Unilateral Positive Pressure Breathing as a Means of Partial Shift of the Pulmonary Blood Flow ¹, ²

R. RIMINI, M.D., F.C.C.P., J. L. DUOMARCO, M.D., R. BURGOS, M.D.,
J. C. DIGHIERO, M.D., J. P. SAPRIZA, M.D. and G. H. SURRACO, M.D.
Montevideo, Uruguay

Introduction

With the increased employment of irreversible collapse therapy and of pulmonary resection in the treatment of pulmonary tuberculosis, it becomes more important to predict the functional value of the remaining parenchyma. These problems have stimulated the development of complicated techniques for the study of pulmonary function with the aim to produce preoperatively the exact alterations of pulmonary and circulatory function which will occur after the proposed surgical intervention.

Bronchospirometry ¹ enables the quantitative determination of the respiratory function of each lung separately. Comparative studies between this technique and angiopneumography⁷, ¹⁴, ¹⁶, ¹⁷, ⁸, ²⁰ have demonstrated that in each stabilized pulmonary pathological process a local increase of the vascular resistance takes place, with the parallel reduction of the local circulation and of the oxygen absorption; therefore bronchospirometry also gives information on the value of the blood flow distribution between the two lungs.

On the other hand angiopneumography permits a good evaluation of the pulmonary irrigation, gives us data about the function not only of each lung separately but also of each pulmonary segment.⁷, ¹⁴, ¹⁶, ¹⁷, ⁸, ²⁰

Both techniques give us information about the actual value of the function of each lung in its two aspects, the respiratory and the circulatory, but do not permit any prevision of the potential value of each of them, i.e. up to what degree one lung is able to take over the function of the other, and insure by itself the oxygen need of the patient.

Selective angiopneumography ⁴ identifies the actual or potential pulmonary circuits, but gives no information about the influence of blood quantity which flows through the same circuits, according to their own resistance and to the pulmonary arterial pressure. For this reason it cannot show the actual functional value of the area under study.

The blockade of one main bronchus by means of a catheter with a rubber cuff,¹ or its connexion with a nitrogen atmosphere ¹⁵, ¹⁸, ¹⁴, ¹⁵, ¹⁷, ³⁶ suppress the function of the corresponding parenchyma and tries to solve "grosso modo" the problem of the potential value of the opposite lung. Both techniques have the fault that the areas excluded from their function may maintain a good irrigation ¹⁴, ¹⁵, ¹⁷, ³, ⁵, ², ¹⁰ for a long time. It

¹ From the Servicio de Asistencia y Preservación Antituberculosa del Ministerio de Salud Pública; and the Instituto de Tisiología de la Facultad de Medicina de Montevideo.
² Presented before the Sessions of the Sociedad Uruguaya de Tisiología y Enfermedades del Tórax, August 2 and November 1, 1955.

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is not therefore possible to establish whether, in the mentioned conditions, the lowered arterial oxygen saturation is due to a blood shunt or to a deficient capacity for oxygen absorption which may be present in the normally breathing lung.

The temporary unilateral occlusion of one trunk of the pulmonary artery, by means of a small rubber cuff at the tip of a cardiac double lumen catheter, is up to now the best method of deviating the blood flow from one lung to the other. This technique permits correct estimate of the potential functional value of the opposite lung and direct study of the effect of reduction of the pulmonary vascular bed on the right heart.

The object of this work is to describe a method which, with a minimum of trouble and danger for the patient, permits the deviation of a great amount of the blood flow from a lung or a lobe towards the remaining pulmonary parenchyma. This circulatory exclusion of a certain segment can be maintained for a time sufficiently long to permit estimate of the potential functional value of the remaining parenchyma. This technique is based on the fact that the increase of the alveolar pressure in a section of the lung produces a compression in the corresponding vessels, with an increase of the local circulatory resistance.

Method and Material

After laryngo-tracheal anesthesia with 5 per cent cocaine and 2 per cent xylocaine solutions, a urethral catheter of the Foley type, from No. 18 to No. 22, 48 cm. long (made opaque to x-rays in its distal end by means of a small piece of lead) is introduced in a main or lobar bronchus. Once the correct position of the catheter has been verified by fluoroscopy, the cuff (whose capacity is 5 cm.$^2$) is inflated with air until the bronchus is completely isolated. The proximal end of the catheter is then connected with the device (Figure 1), whose parts are: a glass tube of 10 mm. interior diameter, a pressurizing unit (A) (an air compressor or a tank containing air, oxygen or nitrogen under pressure), a rubber bulb (B) for the stabilization of the pressure in the system, and a water valve (C) of variable resistance.

