Angioscopic video-assisted pulmonary endarterectomy for post-embolic pulmonary hypertension

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Abstract

Objectives: To assess whether the use of video-assisted angioscopy would increase the outcome of pulmonary thromboendarterectomy (PTE).

Methods: PTE included a median sternotomy, intrapericardial dissection of the superior vena cava, institution of cardiopulmonary bypass, deep hypothermia and sequential circulatory arrest periods. It was always performed through two separate arteriotomies on both main intrapericardial pulmonary arteries, into which a rigid 5 mm angioscope connected to a video camera was introduced to increase the visibility and endarterectomies.

Results: From January 1996 to July 1998, 68 consecutive patients (35 males and 33 females) aged 54 ± 13.5 years underwent PTE. Patients were in New York Heart Association (NYHA) class II (n = 2), III (n = 43) or IV (n = 23) with the following hemodynamics: mean pulmonary arterial pressure (PAP) 54 ± 13 mmHg; cardiac output (CO): 3.8 ± 0.8 l/min, and total pulmonary resistance (TPR): 1207 ± 416 dynes·cm⁻²·s⁻¹. The cumulated circulatory arrest time was 23 ± 12 min and postoperative length of ventilatory support 10 ± 12 days. Nine patients died, for an overall in-hospital mortality of 13.2%. The functional outcome in surviving patients was significantly improved (P < 0.0001) both clinically (NYHA class 3 ± 0.5 vs. 1 ± 0.6) and hemodynamically (PAP (mmHg) 53.1 ± 13 vs. 30.2 ± 11.8, CI (l/min per m²) 2.1 ± 0.5 vs. 2.8 ± 0.6, TPR (dyne·s·cm⁻²) 1174 ± 416 vs. 519 ± 250). Conclusions: Video-assisted angioscopy improves the quality and degree of pulmonary endarterectomy expanding the indications to include patients with previously inaccessible distal disease. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Pulmonary thromboendarterectomy; Pulmonary hypertension; Chronic thromboembolic pulmonary disease; Videoangioscopy

1. Introduction

Chronic thromboembolic pulmonary hypertension (CTEPH) is curable by pulmonary thromboendarterectomy (PTE) [1–4]. Many improvements have been reported over the last 20 years regarding patients’ criteria selection, operative strategy, technical details and postoperative care. Unfortunately, this procedure is still associated with a high mortality rate in distally located obstructions with hemodynamically severe disease, and this is mainly linked to the unrelieved pulmonary hypertension related to insufficient relief of distal obstruction [3].

To test the hypothesis that the use of video-assisted angioscopy (VAA) would increase the quality of PTE and improve outcome, we describe an original technique of VAA PTE and report the results achieved in a series of 68 consecutive patients endarterectomized over a 31-month period.

2. Methods

Sixty-eight consecutive patients with CTEPH (33 women
and 35 men; mean age, 54.3 ± 13.5 years) were operated since the institution of VAA in pulmonary thromboendarterectomy in January 1996.

2.1. Preoperative evaluation

All patients underwent right heart catheterization using a Swan Ganz catheter with measurement at rest of the right atrial pressure, right ventricular pressure, pulmonary artery pressure (PAP), pulmonary capillary wedge pressure and the cardiac output (CO). Total pulmonary resistance (TPR) was assessed as follows:

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TPR = \frac{\text{mean pulmonary arterial pressure (mmHg)} \times 80}{\text{cardiac output (l/min)}}
\]

The surgical accessibility of the obstructing thrombotic lesions was defined on bilateral and selective pulmonary angiography and a computed tomography scan. Coronary angiography was performed only in patients with a previous history of thoracic pain.

2.2. Additional cardiac surgery

Closure of an atrial septal defect or persistent foramen ovale was performed in five patients and aortic valve replacement in one. Tricuspid regurgitation has never been operated since it is considered as a functional consequence of right ventricle dilation which is supposed to resolve spontaneously after successful PTE.

2.3. Surgical technique

All patients were operated on with a standardized technique [3–5]. After median sternotomy and extrapleural pericardotomy, a cardiopulmonary bypass was instituted between both venae cavae and the ascending aorta. The patient was cooled and as soon as the heart fibrillated, a left ventricular vent was inserted through the left atrial appendage to avoid over distension of the left ventricle due to the backbleeding from the systemic circulation. During cooling, the superior vena cava was dissected up to the innominate vein without dividing the azygos vein, and care was paid to avoid injury of the right phrenic nerve.

The right pulmonary artery was not dissected free, but the right atrium and roof of the left atrium were totally separated from it in order to fully mobilize the superior vena cava from the right pulmonary.

