

Surgical and Functional Problems in Pulmonary Resection for Lung Cancer

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Thirty-four cases of pulmonary cancer have been studied by the methods of spirometry and temporary unilateral pulmonary occlusion with and without exercise.

The prognostic significance of cardiopulmonary function for resectional treatment was re-evaluated by these means, and the functional indication values, which had been reported previously, were proved valuable. The postoperative pulmonary failure developed in patients with the RV : TLC ratio over 45%.

It was emphasized that the relationships among pulmonary arterial pressure, diastolic right heart pressure, and cardiac output, were the most important factors in judging how the borderline cases will tolerate surgical intervention. HARVEY's conception was discussed in this regard.

One of the most common of the serious complications, and one which most frequently causes death in pulmonary resection, is postoperative cardiopulmonary failure. Therefore, when pulmonary resection is being contemplated, special determinations for evaluation of cardiopulmonary reserve should be made. This is difficult, because the ability of a patient with impaired cardiopulmonary function to tolerate pulmonary resection is difficult to evaluate. If we consider our current methods for determining the cardiopulmonary function, we can agree that the investigation of the bellows function by means of the vital capacity, the maximal breathing capacity, and RV : TLC ratio determinations do not give us an absolute value for the lower limit operability.

In 1951, CARLENS, HANSON, and NORDENSTROEM¹⁾ occluded one pulmonary artery temporarily with an inflatable balloon at the tip of a cardiac catheter. These techniques have made it possible to produce the circulatory and ventilatory changes which might be expected to follow pulmonary resection as well as to evaluate the ability of the circulatory system to compensate for a reduction in the pulmonary vascular bed.

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Since 1955, studies of the circulatory changes following temporary unilateral occlusion of the pulmonary artery combined with exercise had been carried out in patients being considered for pulmonary resection. In 1957, the results, in 30 patients, including inflammatory lesions, bronchiectasis, far advanced tuberculosis, and lung cancer had already been reported²⁾³⁾, and the lower limit values of pneumonectomy were as follows:

I. Respiratory function

1. Lung cancer: predicted VC, 70%; predicted MBC, 55%; and contralateral predicted VC, 45%.
2. Pulmonary tuberculosis: predicted VC, 55%; predicted MBC, 45%; and contralateral predicted VC, 40%.

II. Circulatory function

1. In rest: mean pressure of P.A., 17.5 mm Hg.; arterial oxygen saturation, 92%; cardiac index, 2.5-4.5 and total pulmonary resistance, 275 dynes/sec/cm⁵
2. After occlusion: mean pressure of P.A., 22mm Hg.; arterial oxygen saturation, 90%; cardiac index, 3-5, and total pulmonary resistance, 325 dynes/sec/cm⁵
3. After occlusion combined with 3 minutes slight exercise: mean pressure of P.A., 24 mm Hg.; oxygen saturation, 87.5%; cardiac index, 4-7 and total lung resistance, 275 dynes/sec/cm⁵

Conclusively, a greater rise in pulmonary artery pressure, a marked fall of arterial oxygen saturation, and failure to increase the cardiac output after temporary unilateral occlusion of pulmonary artery combined with exercise indicated that the patient might not tolerate pneumonectomy.

The prognostic significance of cardiopulmonary function for the surgical treatment of lung cancer has not been fully elucidated. In a recent unselected group, 34 patients suffering from lung cancer were re-examined. whenever the cardiopulmonary function of the patients was under these limit values, CAHAN's radical lobectomy⁴⁾ was carried out, instead of pneumonectomy. Success was gratifying.

MATERIAL AND METHODS

The number of resected cases admitted to the Department of Surgery in Nagasaki University Hospital may be inferred from Table I. The 34 patients (30 men and 4 women) who had lung resection, ranged in age 37 to 72, with an average of 53.6 years. Twenty-one had undergone pneumonectomy and 13 lobectomy (including 2 lobes). Eleven patients were over 60 years of age. In these, the tumors were found to be as follows: 15 were epidermoid; 12 were undifferentiated ;and 7

were adenocarcinoma.

