 50-watt period of exercise than before operation during “no load” exercise. Anticoagulant therapy is being maintained. Repeated cardiac catheterization is not contemplated at this time.

DISCUSSION

The diagnosis and management of this patient included application of a variety of recent conceptual and technical advances. Furthermore, careful planning and interdisciplinary coordination marked each phase of his course. Four such phases are of interest: presurgical; surgical; hospital postsurgical course; outpatient, postsurgical course.

Pre-Surgical Considerations

The first objective in this phase was diagnosis; the second, a decision regarding surgery. The historic, clinical and laboratory features of cor pulmonale due to chronic thrombotic obstruction of the major pulmonary arteries have been well described elsewhere. This patient had all of them, when comprehensive data regarding his illness were finally assembled from multiple sources. He had a history of phlebitis and of pulmonary embolism, chest roentgenographic findings compatible with this diagnosis, and the physical and electrocardiographic findings of right ventricular hypertrophy and pulmonary hypertension. And, perhaps, the most striking clue was the history of longterm, severe dyspnea on exertion, despite spirometric values that were essentially normal. Such dyspnea is characteristic in massive thrombotic occlusion because of the marked ventilation/perfusion disturbances in these patients, particularly the extensive amount of obligatory “wasted ventilation,” which occurs in ventilated but nonperfused areas of the lungs. Finally, a perfusion lung scan had strongly suggested the diagnosis more than three years prior to surgery.

From the available data, it was concluded that chronic thrombotic obstruction of some degree dated back at least 16 years (to his “heart attack” in 1954), because he had had dyspnea on exertion since that time, and that another embolic event had occurred in 1960, ten years before surgery, because this episode of “left-side pleurisy” left him with marked, persistent dyspnea. The first reported electrocardiogram, in 1966, showed “incomplete right bundle branch block,” and the report of the first perfusion scan in 1967 suggests that the findings were identical to those in the scans of 1969 and 1970.

This history further suggested that, after nine years of relatively stable dyspnea on exertion, his disability increased during the year before surgery. Virtually identical perfusion scans in March, 1969, in February, April and July of 1970, suggest this increased disability was not due to additional emboli. It was concluded that his severely compromised pulmonary vascular bed, subjected to prolonged high pressure and flow, probably had undergone accelerated anatomic change during this period. The appearance of dizziness on exertion and greater exercise limitation suggests that the limited “open” vascular bed was becoming further compromised.

Thus, it was proposed before operation that this patient had a “two compartment” pulmonary vascular bed: the “open” pulmonary arteries which probably had advanced changes of pulmonary hypertension; and the “closed” vascular bed which had never been subjected to high pressures and therefore had retained normal structure. Faced with such a “two-compartment” vascular bed, we anticipated that exposure of the “normal” vasculature to sudden reinfusion of blood under high pressure might induce acute hemorrhagic edema. This complication has been reported after embolectomy in man, indeed, in one instance, it was observed at the operating table immediately after embolus removal. A similar sequence has been observed in animals in which normal pulmonary arteries are subjected to perfusion with blood under high pressure. Such animals develop an acute hemorrhagic vasculitis. Anticipation of this problem was a major factor in the decision for elective tracheostomy.

The ventilation/perfusion scintiphotographs identified clearly that the nonperfused zones were nor-
mally ventilated and had not undergone some form of degenerative change. This also suggested good bronchial arterial flow and the likelihood that smaller branches of the pulmonary arteries were patent.

In assessing the patients' operability, the pulmonary angiogram was, of course, crucial. Chronic thrombi are subject to removal only when they are in the main and lobar pulmonary artery branches. The appearance of the right main pulmonary artery and its inferior branch was quite unusual. Their small size angiographically, along with severe pulmonary hypertension, led to the conclusion that these structures were narrowed by substantial thrombus, thus making the patient an acceptable candidate for surgery, from the anatomic point of view.

**Surgical Considerations**

While the patient had bilateral thrombotic disease, it was decided to perform the operation through a unilateral right thoracotomy rather than through a bilateral approach, because it was believed that the ventilatory problems associated with bilateral thoracotomy would be undesirable. The right side was chosen, since perfusion scans disclosed that the left lung was accepting almost 65 percent of the total pulmonary blood flow.

His data before operation also suggested that elective use of a heart-lung machine was advisable. A closed approach would have required temporary obstruction of the right pulmonary artery, which would have further impaired respiratory gas exchange and, additionally, would have transiently augmented his already severe pulmonary hypertension. Lastly, bypass permitted adequate exploration of both pulmonary arteries simultaneously through the right-sided arteriotomy. This was facilitated at operation by the enormous dilation found in these vessels.

One important surgical point in the literature was reconfirmed in this patient: namely, palpation of the pulmonary arteries is an unreliable indicator of the presence or absence of an intraluminal clot in the presence of severe pulmonary hypertension. It was impossible to determine if there was intraluminal clot simply by palpation of the pulmonary arteries in the patient at the time of surgery. Clearly, it is essential to actually open the vessel whenever the diagnostic studies before operation strongly suggest the presence of an intraluminal obstructing lesion in a pulmonary artery. Even after the complete removal of the thromboembolic deposit from the pulmonary artery and its closure, this vessel remained extremely tense. The presence of calcific deposits in the vessel wall probably contributed to this finding.

Other authors also have emphasized that one cause of morbidity and mortality after surgery in these patients is the hemorrhage incurred when the dense pleural adhesions often present are interrupted during the dissection necessary to expose the pulmonary arteries through a conventional lateral thoracotomy approach. As demonstrated in our case, this problem can be completely avoided by choosing a mode of exposure which permits intrapericardial dissection of the main right pulmonary artery in the groove between the aorta and the superior vena cava. By freeing the superior vena cava and aorta posteriorly, both vessels can be retracted, providing ample room for a generous pulmonary arteriotomy. The enormous dilatation of the pulmonary arteries which was evident in this particular patient also facilitated use of this approach and made simultaneous removal of thromboembolic deposits from both pulmonary arteries feasible through the arteriotomy in the right main pulmonary artery.

A final question relates to the ability of the surgeon to remove thrombotic material which has been present in the pulmonary arteries for months or years. Relatively few patients have been reported who have undergone successful removal of a thrombus known to have been present for several years or more. Thus, the chronicity of the thromboembolism in this patient, ie, ten years or more, provides particularly impressive confirmation of both the ability to remove such material and to achieve longterm patency at operation. Of particular note was the relative ease with which this material could be removed at the time of operation, not only from the larger proximal, but from the smaller distal branches as well. On histologic examination there was no evidence of fibroblastic infiltration of the material which, in fact, was so friable that it could not be removed as a single cast. However, neither the fact that the thrombotic material had to be removed piecemeal, nor the fact that an ideal cleavage plane could not be developed between clot and intima, impaired the ability to remove it in its entirety. The subsequent angiographic evidence of patency suggests that healing was satisfactory, despite the traumatized endothelial surface initially present.

**Postsurgical Considerations / In Hospital**

The course of this patient was complex after operation, including six weeks of assisted ventilation. The most serious problem was the "pulmonary edema, which appeared in the areas of prior occlu-
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