On the left, dissection consisted of the separation of the ascending aorta from the pulmonary artery, division of the arteriosus ligament and encirclement of the main pulmonary artery trunk as well as the origin of the right pulmonary artery to tape and occlude them during the endarterectomy procedure on both sides. When the patient’s temperature reached 20°C, the ascending aorta was cross-clamped and cold crystalloid cardioplegic solution was administered through the aortic root with an additional dose being administered every 30 min. A longitudinal incision was made on the anterior aspect of the right pulmonary artery, extending from beneath the ascending aorta out under the superior vena cava to the take-off of the middle lobe artery. The video camera, connected to a rigid angioscope 5 mm in diameter, was placed into the lumen of the artery and mobilized by one of the assistant surgeons. The endarterectomy plane was raised posteriorly, the dissection of the first mediastinal artery and its different branches was done first, after which the remainder of the right side was progressively endarterctomized up to segmental branches of the lower lobe. As soon as the intravascular dissection was faced with backbleeding from the bronchial arteries, circulatory arrest was instituted. At completion of the right endarterectomy, reperfusion was carried out and arteriotomy closed. On the left side, the arteriotomy was made from the origin of the main trunk up to 1 cm from the take-off of the first branch. The same procedure as on the right side was performed. After conventional deairing and ascending aorta clamping off, the patient was re-warmed and weaned from cardiopulmonary bypass at 37°C.

The mean cardiopulmonary bypass time was 237 ± 35 min and cumulated circulatory arrest time 23 ± 12 min.

2.4. Postoperative evaluation

All patients had intravenous heparin instituted 2 h after the operation. Warfarin sodium therapy was established before hospital discharge with international normalized ratio, 2.5:3.5, and continued indefinitely. A clinical and hemodynamical reassessment was performed in all survivors at 3 months and every year thereafter.

2.5. Statistics

Values were expressed as mean ± standard deviation and comparisons made using non-parametric tests.
3. Results

3.1. Preoperative patient data

Preoperatively, 23 patients were in New York Heart Association (NYHA) functional class IV, 43 in class III, and two in class II. The overall mean PAP was 54 ± 13 mmHg, the CO 3.8 ± 0.8 l/min and cardiac index (CI) was 2.1 ± 0.5 l/min per m². Mean TPR was 1207 ± 416 dyne·s·cm⁻⁵. Mean venous oxygen saturation (SVO₂) was 54 ± 9%. An inferior vena cava filter was placed in 14 patients before operation. The mean interval between onset of pulmonary hypertension symptoms and operation was 47 ± 43 months (range, 1–278 months). Forty-three patients (63%) had a previous history of pulmonary embolism and 30 patients (44%) of deep venous thrombosis. In 12 patients (18%), the pulmonary thromboembolic disease was revealed by dyspnea on exertion, associated with syncope on exertion (n = 6), paradoxical systemic embolism (n = 3), hemoptysis (n = 2) and thoracic pain (n = 1). Two patients underwent an unsuccessful pulmonary thromboendarterectomy before referral.

3.2. Survival

The overall operative mortality was 13% (Table 1). There were four intraoperative deaths, three of them were related to high residual PAP preventing weaning from cardiopulmonary bypass, and one was due to massive alveolar hemorrhage consecutive to a distal tear of the artery wall. Five patients died during the postoperative course due to a severe reperfusion pulmonary edema, despite a good repermeabilization (n = 2), to incomplete repermeabilization responsible of persistent pulmonary hypertension (n = 2) and to tamponade after discharge of the hospital (n = 1). Fig. 1 shows the operative mortality according to TPR levels (300 dyne·s·cm⁻⁵ increments).

3.3. Postoperative morbidity

In survivors, a reperfusion edema occurred in 23 cases (39%) resulting in prolonged (>3 days) mechanical ventilation with a high positive end-expiratory pressure. The mean length of overall ventilatory support was 10 ± 12 days. Twenty-one patients (36%) presented a severe reperfusion edema and were ventilated for more than 10 days. The other complications are represented in Table 1. Three patients presented 1 week after a successful pulmonary thromboendarterectomy hemoptysis that was successfully managed by bronchial artery embolization (Fig. 2). Among two patients...
who developed postoperative rethrombosis of the pulmonary arterial bed, one was successfully treated with fibrinolytic agents.