Table 1
Age of Patients — Procedure Performed

	30-39	40-49	50-59	60-69	70-79	Total
Pneumonectomy	3	7	5	6	0	21
Lobectomy (Including 2 Lobes)	0	5	3	3	2	13
Total	3	12	8	9	2	34

The causes of death and serious complications within 6 months are given in Table 2. There was no death within one month postoperatively. In 4 cases, acute pulmonary edema and one hemorrhagic gastric ulcer after pneumonectomy developed within 72 hours postoperatively. All recovered after adequate procedures. One patient died 40 days after right pneumonectomy, with symptoms of suffocation caused by occluding sputum at the portion of anastomosis between trachea and left main bronchus. (fig. 1.)

Table 2
Causes of death and complication in 6 months (34 cases)

No. of cases	Operation	Causes	Outcome
1	Rt. pneumonectomy and anastomosis between trachea and lt. main bronchus	Suffocation	Death: 40 days postop.
1	Rt. upper lobectomy	Coronary insuff.	Death: 5 months postop.
1	Lt. pneumonectomy	Contralateral pleurisy	Death: 2 months postop.
2	Rt. pneumonectomy Rt. upper lobectomy	Cerebral metastasis " "	Death: 2 months postop. " 3 " "
1	Rt. lower lobectomy and middle lobectomy	Empyema	Death: 2 months postop.
4	Pneumonectomy	Acute lung edema	All recovered
1	Rt. lower and middle lobectomy	Hemorrhagic gastric ulcer	Gastrecomy, recovered

Pulmonary Function Test.

Routine spirometric and bronchospirometric determinations were ob-

tained in all cases. The maximum breathing capacity was determined by the semi-closed circuit method, utilizing MOTLEY'S apparatus.⁵⁾ Normal values were calculated on the basis of BALDWIN'S equation.⁶⁾ The observed values were expressed in percentage of the predicted normal values. The residual volume was determined by a modification of the DARLING open circuit technique⁷⁾. Nitrogen washout curve was obtained, using a nitrogen analyzer (Waters Corporation).

Cardiac Catheterization and Unilateral Pulmonary Artery Occlusion :

Cardiac catheterization was carried out in the usual manner, using light sedation (usually Opistan, 75mg) in all cases. In 32 cases, pulmonary occlusion was achieved with a double or triple lumen catheter⁸⁾. If needed, occlusion combined with slight exercise was done successfully in 12 cases. In every part of the studies, the following determinations were made: pulmonary and right ventricular pressure, and cardiac output. Pulmonary artery pressures were recorded with the Nippon Kodon electrometer and recorder. Cardiac output



Fig. 1.

was determined by the Fick principle. Simultaneously mixed venous and systemic arterial blood samples were analyzed for oxygen content by the VAN SLYKE method⁹⁾. The usual duration of pulmonary artery occlusion was 20 minutes. A three minute period of moderate exercise was required of each patient in a supine position by flexing each leg against a 2 Kg. resistance. The data was obtained during the last one minute.

Measurement of Cardiac Output during Lung Resection.

