SECTION ON
CARDIOVASCULAR DISEASES

Pulmonary Function in the Selection of Patients for Open Heart Surgery*

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Open-heart surgery provides new and definitive operations. The complicated relationship of pulmonary function to heart disease and to previous thoracotomy imposes new obligations in assessing pulmonary function if further surgery is contemplated. If either initial or reoperation is destined to failure because of coexisting and irreversible lung destruction, it is important to know it.

A retrospective look at some of our successes and failures demonstrated some fallacies in our preoperative evaluation. The purpose of this discussion is to relate these experiences and organize the lessons we have learned.

All of the patients in this study had had previous intracardiac surgery. They had either failed to improve or had deteriorated after initial improvement following that intracardiac operation. Ellis' follow-up study of our first 1,000 valvuloplasties for mitral stenosis showed that mild to moderate mitral insufficiency did not alter the late results if mitral stenosis dominated and was corrected. However, dominant regurgitation present or produced by the initial surgery was a major cause of deterioration after valvuloplasty.

Other patients in this study who deteriorated after initial improvement were shown at the time of re-evaluation to have recurrent stenosis. Usually this is due to an inadequate initial operation, but a small number have had recurrent rheumatic valvulitis.

This mixed group with either borderline or frank congestive failure have been re-evaluated with a view to open-heart correction of their valvular defects. These patients had had prior left thoracotomy, were in and out of congestive failure and were known to have extensive pulmonary vascular disease. It was necessary to ascertain the contribution of each lung to overall respiratory function as the original operation had been through the left hemithorax and the approach to the left atrium

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for open operation was to be through the right side. Unilateral lung function is critical in a patient's course during the immediate postoperative period when voluntary effort is not assisted as it is during the operation.

Previous experience in the evaluation of postoperative pulmonary function, suggested that prior thoracotomy would impose a relatively minor loss of vital capacity due to the "thoracotomy effect." It was anticipated that there would be a slight shift of function to the unoperated lung, but that the degree of shift would not be of sufficient magnitude to preclude a contralateral thoracotomy.

This report describes the results of a preoperative evaluation of pulmonary function following maximal treatment in patients with prior left thoracotomy requiring reoperation. The influence of the findings on the final surgical plan will be described.

**Clinical Material**

Eighteen patients were studied, 14 women and 4 men, ranging from 22 to 64 years in age. All had had rheumatic mitral valve disease and had had prior cardiac surgery through left thoracotomy. They were readmitted for study with a clinical diagnosis of mitral stenosis and insufficiency. Five were in Group III and 13 in the Group IV category. All were candidates for open-heart surgery. In addition to the pulmonary function studies reported here, cardiac catheterization, electrocardiograms, serum electrolytes, as well as standard laboratory tests to assess hepatic and renal function were obtained. Clinical evaluation was the combined responsibility of the medical and thoracic surgical services.

**Methods of Pulmonary Function Testing**

Ventilatory measurements, including maximum breathing capacity, vital capacity, as well as bronchospirometry were performed before surgery.

Ventilatory tests on all patients were performed by the same technician, using the same equipment and methods for all tests.

Maximum breathing capacity was performed with the subject in the sitting position breathing room air for 30 seconds. A direct spirogram

![](https://i.imgur.com/5W5Z5.png)

**Table 1—Patients Operated By Open Heart Procedure**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (yrs.)</th>
<th>Ht. (cm.)</th>
<th>Wt. (Kg.)</th>
<th>VC (L.)</th>
<th>Per cent pred.</th>
<th>Lea. VC per cent</th>
<th>MBC (L./min.)</th>
<th>Per cent pred.</th>
<th>Rt.</th>
<th>Per cent total</th>
<th>Left</th>
<th>Per cent total</th>
<th>Rt.</th>
<th>Per cent total</th>
<th>Left</th>
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<td>4.0</td>
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<td>6.0</td>
<td>6.4</td>
<td>3.4</td>
<td>179</td>
<td>57</td>
<td>134</td>
<td>43</td>
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<td>61</td>
<td>179</td>
<td>53</td>
<td>157</td>
<td>47</td>
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was made using a counterbalanced Collins Vitalometer from which the CO₂ cannister had been removed.

The resistance of this equipment was less than 0.1 cm. of water. The maximal value of two efforts recorded at A.T.P.S.* (73 ± 2°) was reported in liters per minute.

Vital capacity was measured directly on a 9 L. Collins respirometer. The best of two efforts with the subject sitting was recorded in liters.