FIGURE 1: Diagram of the device used to produce unilateral endobronchial positive pressure; see text.
With the patient in supine position, the pressure in the bronchus is increased under fluoroscopic observation, in order to avoid excessive displacement of the mediastinum. With pressures between +20 and +25 cm. of water one can notice a slight displacement of the mediastinum, a lowering of the half of the diaphragm in which the mobility is reduced, increased clearness in the half of the thorax to which the positive pressure is applied, with reduction of the transparency in the opposite half.

Under these conditions, an angiopneumography was made by injecting in one of the veins of the elbow 40 cm. of a 75 per cent solution of an iodine compound. A hand operated horizontal serigraph was used which permitted four exposures at intervals of one second. Tests were made in 10 patients: four normal, two with slight unilateral residual fibrous lesions, and four with unilateral pulmonary or pleuro-pulmonary active tuberculosis. In the six pathological cases we always tried to deviate the blood towards the sick side.

Tests were made without important disturbances for the patients and without complication. At least in rest conditions, under which these tests were made, the patients did not show respiratory difficulty and it was only possible to detect a slight acceleration of the pulse and of the respiratory rhythm.

As a complementary work, 40 subjects (6 normal and 34 with unilateral or bilateral moderately advanced active pulmonary tuberculosis) were studied following standard bronchospirometry in the sitting position. We then studied the changes in the spirometric tracing of a lung breathing oxygen at atmospheric pressure while the other lung was ventilated in open circuit with nitrogen at atmospheric or positive pressure or with oxygen at positive pressure by means of the device shown in Figure 1. With this aim, we used Gebauer's catheters* and double bronchospirometer, manufactured by McKesson, Inc. We have made tracings of the tolerance of the patients to the unilateral positive pressure test, and of the variations of the respiratory rhythm, of the minute oxygen uptake (Cons. O₂), of the respiratory minute volume (V.R.M.) and of the ventilatory or respiratory equivalent (E.R.). The unilateral positive pressure was many times applied alternatively to each lung. No deleterious effect was noted in this group of patients.

**Results and Discussion**

Figure 2 shows the series of four films obtained in a normal woman (22 years old), whose left main bronchus had been connected to a +13 cm. of water atmosphere of air. The opaque end of the catheter can be seen in the left main bronchus. There is a slight lowering of the left half of the diaphragm without deviation of the mediastinum. In the left half of the thorax can be observed a great increase in clearness because of the increased amount of air and the corresponding reduction of the capillary bed. There exists, besides, a lack of simultaneous development of opacity

*This catheter offers a great resistance to the air flow and does not permit a prolonged testing; we were not in possession of a Carlens catheter, with which we would have sufficiently overcome this inconvenience.
in the two pulmonary arteries. In films 1 and 2 the right pulmonary tree appears in its full contrast, with the typical mottling of the capillary circulation, while the left one shows less contrast limited to the principal arterial branches. Films 3 and 4 show a marked predominance of the venous tree on the right side, while the arterial filling in the left side still remains.

Figure 3 shows four films obtained in a normal woman (38 years old), whose intermediate right bronchus was maintained under positive pressure of 25 cm. of water with nitrogen (see the opaque end of the catheter in film 1). The right half of the thorax appears visibly distended, with moderate shift of the inferior mediastinum, lowering of the right half of the diaphragm and enlargement of the inferior intercostal spaces. One can notice an increase in the clearness, caused by the increased amount of air and reduction of the pulmonary capillary bed. The development of opacity in the pulmonary arteries of the two areas is not synchronous. In fact, the arteries that correspond to the right inferior and middle lobes

FIGURE 2: 23 year old woman, normal; see text.
(which undergo the positive pressure) do not appear in film 1, are evident in film 2 and remain without any further great change up to film 4, when the opaque substance has practically abandoned the unexpanded pulmonary zones (left lung and right superior lobe).

Figure 4 shows four films obtained in a woman 22 years old suffering from a right constrictive pachypleuritis subsequent to a pneumothorax and a small cavity of the right apex. A positive pressure of 25 cm. of water was maintained (in the left main bronchus) with nitrogen. The shift of the mediastinum to the right, the lowering of left leaf of the diaphragm and the increased radiolucency of the left half of the thorax existed before the test. The opaque substance circulates mostly through the sick lung as it is shown by the opacity of the right half of the thorax that attains its maximum in film 2 and decreases in the following. There are signs of circulatory delay in the left lung, in which the pulmonary artery remains unchanged in the first three films of the series.