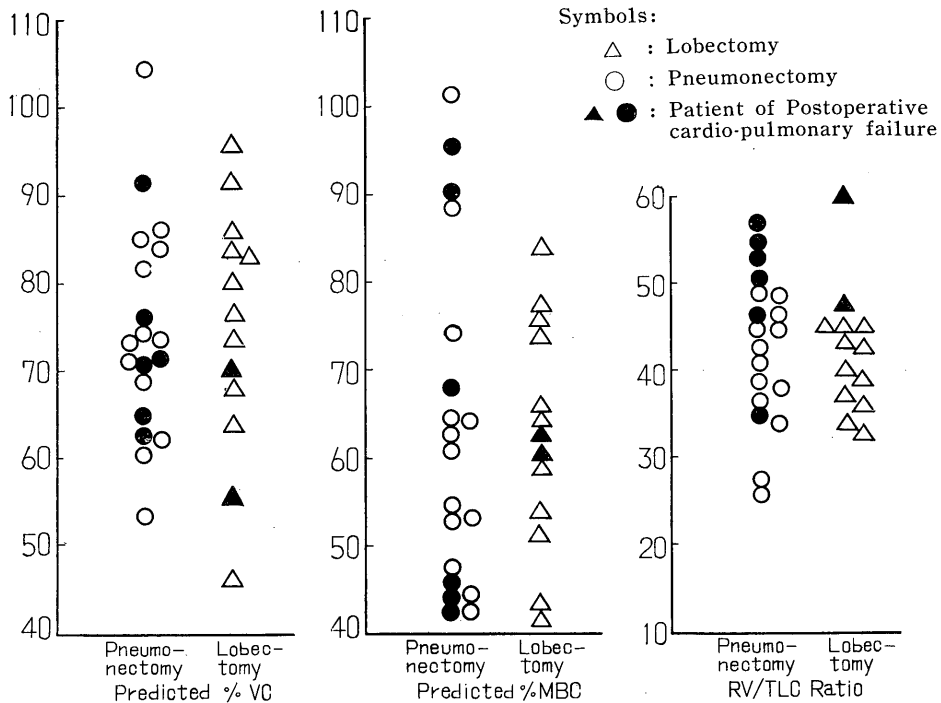
In 9 of the patients, by using the dilution technique^{10),11)}, the cardiac output was determined to show what the usual circulatory changes may be as a result of lung resection. Of 9 patients undergoing lung resection, there were 6 pneumonectomies and 3 lobectomies. Actually, measurements of cardiac output were performed in the following

sequence:

1. just before operation,
2. following chest opening,
3. following lung resection,
4. just before chest closing,
5. early in the postoperative period,
6. On the first postoperative day,
7. On the second day,
8. after one week.

The dye used for injection was T-1824. Serial arterial samples were collected in tubes rotating on a kymograph. Determinations of dye in the samples were made with Hemoreflector. In all the patients, a combination of pentothal, saccinylcholine, and nitrous oxide or Fluothane was employed for anaesthesia. The majority were ventilated by automatic respirator during operation. Post-operative care included the use of oxygen by nasal catheter for 2 days, or more, if needed, but during measurement of cardiac output, oxygen inhalation was temporarily stopped. Fluids were limited to blood replacement and approximately 1,000cc of 5% glucose in was injected subcutaneously during the first 3 days.

Fig. 2 Pre-operative Ventilatory Values of 32 patients



RESULTS

In 8 cases cardio-pulmonary failure developed post-operatively.

1. *Ventilatory Function.*

The vital capacity, the maximal breathing capacity and RV : TLC ratio are presented in Fig. 2, as compared between a satisfactorily functioning group and the cardio-pulmonary failure group. Even if the pulmonary function tests fail to give us an absolute lower limit for operability, we find values that indicate that lung resection is dangerous or that operation may result in further reduction of the function as in pneumonectomy. In these series MBC was more important factor than VC. Predicted MBC value of 45% was serious. Despite predicted 52% VC, and predicted 42% MBC based on calculations, in total atelectasis of one lung following stenosis by bronchogenic infiltration (as shown in Fig. 3), the post-operative alterations of both respiratory and circulatory functions were so well tolerated that resultant symptoms were minimal.

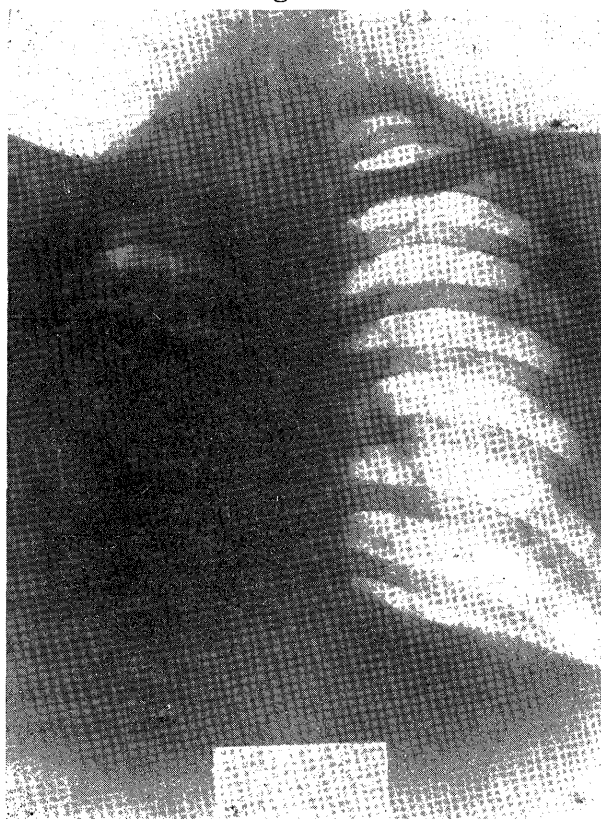
The RV:TLC ratio shows a gradual but consistent increase with advancing age. Some early studies¹²⁾¹³⁾ have concluded that RV : TLC ratio greater than 35% is strongly suggestive of hyperinfiltration or impaired alveolar ventilation.

