Differential Forced Expiratory Spirograms
A Bronchspirometric Study*

LeRoy Doctor, M.D.,** Gordon L. Snider, M.D., F.C.C.P.† and Allan R. Shaw‡
Chicago, Illinois

Bronchspirometry has been used to measure many aspects of the function of individual lungs, but unilateral forced expiratory spiromgrams have not been compared with one another because of the increased resistance to breathing through catheters and the difference in resistance between the right and left lumens of bronchspirometry catheters. Indeed, resistance to flow through bronchspirometry catheters has not previously been studied at levels above 40 liters per minute. In the present study, the difference in resistance between the right and left lumens of Carlens catheters at flows up to about 120 liters per minute was found to be small.

Differential forced expiratory spiromgrams in 19 patients with pulmonary disease were subsequently analyzed.

Method

Part I

Measurements of resistance to flow were made on nine Carlens catheters, three size 35, three size 37, and three size 39, French. Each Carlens catheter was sealed into a length of rubber tubing, 1 1/2 inches inside diameter, which served as a simulated trachea (Fig. 1). One lumen of the catheter was connected to a previously calibrated wedge spirometer using a 3/8 inch inside diameter connector identical to that employed during bronchspirometry; the other lumen was occluded. Two 13 gauge needles, seated flush with the tubing wall, were connected to a P23AA Statham strain gauge. Pressure and air flow velocity signals were recorded with a cathode ray oscillograph. A normal subject blew into the simulated trachea at various rates, attempting to hold each flow constant for as long as possible. In addition, several forced vital capacities were performed. This process was repeated for each lumen of all catheters tested. Pressure-flow plots were constructed for each catheter using a mean of at least three observations taken from both steady flow and forced expiration records for each point plotted. Pressure in the inlet to the wedge spirometer during expiratory efforts by the subject was less than 0.5 cm. H2O at all flows; the pressure gradient across the lumen of the Carlens catheter was not corrected for this back pressure.

Part II

Forced expiratory spiromgrams were made on 19 patients undergoing preoperative bronchspirometry under local anesthesia. The procedure was performed in the sitting position as previously described. A Collins nine liter bronchspirometer fitted with box-balloon systems was used, so that the subjects breathed air. There were 15 men and four women, and their ages ranged from 15 to 57 years. Eighteen had advanced tuberculosis and one patient had universal bronchiectasis.

Carlens catheters, size 37F, were used in all subjects, and catheter position was checked fluoroscopically. Minute ventilation, oxygen uptake, and slow vital capacity were recorded. Forced expiratory spiromgrams were then made using a drum speed of 32 mm. per second. Lung volumes,
measured by the nitrogen wash-out method, and routine spirometry, using a Stead-Wells spirometer, were obtained during the week preceding bronchospirometry. The methods of measurement, terminology, and symbols are those recommended by the Committee on Pulmonary Physiology of the American College of Chest Physicians. The following additional symbols will be used:

FEV(S)\(_{0.5}\%\_t\) — Forced expiratory volume for one-half second of the smaller lung, expressed as per cent of the total volume delivered by both lungs in one-half second.

FEV(S)\(_{1.0}\%\_t\) — Forced expiratory volume for one second of the smaller lung, expressed as a per cent of the total volume delivered by both lungs in one second.

FVC(S),%T — Forced vital capacity of the smaller lung expressed as a per cent of the sum of the forced vital capacities of both lungs.

VC(S),%T — Vital capacity of the smaller lung, expressed as a per cent of the sum of the vital capacities of both lungs.

MV(S),%T — Minute ventilation of the smaller lung, expressed as per cent of the minute ventilation of both lungs.

O\(_2\)(S),%T — O\(_2\) uptake of the smaller lung, expressed as per cent of oxygen uptake of both lungs.