3.4. Functional outcome

Fifty-six (82%) patients had a marked improvement of their symptoms compared with their preoperative status, and three patients were not improved by the operation, remaining in a NYHA class III postoperatively (Fig. 3). Oxygen treatment was necessary in 26 patients (38%) preoperatively but only three patients needed oxygen therapy at the time of reassessment. Mean arterial oxygen tension under room-air conditions was significantly higher at follow-up compared with preoperative values (64 ± 10 mmHg vs. 90 ± 50 mmHg, P < 0.01). Postoperative reassessment at 3 months (Table 2) shows a decrease in mean PAP when compared to preoperative values (53.1 ± 13.0 mmHg vs. 30.2 ± 11.8 mmHg, P < 0.0001). Also, CO and CI were significantly increased (3.8 ± 0.9 l/min vs. 5.0 ± 1.3 l/min, P < 0.0001) and (2.1 ± 0.5 l/min per m² vs. 2.8 ± 0.6 l/min per m², P < 0.0001), respectively. SVO₂ increased significantly when reassessed postoperatively (preoperative: 55 ± 8%; postoperative: 63 ± 9%, P < 0.01). Mean TPR values were decreased when compared with preoperative values (1174 ± 416 dyne·s·cm⁻⁵ vs. 519 ± 250 dyne·s·cm⁻⁵, P < 0.0001).

4. Discussion

Chronic thromboembolic pulmonary hypertension is curable by pulmonary thromboendarterectomy following the different reports of the group of the University of California at San Diego [1–5]. Because of the related morbidity and mortality, this operation is, however, still performed with success only at a few centers worldwide. The main cause of intraoperative mortality is failure to remove sufficient chronic thromboembolic material to lower pulmonary vascular resistance, especially in patients with severe pulmonary hypertension and right ventricular dysfunction. Our own prime experience of pulmonary endarterectomy before introduction of VAA also resulted in an absence of mortality in patients with TPR lower than 900 dyne·s·cm⁻⁵ and a 35% mortality rate in patients showing TPR higher than 900 dyne·s·cm⁻⁵. We hypothesized that, by using a video camera connected to a rigid angioscope, the endarterectomy procedure might be easier and more complete.

The first advantage of the video assistance is the light brought into the lumen of the pulmonary arteries, which considerably increases the visibility and consequently the quality of the procedure. Video assistance converts a confidential procedure for the surgeon into a more conventional procedure, making possible the participation of every operative team member. The co-surgeon can help the principal surgeon in holding a spatula and spreading the outer layer of the wall of the artery from the endarterectomy specimen and then facilitating the endarterectomy procedure.

Second, using video assistance, pulmonary thromboendarterectomy becomes a true endovascular procedure requiring a short and strictly intrapericardial pulmonary arteriotomy, without needing extension beyond the pericardial reflection. The pulmonary arteriotomy on the right side is stopped before the take-off of the middle lobe artery, and on the left side it is made from the main pulmonary trunk up to 1 cm from the take-off of the first left upper lobe branch. This concept of short and proximal arteriotomies avoids difficulties of closing the distal part of arteriotomies and the risk of extensive tearing of the arteries.

Third, video-assisted endarterectomy facilitates access to the distal branches of the pulmonary arterial tree and makes relief of obstruction of the lower lobes easier and more complete, especially on the left. Thus, based on our experience, video assistance seems indispensable in performing maximal endarterectomy so that the maximum decrease in TPR could be anticipated. By accepting the concept of an endovascular procedure, the operation can be greatly facilitated and the endarterectomy can relieve more obstruction. The results achieved are very satisfactory since, to our

<table>
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<th>Measurement</th>
<th>Preoperative</th>
<th>Postoperative 3 months</th>
<th>P</th>
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<tr>
<td>PAP (mmHg)</td>
<td>53.1 ± 13</td>
<td>30.2 ± 11.8</td>
<td>&lt;0.0001</td>
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<tr>
<td>CI (l/min per m²)</td>
<td>2.1 ± 0.5</td>
<td>2.8 ± 0.6</td>
<td>&lt;0.0001</td>
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<td>CO (l/min)</td>
<td>3.8 ± 0.9</td>
<td>5.0 ± 1.3</td>
<td>&lt;0.0001</td>
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<td>SVO₂ (%)</td>
<td>55 ± 8</td>
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<td>TPR (dyne·s·cm⁻⁵)</td>
<td>1174 ± 416</td>
<td>519 ± 250</td>
<td>&lt;0.0001</td>
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*PAP, pulmonary artery pressure; CI, cardiac index; CO, cardiac output; SVO₂, venous oxygen saturation; TPR, calculated total pulmonary resistance. Data are expressed as mean ± standard deviation.
knowledge, a series of patients with such an elevated PVR has never been published. Hartz et al. [6] reported a series of 34 patients with a mean PVR of 1094 ± 116 dyne·s·cm⁻⁵ operated on with a 23% operative mortality and from an analysis of the predictors of mortality, they concluded that a PVR higher than 1100 dyne·s·cm⁻⁵ predicted a 41% rate of mortality. Jamieson in the discussion of this same article [6], reports a 12.6% mortality rate in a group of patients with a PVR higher than 1100 dyne·s·cm⁻⁵ compared with 5% in those with a lower resistance.