Other investigators, studying groups of older people in good health, have recently found the RV: TLC value of 41 per cent (males) and 42 per cent (females)¹⁴⁾.

In 5 of 6 cases of our series above the age of 65 years, the RV:TLC ratio was over 45 per cent and postoperative pulmonary failures developed in 7 of 10 patients with the RV : TLC ratio of over 45%. Therefore, in this situation, patients in the advanced age group should be refused pneumonectomy.

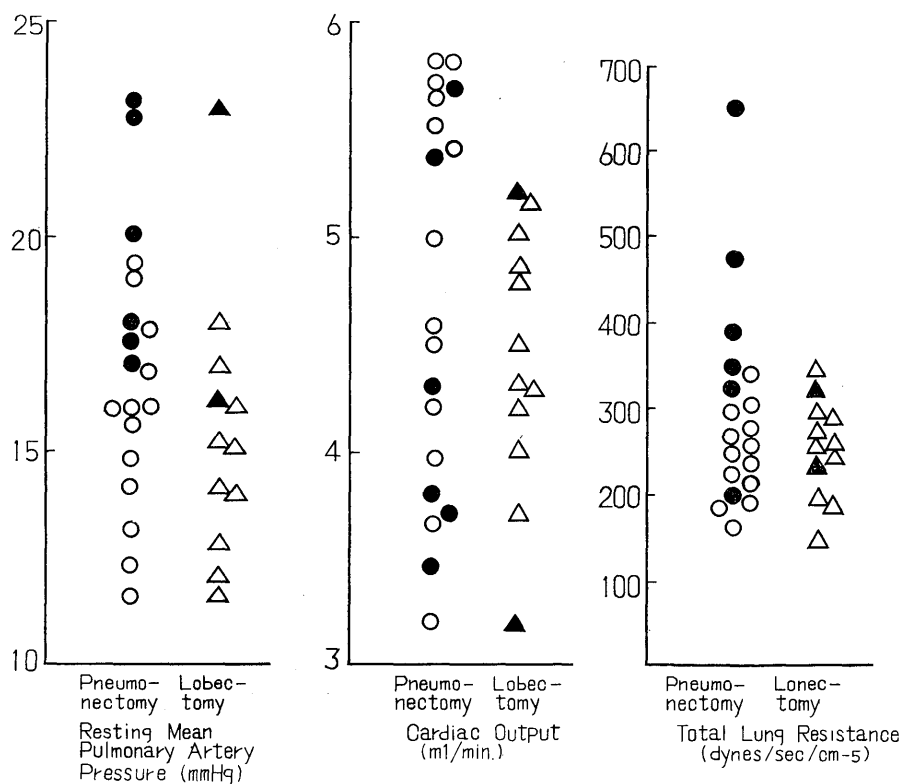
2. *Circulatory Function.*

Fig. 3.



As shown in Fig. 4, in routine heart catheterization,^{15,16)} the mean resting pressure for all cases was between 13 and 23 mmHg. An elevated pressure is not necessarily a contraindication to resectional lung surgery. On the other hand, the patients with normal pressures at rest may have no reserve with respect to accommodation to increased blood flow and, therefore, may be poor risk for such surgery. The majority of patients, who had post-operative cardio-pulmonary disorder, were seen to have had over 17.5 mmHg. of mean pressure, low cardiac flow, or remarkably high flow, and above 300 dynes\sec\cm⁻⁵ in total lung resistance.