Bronchospirometry was performed on fasting subjects premedicated with 50 or 100 mg. of pentobarbital. All subjects were alert and cooperative. A double-lumen flexible rubber Carlen's catheter was introduced with the aid of a laryngeal mirror. Topical anesthesia was obtained with 0.5 per cent tetracaine hydrochloride (Pontocaine) as an oropharyngeal spray and a 0.25 per cent tracheal instillation.

Correct catheter position was confirmed by auscultation and fluoroscopy. In the supine position, the subject breathed a 35 per cent oxygen-rich mixture from a Collins twin recording spirometer. Two three-minute tracings were obtained at each examination. In many cases, each lung was separately evaluated by clamping the contralateral tubing. Ventilation rate, oxygen uptake, and minute volume were measured. The contribution of each lung as a per cent of the total function was computed.

Results

Four of the 18 patients studied were found not to be candidates for open-heart surgery for reasons not related to their pulmonary function. One was found to have recurrent mitral stenosis by cardiac catheterization. Reoperation was carried out using the "closed" Ivalon® tunnel procedure.\(^4\) Mitral stenosis without regurgitation was found and corrected. Another patient had coronary sinus blood flow studies suggesting severe coronary artery disease. Left heart catheterization indicated no significant stenosis or regurgitation at either the aortic or mitral valve. Pulmonary function was within normal limits. No operation was advised. The remaining two patients were in terminal congestive heart failure and considered inoperable.

FIGURE 1: Posteroanterior and lateral chest roentgenograms of E. D., patient 8, Table 1. Note giant left atrium.

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*Ambient temperature and pressure, saturated with water vapor.
Of the remaining 14 patients, 2 were in Group III and 12 in Group IV of the Harken-Ellis classification. It is emphasized that virtually all of these patients were totally disabled and were on intensive medical therapy. These efforts generally would be regarded as salvage surgery.

These patients have been grouped into three general categories: (1) acceptable for right thoracotomy and open-heart surgery; (2) acceptable for cardiac surgery, but not for right thoracotomy; and (3) unacceptable for surgery.

The first category included eight patients who had mild to moderate restrictive ventilatory patterns by routine spirometry (Table 1). As determined by bronchospirometry, four patients (No. 1 - No. 4) showed approximately equal division of function. These individuals, with relatively good over-all function, underwent right thoracotomy and correction of their mitral insufficiency by an open-heart technique. Respiratory insufficiency, either during the intra-operative or postoperative period, was not a problem in their management. Patients 5, 6 and 7 demonstrated a significant inequality of function between the two sides (greater than 65 per cent to 35 per cent). Dominant function was present on the right side. Surgery was carried out on the basis that they had relatively good over-all function, (i.e., VC and MBC were greater than 55 per cent of predicted). Although respiratory insufficiency was not a problem during the operative procedure, it was a significant factor in the postoperative course of two of these patients.

The eighth patient presented a more complex problem. Her x-ray films are shown in Figure 1. The giant left atrium was calculated by planigraphic studies to contain four to five liters of blood. There was definite alteration of the bronchi, particularly elevation of the right main-stem bronchus. This may well have accounted for the disparity between ventilation (39 per cent right, 61 per cent left) and oxygen uptake (53 per cent right, 47 per cent left). In spite of a significant reduction in over-all function, (VC and MBC less than 45 per cent of predicted) right thoracotomy was undertaken. The heart (left atrium) occupied an inordinate part of the intrathoracic space. It was planned to excise much of the left atrium and thus permit better expansion and more adequate ventilation of the right lung. This should have augmented total pulmonary function. This was technically feasible, but maintenance of adequate ventilation was difficult during the operation. Right thoracotomy was per-

<table>
<thead>
<tr>
<th>TABLE 2—PATIENTS REJECTED FOR OPEN HEART SURGERY (REOPERATION, LEFT THORACOTOMY)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spirometry</strong></td>
</tr>
<tr>
<td>Age (yr.)</td>
</tr>
<tr>
<td>1 C.Y.</td>
</tr>
<tr>
<td>2 S.K.</td>
</tr>
<tr>
<td>3 E.S.</td>
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</tbody>
</table>
formed. The giant left atrium compressed the right lung. The patient was placed on cardiopulmonary bypass. The atrium was opened. Much of the redundant auricular wall was excised to reduce the heart volume. The mitral valve was found to be freely incompetent. The mitral insufficiency was repaired, but in so doing the left ventricle presumably ejected air into the base of the aorta. The patient did not regain consciousness. Death occurred 12 hours later presumably due to cerebral air embolus. Even in retrospect this unusual operation seems to have been rational. The defect lay in the complete correction of the mitral insufficiency without perfect air evacuation before closing the heart.