In some instances, the disease starts distally at the origin of the segmental vessels making the procedure fastidious and particularly difficult since the obstruction is too distal and macroscopically inaccessible. These patterns unavoidably resulted in intraoperative or postoperative death. In accordance with Jamieson [7], we believe that some of these failures are related to a misdiagnosis. These patients have, in fact, initially a primary pulmonary hypertension which along the time complicated with thrombosis and resulted in obstruction of segmental or subsegmental vessels and/or thickening of the artery wall. These considerations underline, once again, the difficulty in preoperative assessment of these patients and the lack of a firm criteria to determine patients’ operability. Among the different postoperative complications encountered, we would like to emphasize the frequent need for long ventilatory assistance, probably related to: (1) pulmonary edema which seems more frequent in very severe disease; (2) right phrenic nerve palsy due to surgical injury or right internal jugular vein catheterization; (3) infectious pneumopathy; and (4) alveolar hemorrhage. Bronchial bleeding which occurred three times intra or postoperatively under efficient anticoagulation was systematically investigated by bronchial arteriography and successfully treated by bronchial artery embolization.

In conclusion, video angioscopic assistance has been a breakthrough in our experience of pulmonary endarterectomy for postembolic pulmonary hypertension, because it permits a much improved quality and degree of pulmonary endarterectomy. This expands the indications of this surgical procedure to include patients with previously inaccessible distal disease associated with severe pulmonary hypertension.

References


Appendix A. Conference discussion

Dr U. von Oppell (Cape Town, South Africa): As you have pointed out, a good outcome is related to patient selection. How do you select your patients, especially young women with significant pulmonary hypertension, and who do not have gross abnormalities on pulmonary angiography.

Dr Dartevelle: It’s a major problem. The selection of patients is very difficult. But with experience, and especially with this experience with video assistance, we can go very far. And I think that our failures in this series are essentially due to misdiagnosis, because some of the patients were, in fact, primary pulmonary hypertension with some thrombus. But it’s very difficult. We have not in this experience the routine use of preoperative angiography as they do in San Diego. I think that the use of endobronchial echography of the pulmonary vessels could be of interest. And it’s probably the future to assess the operability of these patients. But with the video assistance it is possible sometimes to start the endarterectomy plane just at the origin of the segmental vessel obstructed. I think that with this video assistance it’s possible to go farther than it was possible without video assistance, but it remains a difficult procedure.

Dr W. Klepetko (Vienna, Austria): Since you are looking further into the distal segments, do you think that you’re willing to take a higher risk in the dissection with that method as compared to the conventional method? In your two cases of alveolar hemorrhage, do you think that it is possible that you lost the correct plane and went into the parenchyma?

Dr Dartevelle: Your second question is interesting. In this series there is no hemorrhage from a bad plane, because we catch the plane with video assistance, we can go very far. And I think that our failures in this experience. But the hemorrhages we had were postoperative, sometimes 5 or 10 days after the procedure, and they are related to the highly developed collateral circulation. What was your first question? I don’t remember actually.

Dr Klepetko: I think you covered it already with this answer.

Dr Wolner: He asked the question whether you want to take a higher risk than with the conventional method.

Dr Dartevelle: I think this operation is at high risk, and we can go farther. Sometimes there are very few things on angiography and it’s with high vascular resistance and it’s possible to operate on these patients if we accept some risk.

Dr O. Oto (Izmir, Turkey): I just wondered about the quality of life at the long-term period, with the postoperative period, and have you compared it with just giving them medical therapy?

Dr Dartevelle: I think it’s very different. Because when we look at patients, we have not accepted to operate on them because we have considered that the obstruction was too distal and it was impossible. These patients died very quickly. Because when the pulmonary vascular resistance is as high as I showed, these patients have a very short life in front of them and often they die. And I think that the life of the patients who were endarterectomized is excellent, except for the three patients who stayed in stage III, and it was because it was impossible to endarterectomize these patients. These patients now are referred on a waiting list for transplantations.

Dr M. Turina (Zurich, Switzerland): Dr Dartevelle, congratulations on excellent results and a very courageous approach. You are going further than most of us would do. You are doing a very, very distal endarterectomy. Extrapolating from the results of the small vessel endarterectomy in the
coronary arteries, you are bound to get some problems of the intimal hyperplasia and smooth muscle cell hypertrophy later on. So my question is, do you have the data about your patients 3–5 years later, e.g. the echocardiographic pressures of the right ventricle, and does the pulmonary artery pressure stay low or do you have cases which continue to progress with the pressure?

Dr Dartevelle: When we look at the pulmonary vascular resistances late, they continue to decrease. Often the postoperative pulmonary artery pressure is higher than it will be 3 months or 1 year after, because probably the flow in the non-obstructed pulmonary artery is too important before endarterectomy. After endarterectomy, you still have the syndrome. All the flow passes into the arteries which are endarterectomized and there is nothing in the other arteries.