Fig. 4 Pre-operative Hemodynamic Values of 32 Patients



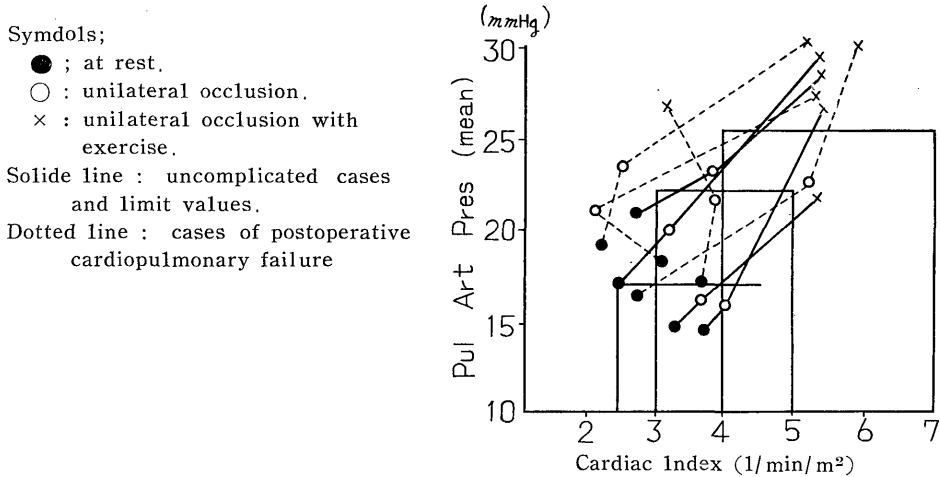
3. Unilateral Pulmonary Occlusion with and without Exercise.

In Fig. 5 are plotted the flow-pressure relationships existing in those cases of postoperative cardio-pulmonary failure, of acute lung edema, and of uncomplicated cases, which responded in a normal manner to a slight rise in main pulmonary artery pressure and increase in flow following occlusion. Still further increases within upper limits of normal values, were produced with exercise.

4. Cardiac Output during Lung Resection.

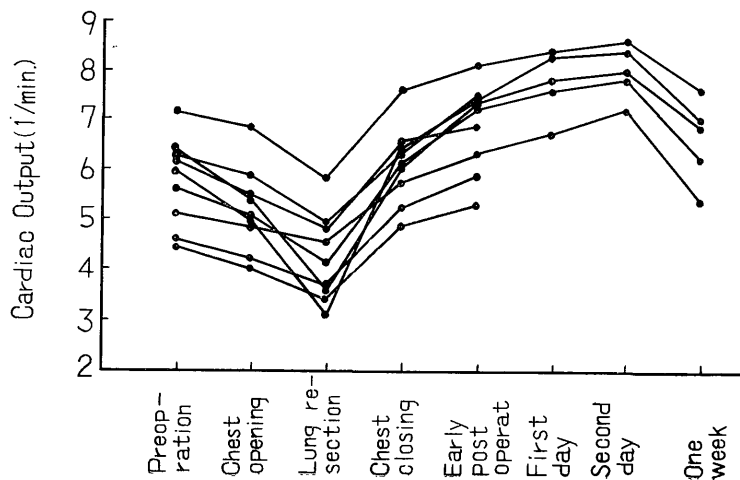
As may be seen from Fig. 6 the average preoperative cardiac

Fig. 5 Flow-Pressure Relationships in Patients with Lung Cancer
Pulmonary artery mean pressure are plotted against cardiac index



output by the dilution curve was per minute. Following chest opening, it fell to 10.2%, and following lung resection to 20.8% from the control level. The cardiac output returned toward normal, being 3.4% over the preoperative level. Early in the postoperative period, it increased in all cases. The average value was 17.2% above the preoperative level. For one week, cardiac output remained elevated, the greatest elevation being on the second post operative day, when it was 36.2% over the preoperative level. By the end of the week, it returned to 1.2%