RESULTS

Part I

Table 1 gives flows for the nine catheters and the mean data for each size at three different driving pressures. Resistance varied inversely with the lumen size of the catheter. Resistance was greater in the right than the left lumens of the 37F and 39F catheters; the opposite was true of the 35F catheters. Resistance differences between right and left lumens at all flow rates were least for the 37F catheters (Fig. 2). For

![Figure 1: Schema of the equipment for obtaining resistance and flow data at high flow rates through a Carlens catheter. The catheter (a) was sealed into a length of rubber tubing (b) 1 1/2 inches inside diameter, which served as a simulated trachea. One lumen of the catheter was connected to a wedge spirometer (c) using a 3/8 inch inside diameter connector (d), while the other lumen was occluded. Two 13 gauge needles (e), seated flush with the tubing wall, were connected to a strain gauge (f), and pressure and air flow velocity signals were recorded on a cathode ray oscillograph (g) when the subject blew into the simulated trachea.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21436/ on 06/21/2017)
Table I—Flow of Humidified Expired Air at 3 Driving Pressures for Right and Left Lumens of 35, 37, and 39F Carlen's Bronchopulmonary Catheters. Values for 3 Catheters in Each Size Are Given.

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Δ = Difference between the flows of the right and left lumens of the catheters.

this reason, only 37F catheters were used in the second part of the study.

Part II

The expiratory spirograms of the two lungs were re-drawn with time-volume reference points superimposed (Fig. 3). The paired curves were then inspected for obvious differences in contour. When the volumes of the two lungs were similar, differences in flow were easily discerned. If, how-

![Figure 2](http://journal.publications.chestnet.org/pdaccess.ashx?url=/data/journals/chest/21436/ on 06/21/2017)

**Figure 2:** Curves of mean flow rates at different pressures for the left and right lumens of the three 35F, 37F, and 39F catheters. At very low flow levels the relationship is linear, denoting laminar flow; at higher flow rates, the relationship is curvilinear, representing turbulent flow. The difference in resistance between the two catheter lumens is least for the 37F catheters.
however, there was a wide discrepancy in volumes, the smaller lung reached the flattened terminal portion of the expiratory spirogram earlier than the larger lung, giving the appearance of delay in expiration and making comparisons of flow rates difficult (Figs. 3a and 3b).

In order to compare the relative degree of expiratory delay of the two lungs more precisely, a study was made of the relationship between the amount of air delivered at various times during forced expiration by a lung and the proportion of total vital capacity delivered by that lung. Thus, the 19 cases were divided into three groups on the basis of the relationship between the amount of air delivered by the smaller lung in 0.5 seconds expressed as per cent of volume delivered by both lungs at that time [FEV(S)0.5%,] and the forced vital capacity of the smaller lung expressed as a per cent of total forced vital capacity [FVC(S),%T] (Table 2).

**Group 1**—comprised 12 cases in which the FEV(S)0.5% did not deviate by more than 5 per cent from the FVC(S),%T (Fig. 4a).

**Group 2**—comprised five cases in which the FEV(S)0.5% was more than 5 per cent larger than the FVC(S),%T (Fig. 4b).

**Group 3**—comprised two cases in which the FEV(S)0.5% was more than 5 per cent smaller than the FVC(S),%T (Fig. 4c).

When the FEV (S)1.0%, was used instead of the FEV (S)0.5%, the cases fell into the same groups.

In the 19 cases studied, the smaller lung had the greater amount of disease as determined by rating the severity of roentgenographic changes in each lung. The mean per cent of total vital capacity and minute ventilation performed by the smaller lung was similar for the Groups 1 and 3 patients, while the smaller lung in the Group 2 patients was more severely compromised. The diminution of the oxygen uptake of the smaller lung in Group 2 patients was even more severely impaired than vital capacity or minute ventilation.

The mean values for the FEV0.5 and FEV1.0 for the larger and smaller lungs, when expressed as a per cent of vital capacity of that lung, were similar for the

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**Figure 3:** Forced expiratory spirograms obtained during bronchospirometry on patients with marked differences in volume between the right and left lungs. The interrupted line represents the left lung. The spirograms have been re-drawn with time-volume reference points superimposed. On inspection it appears that the relationship of flow rates between the two lungs is similar in both cases. Actually, as seen in the data in Table 2, the left lung in Case 11 has more expiratory delay than the left lung of Case 2.
Group 1 patients, although the mean values for the FEF_{0-52} and FEF_{25-75} for the smaller lung were less than for the larger lung. In Group 2 patients, the mean values for the FEV_{0.5} and FEV_{1.0} expressed as a per cent of the vital capacity of that lung were higher for the smaller lung, while the mean values for the FEF_{025} and FEF_{25-75} for the larger and smaller lungs were in the same range.