The second category consisted of three patients whose pulmonary function studies revealed predominant ventilatory function by the right lung (in excess of 65 per cent), Table 2. Cardiac catheterization studies revealed a significant degree of mitral stenosis. In the light of prior experience, it was believed that these individuals would not tolerate an operation through the right chest which would compromise their dominant hemithorax. These individuals were reoperated through a left thoracotomy using an Ivalon® operating tunnel, for repeat mitral valvuloplasty. Respiratory insufficiency was not encountered during the operative or postoperative period in these patients.

The third category consisted of three patients with dominant function remaining on the right side (Table 3). Two demonstrated a function difference in ventilation greater than 70 per cent to 30 per cent while the third had a 65 per cent to 35 per cent division for oxygen uptake with an essentially equal partition of ventilation. This last individual had a giant left atrium as did patient 8 in the first category. These individuals were Group IV patients (refractory congestive failure). Diminished cardiac reserve and inequality of pulmonary function were the contraindication to surgery.

Discussion

The limitations of pulmonary function tests must be recognized in evaluating this study. Variations in motivation, errors of measurement, changes in respiratory muscle capabilities and changes in the lung itself account for variations in vital capacity and maximum breathing capacity. Regardless of these factors, previous experience led us to expect only moderate restriction of the over-all function without marked discrepancy of ventilation due to previous thoracotomy. Three patients (not included in the original 18 patients) with equivalent degrees of mitral valvular disease and heart failure, but without prior thoracotomy, were studied. These showed normal division of function between the lungs. The influence of heart disease and congestive failure therefore did not appear to alter the normal partition of ventilatory function.

**TABLE 3—PATIENTS REJECTED FOR SURGERY**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Spirometry</th>
<th>Bronchoespirometry</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ventilation L./min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Per cent prod.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 sec. VC</td>
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<tr>
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<td>A.M. 41</td>
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</tr>
<tr>
<td>2</td>
<td>V.G. 51</td>
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</tr>
<tr>
<td>3</td>
<td>G.C. 37</td>
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</table>
While all of 18 patients had mild to moderate restriction of their over-all pulmonary function, only four showed an essentially equal partition. The remaining ten patients had significant differences in their unilateral lung function. Three of these ten were not accepted for operation. Each of these individuals demonstrated dominant function in the right hemithorax and all had severe mitral regurgitation. These individuals would certainly not have tolerated a right thoracotomy. The combination of marginal pulmonary function and advanced congestive heart failure precluded operation. These decisions were made before a technique of reoperation for mitral insufficiency through the left hemithorax was developed.

An additional three patients did not have open-heart surgery, but were reoperated through the left chest. These patients with marginal pulmonary function, dominant on the right side, had significant degrees of residual or recurrent mitral stenosis. The necessity to preserve the dominant hemithorax dictated an alteration of the surgical approach.

Four patients were accepted for an open procedure through the right chest in spite of inequality of pulmonary function. Three of the four presented problems in handling respiratory insufficiency either during the intraoperative or early postoperative period.

The foregoing experience has led to the development of an alternative approach, through the left chest wall, to open reoperation for the correction of mitral valve disease. This affords better exposure of the mitral valve and a better direct valvuloplasty. It does have the disadvantage of operating through a field of adhesions in an individual heparinized for by-pass.

The primary consideration, however, is that adequate ventilatory studies have improved patient selection, helped in clarifying an inoperable group and stimulated the development of a more appropriate operation through the left hemithorax in order to adapt to this problem of compromised pulmonary function.

**SUMMARY**

1. Thoracotomy incident to cardiac surgery causes a variable restriction on pulmonary function. Bronchospirometric studies have shown that the predominant loss is due to restrictive disease in the operated hemithorax. Routine ventilatory studies will not ascertain this unilateral difference in function.

2. Pulmonary function testing in patients under study for repeat cardiac surgery distinguished three groups of patients:
   I. Those whose respiratory limitations contraindicated further surgery.
   II. Those with marginal function acceptable for surgery if it did not compromise the lung performing major function.
   III. Those whose respiratory status permitted open-heart surgery through either hemithorax.

3. The unoperated hemithorax has been established as essential to survival in some patients. A surgical approach to the mitral valve through the previously operated hemithorax (left side) has been developed and used.