Fig. 6 Changes of Cardiac Output during Lung Resection



DISCUSSION

At the present time, cor pulmonale due to cardiopulmonary insufficiency is the most frequent cause of death following pneumonectomy for carcinoma of the lung, especially in emphysematous status^{16,17,18}. This is indicated in the mortality rate of pneumonectomy, which varies from 15 to 25 percent for patients over 60 years of age. Thus, it is obvious that complete and special study of preoperative cardiopulmonary status is important to reduce the resectional mortality in lung cancer.

Spirometric investigations do not accurately predict the patient's capacity after the proposed operation. According to KUNZ¹⁹ lobectomy is contra-indicated if the RV:TLO ratio is increased by more than 20 per cent, and pneumonectomy, if the ratio is increased by more than 8 per cent, and also a lobectomy is contra-indicated if the MBC is decreased by more than 20 per cent, and pneumonectomy, if the capacity is decreased by more than 16 per cent. Nevertheless, resections have been done in the presence of poorer function than those indicated^{20,21}.

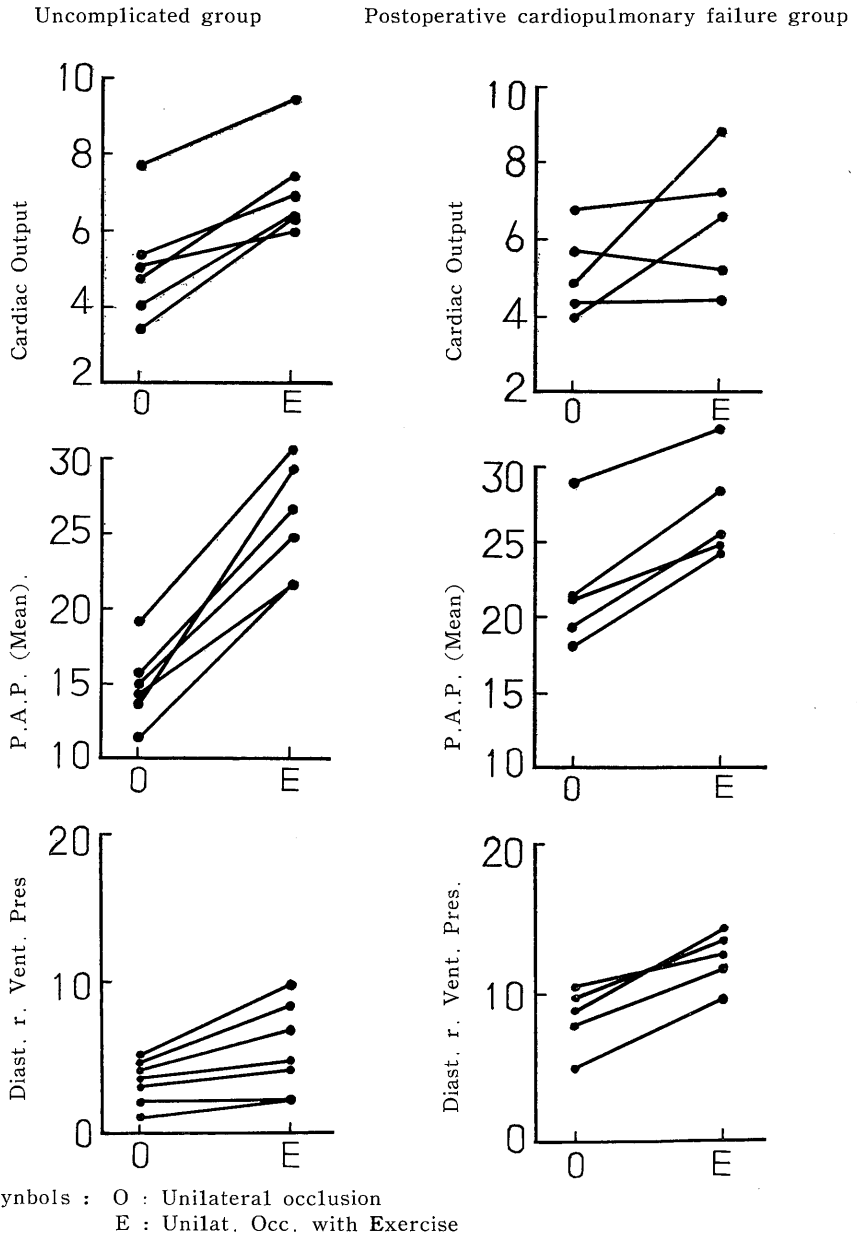
Vital Capacity has been found to be of little value in detecting the presence and severity of pulmonary emphysema, but RV:TLC ratio particularly important, since it indicates distention, which is increased in emphysema as the lung loses its elasticity and distensibility. As shown in Fig. 2, in 5 of 6 cases of our series over 65 years of age, the RV:TLC ratio was over 45 per cent, and the postoperative pulmonary failures developed in 7 of 10 patients of the RV:TLC ratio over 45 per cent.