Routine spirometry (Table 2) revealed that the mean vital capacity was minimally diminished in Groups 1 and 3 (84 and 87 per cent of predicted, respectively) as compared to a moderate diminution in Group 2 (64 per cent of predicted). The total lung capacity was also smaller in Group 2 patients. There was evidence of more airway obstruction in Groups 1 and 3 patients than in Group 2, as indicated by the lower FEV_{1.0\%VC} and FEF_{25-75}.

**Discussion**

In the present study of resistance to flow through Carlens catheters, the flows attained are higher than those reported earlier by Gaensler *et al.*, and Swenson and Birath. Since the latter investigators noted that moist air has greater viscosity than dry air, in the present study expired air was used to provide gas at near body temperatures and humidification. As has previously been found, resistance plots obtained under these conditions deviated from linearity when flows were above 10 liters per minute, indicating the development of turbulent flow. Nevertheless, the difference in resistance between the two lumens of 37F catheters remained small and reasonably constant at flows ranging up to 120 liters per minute (Fig. 2). These findings appeared to justify investigation of differential forced expiratory spirograms in disease.

Since normal values for forced expiratory flows through bronchospirometry catheters are not available, we were limited to a comparison of differences of flow between the larger and smaller lungs. The validity of such a comparison lies in the similarity of resistance to flow of the two lumens of the 37F Carlens catheter and of the twin spirometers. Furthermore, a poor cooperative effort by the patient would be
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†%F, per cent predicted; TLC, total lung capacity; all other symbols are as given in the text. 
*%VC for that lung.
expected to effect both lungs proportionally. Inspection of the spiromgrams gave a misleading impression of relative flow when there were large volume differences between the lungs. This difficulty was overcome by grouping the cases using time-volume relationships.

In the Group 1 patients, the FEV_{0.5\%}\,VC was proportional to the FVC(S)\,-\,\%T. Although there is a 60 per cent-40 per cent split of vital capacity, the flow indices which are expressed as a per cent of the vital capacity, that is, the mean FEV_{0.5\%}\,VC and FEV_{1.0\%}\,VC are similar for the larger and smaller lungs. This suggests that the lung with the lesser volume has more expiratory delay than the larger lung, since the amount of air delivered in one-half and one second is proportional to a smaller volume. The mean values of the differential forced expiratory flows for the first and second quarters of the forced vital capacity show that the smaller lung, indeed, has increased resistance to flow. Furthermore, the routine spirometry data for the Group 1 patients reveal a mild obstructive ventilatory defect as demonstrated by the mean maximal voluntary ventilation in per cent predicted and mean FEV_{1.0\%}\,VC of 76 per cent and 69 per cent, respectively, with a vital capacity of 85 per cent of predicted.

In the Group 2 patients, the smaller lung delivered a greater proportion of the FEV_{0.5} as compared to the forced vital capacity than did the larger lung. The mean FEV_{0.5\%}\,VC and mean FEV_{1.0\%}\,VC are greater for the smaller lung than for the larger. However, in this group, the smaller lung was more severely restricted than in Groups 1 and 3, and the relatively large FEV_{0.5\%}\,VC and FEV_{1.0\%}\,VC of the smaller lung reflect a diminished lung volume rather than a relatively increased flow. This is confirmed by the forced expiratory flows for the first and second quarters of the forced vital capacity, which are in the same range for the larger and smaller lungs. The degree of expiratory delay is similar for the two lungs, and in contrast to the Group 1 cases, routine spirometry of the Group 2 patients revealed normal mean values for maximal voluntary ventilation per cent predicted and FEV_{1.0\%}\,VC and a diminished vital capacity (64 per cent of predicted).

Group 3 patients, of whom there were only two, were similar to the Group 1 patients except that the smaller lung showed even more severe obstruction when compared to the larger lung.