**RESUMEN**

1. La toracotomía que se hace con motivo de cirugía cardíaca causa una restricción variable de la función pulmonar. Los estudios broncoespírométricos han demostrado que la pérdida que predomina es debida a la enfermedad restrictiva en el lado operado del tórax. Los estudios de ventilación no aclaran esta diferencia unilateral de la función.

2. Los estudios funcionales en enfermos que se han estudiado por cirugía reiterada del corazón distinguen tres grupos:
   I. Aquellos cuyas limitaciones respiratorias contraindican hacer nueva cirUGía.
   II. Los que tienen función marginal aceptable si no comprometieron la mayor función del pulmón.
   III. Los que tienen una condición respiratoria que permite la cirugía de corazón abierto en cualquier lado.

3. El hemitórax no operado se ha establecido como esencial para la sobrevida en algunos enfermos. Se ha ideado una técnica quirúrgica para el tratamiento quirúrgico de la mitral a través del lado previamente operado (lado izquierdo) y tal técnica se ha usado.

**RESUMÉ**

1. La thoracotomie qui accompagne les opérations cardiaques provoque une atteinte variable de la fonction pulmonaire. Des études bronchospirométriques ont montré que la perte prédominante est imputable à une diminution fonctionnelle de l'hémithorax opéré. Les études fonctionnelles de routine ne peuvent faire la preuve de cette différence unilatérale dans la fonction.

2. L'étude de la fonction pulmonaire chez les malades en observation pour des opérations cardiaques répétées permet de distinguer trois groupes de malades:
   I. ceux dont les limitations respiratoires contre-indiquent une opération ultérieure;
   II. ceux dont la fonction pulmonaire marginale est acceptable pour une opération, si celle-ci ne compromet pas le poumon fournissant la fonction majeure;
   III. ceux dont l'état respiratoire permet une chirurgie à cœur ouvert par l'un des hémithorax.
3. Il a été établi que l'hémithorax inopéré est essentiel à la survie chez certains malades. Une tentative chirurgicale sur la valves mitrale par l'hémithorax antérieurement opéré (côté gauche) à été pratiquée.

ZUSAMMENFASSUNG
2. Lungenfunktionstests bei Kranken, die wegen wiederholter Herzoperationen unter Beobachtung stehen, ließen drei Gruppen von Patienten unterscheiden.
I. Solche, deren eingeschränkte Atmung eine Kontraindikation für weitere Eingriffe ist.
II. Solche mit Grenzwerten, die zur Operation zugelassen werden können, wenn diese nicht die größere Leistung aufweisende Lunge beeinträchtigt.
III. Solche, deren respiratorische Verfassung Operationen am offenen Herzen bei jedem Halbthorax zuläßt.

REFERENCES

VASODILATING DRUGS AND CORONARY BLOOD SUPPLY
Treatment of localized myocardial ischemia depends upon addition of arterial blood by way of intercoronary arterial communications. Pentaerythritol tetranitrate adds 0.81 cc. per minute to the ischemia circumflex area of the dog heart. Amyl nitrite adds 0.96 cc. per minute to the ischemic circumflex area of the dog heart. Alcohol decreases intercoronary flow by 1.93 cc. per minute. Increased intercoronary flow resulting from drug action is temporary. Addition of 0.81 cc. per minute as produced by pentaerythritol tetranitrate did not reduce mortality or infarct size following test coronary artery ligation in a series of 21 experiments.

IMPAIRMENT OF DIFFUSION IN MITRAL STENOSIS
Methods of determining alveolar diffusing capacity and its clinical significance in connection with pathologic physiology of mitral stenosis and effect of commissurotomy are described. It was shown that the PO2 difference between alveolar gas and arterial blood (A-a gradient) depends upon various factors such as membrane component, venous admixture component and hyperventilation. Pulmonary diffusing capacity (Dlco) was measured by CO method. It was found the impairment of diffusing capacity (or increased A-a gradient) mainly due to disturbance in membrane component was irreversible with commissurotomy, while that mainly due to disturbance in venous admixture component or due to hyperventilation was comparatively reversible with commissurotomy. In the cases with decreased Dlco, a marked thickening of the basement membrane on the blood-air pathway was revealed by electron microscope.

In deciding the indication of commissurotomy for mitral stenosis, determination of impairment of diffusing capacity has great significance as well as pulmonary arterial pressure, capillary pressure, vascular resistance and A-a gradient.