The only means of eliciting adequate information is probably direct measurement of the pulmonary vascular pressure by heart catheterization, with and without temporary occlusion of the pulmonary artery on the affected side. In 32 patients suffering from lung cancer, the prognostic significance of cardiopulmonary function for resectional treatment was scrutinized by this means, and pneumonectomy and lobectomy were performed with gratifying success, despite the function indication values which have been mentioned. These results apparently indicate that this author's lower limit values in pneumonectomy³ are valuable.

As shown in Fig. 7, temporary unilateral occlusion with exercise makes it possible to judge accurately how the borderline cases will tolerate a surgical intervention. In these cases, whether the resting pressure was normal or greatly elevated, occlusion with exercise produced a significant increase in pressure, indicating fibrosis of the pulmonary arterial tree, loss of elasticity, and hence, a fixed lung resistance. The limitation of this distensibility due to advanced pulmonary lesions can be fairly well defined by the method described.

Furthermore, HARVEY²²⁾ has shown that two different patterns have been observed in response to exercise in cor pulmonale due to emphysema. The first of these has elevation of cardiac output and all pulmonary circulatory pressure at rest, but is able to increase blood flow in a normal fashion while right heart pressure rises rather strikingly. But, if the right ventricle can tolerate this response, its diastolic pressure does not exceed the normal during exercise.

Fig. 7 Hemodynamic Changes during Unilateral Occlusion with and without Exercise



The second has low cardiac output at rest, and it is fixed on exercise; i. e., there is no increase at all. The already elevated right heart ventricular diastolic pressure rises further. Therefore, the relationship of pulmonary artery pressure to diastolic right heart pressure and cardiac output is most important. (Fig.7). A greater rise in pulmonary arterial pressure, or a marked elevation of diastolic right ventricular pressure, and a failure to increase the flow after temporary unilateral occlusion of pulmonary artery combined with exercise, indicate the most serious status. This corresponds to the second phase of Harvey's conception. In these functional conditions, lobectomy should be carried out, instead of pneumonectomy.

The response of cardiac output to lung resection as observed in 9 cases is shown in Fig. 7. The anaesthetic and operative procedure produced a decrease of cardiac output (-20.8%). From the end of the operation on, the cardiac output increased throughout the rest of the recovery period. On the average, the cardiac output was at its greatest (+36.2%) on the second postoperative day. At the end of the week it approached to normal values.

On this subject, MAIER²⁸⁾ also noted this, and suggested that blood stasis in the lung might be a factor in producing postoperative edema. In 4 cases, acute pulmonary edema developed postoperatively. All recovered by adequate procedures, intermittent positive pressure breathing through the tracheotomy above all Aminophylline and Diamox were most helpful. In these situations, postoperative care is obviously of vital importance. Blood replacement is essential. However, it must be remembered that an elderly person's circulatory system cannot stand abuse as readily as that of a younger person. Fluid and electrolytes must be doled out in an especially frugal manner to prevent pulmonary edema. Since the cardiac output tends to increase postoperatively, it is better to err on the side of a slight dehydration and slight chloride deficiency.

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