Thus, using the above method of analysis, it has been possible to estimate the relative degree of expiratory delay of the two lungs. In such an analysis, it is important to consider the loss of lung volume due to disease, and to use time-volume indices, such as the FEV_{0.25\%} and FEF_{25-50\%}, as well as indices which are more related to volume, such as the FEV_{0.5\%}\,VC and FEV_{1.0\%}\,VC.

**Summary**

1. Resistance to flow through the right and left lumens of Carlens bronchospirometry catheters was determined at flows above 120 liters per minute, using expired air. In 37F catheters, the difference in resistance between the two lumens remains low throughout the range tested.

2. Differential forced expiratory spiromgrams, made using 37F Carlens catheters, were studied in 19 patients with pulmonary disease, chiefly tuberculosis.

3. By comparing the split of the amount of air expired in the first one-half second with the split of the forced vital capacity, and by comparing the FEF_{0.25\%} and FEF_{25-50\%} for each lung, it was possible to estimate the relative degree of expiratory delay of the two lungs.

4. In 12 of the 19 cases, there was more expiratory delay in the smaller lung as compared with the larger; in two cases, there was much more expiratory delay in the smaller lung than the larger; and in five cases with relatively severe restriction, especially in the smaller lung, there seemed to be an equal amount of expiratory delay on the two sides.
Resumen

(1) La resistencia al flujo a través de los dos conductos, derecho e izquierdo del cateter broncoespirométrico de Carlen fue determinado para valores superiores a 120 L/min, empleando aire de expiración. En catéteres 37 F la diferencia en la resistencia entre los dos conductos se mantiene baja en toda la gama de valores en que se realizó la prueba.

(2) En diez y nueve pacientes con enfermedades pulmonares, principalmente tuberculosis, se estudiaron los espirogramas diferenciales de expiración forzada, obtenidos mediante el empleo del catéter 37 F.

(3) Comparando la cantidad de aire expirado en el primer medio y segundo y la capacidad vital forzada a través de cada conducto y comparando el flujo expiratorio forzado FEF 0-25% y FEF 25-50% para cada pulmón ha sido posible estimar el grado relativo de retardo expiratorio de ambos pulmones.

(4) En doce de diez y nueve casos se comprobó mayor retardo expiratorio en el pulmón menor, comparado con el mayor. En dos casos hubo mucho mayor retardo expiratorio en el pulmón menor comparado con el mayor y en cinco casos, con déficit de naturaleza restrictiva relativamente severo predominante en el pulmón menor, se observó un retardo expiratorio equivalente en ambos pulmones.

Zusammenfassung


2. Es wurden differenzierte Spirogramme bei forciertem Expiration überprüft unter Verwendung von Carlen’s Katheter 37 F und zwar bei 19 Patienten mit Lungenerkrankungen, hauptsächlich Tuberkulose.


4. Bei 12 von Fällen ergab sich ein stärkerer expiratorischer Verzug in der kleineren Lunge im Vergleich zur größeren; in zwei Fällen bei and eine größere expiratorische Verzögerung in der kleineren Lunge als in der größeren; und in 5 Fällen mit relativ schwerer Restriktion, besonders in der kleineren Lunge schien ein reiches Ausmaß des expiratorischen Verzugs auf beiden Seiten vorzuliegen.

Referencias


TRICUSPID VALVE REPLACEMENT

Five patients having severe mitral valve disease with significant organic tricuspid stenosis or insufficiency were treated successfully without hospital or late mortality. Four had open mitral commissurotomy with a ball-valve prosthesis in the tricuspid valve area. The fifth patient had a ball-valve prosthesis placed in both tricuspid and mitral areas along with removal of extensive left atrial clots. In all valve replacements (with one exception) the chordae tendineae-papillary muscle-annulus continuity was preserved to improve postoperative ventricular function. The valve tissue left in situ was rolled up to the annulus with a running suture before prosthetic placement. The functional capacity of these five patients has been significantly improved. There have been no late complications in any patients during the follow-up period which now ranges from 17 to 31 months.

Total ball-valve replacement of the organically inadequate tricuspid valve associated with advanced rheumatic mitral valve disease restores the right side of the heart to a more physiologic state, and this may be essential for survival in certain far-advanced cases and most certainly improves the long-term surgical palliation achieved in others.