The results obtained can be compared in the 10 cases we studied, taking,
of course, into consideration the anatomopathological differences between the areas through which we tried to deviate the blood flow and the different pressures used (between +13 and +25 cm. of water). These results demonstrate the efficiency of the suggested method as a means of blood shunting; in fact, the angiopneumograms show that in the territories which undergo the positive pressure, the contrast substance does not appear clearly, or is delayed, or is stagnant longer than in normal areas. These serious circulatory alterations, of the chronological type, correspond evidently to a great decrease in blood flow. These tests also confirm the hypothesis that the blood flow through a certain territory can naturally and easily increase with corresponding improvement of the respiratory function when the hydraulic resistance of the remaining circuits increases.\textsuperscript{14, 16, 17}

From the theoretical point of view, it is important to notice that the increase of the alveolar pressure acts in two different ways: 1) it com-

FIGURE 4: 22 year old woman, with right constrictive pachypleuritis, subsequent to a pneumothorax; see text.
presses the collapsed pulmonary veins and therefore reduces the circulatory gradient in the territory under positive pressure; 2) it reduces the vascular bed and therefore increases its resistance. It is due to this double effect that relatively small increases in pressure cause relatively marked results, even if the complete circulatory blockade can only be achieved when the intraalveolar pressure is greater than the maximum pulmonary arterial pressure.

For this reason, the present method might be in a way inferior to that due to the Swedish authors, particularly in cases in which the pressure of the pulmonary artery is high, even if the field it covers is similar. In fact the blood deviation obtained with the unilateral endobronchial positive pressure is sufficient to eliminate a great part of the blood flow from the distended pulmonary areas; it can consequently give information on the potential functional value of the remaining parenchyma and could help in the clinical valuation of the cardiac reaction to a quick increase of the circulatory resistance in a pulmonary territory. The technique herewith described reduces the ventilation and the mobility of the half of the thorax which undergoes the positive pressure while this does not happen with the temporary occlusion of a pulmonary artery.

The increase of pressure does not cause dangerous action on the pulmonary parenchyma. Much greater increases take place with the Val- salva test during which the pulmonary pressure can reach a value six times higher than the maximum pressure we used. The only limitation might be the displacement of the mediastinum which, however, has been minimal and well tolerated with the pressures we used. Lastly, it should be remembered that this technique is a simple and easy means for a blood flow shunt within the possibilities of any hospital.

We come now to some deductions from the examination of the broncho-spirometric tracings. Figure 5 represents the same normal woman as in figure 3. The spirometric tracings of both lungs are similar. The 20 cm. of water positive pressure applied with nitrogen to the right lung caused an oxygen absorption in the left lung in an amount approximately the sum of the consumptions of both lungs before the test. The same
thing happens with the ventilation while the respiratory equivalent does not change.

Figure 6 represents a woman 16 years old with residual fibrous lesions in the right lung. The minute oxygen absorption of this lung was 110 cm.\(^3\) before the test. The 20 cm. of water positive pressure applied with nitrogen to the healthy left lung increased the minute oxygen absorption of the sick lung up to 350 cm.\(^3\). This is nearly the sum of the two consumptions before the test. The ventilation of the sick lung also increases, but in a smaller proportion than the oxygen uptake, so that an increase of the respiratory equivalent (from 5.8 to 2.8) of this lung takes place.

Figure 7 represents a 22 year old woman with a right constrictive pachypleuritis subsequent to pneumothorax (the same as in figure 4). The minute oxygen absorption of the sick right lung was of 30 cm.\(^3\) before the test. The 20 cm. of positive pressure with water applied with nitrogen to the healthy left lung increased the oxygen absorption of the sick lung up to 285 cm.\(^3\). The ventilation also increased, but in a much smaller pro-

**FIGURE 6:** 16 year old woman, with residual fibrous lesions in the right lung; see text.

**FIGURE 7:** 22 year old woman, with right constrictive pachypleuritis, subsequent to a pneumothorax; see text.
portion, so that an almost complete correction of the respiratory equivalent took place (from 15.4 to 3). The positive pressure in the healthy lung was tolerated well, showing that a seriously sick lung, which previously carried only 10 per cent of the respiratory function, can handle the total amount when circumstances make it necessary at least while the patient is at rest. The positive pressure in the sick lung shows that the spirometric tracing of the healthy lung has characteristics similar to those of the tracing obtained before the test.

Figure 8 represents a man 25 years old with a right retroclavicular cavity who had to have a thoracoplasty. When the sick lung underwent 20 cm. of water positive pressure with nitrogen, oxygen absorption in the opposite lung increased from 170 to 295 cm.$^3$. The total absorption of both lungs before the test was 270 cm.$^3$. When the sick lung ventilates nitrogen at atmospheric pressure, the oxygen absorption of the left lung increases up to 450 cm.$^3$.

The results of all these bronchospirometric tests permit the deduction that, during unilateral intrapulmonic positive pressure, the absorption of the lung that breathes oxygen normally has a value close to the one corresponding to the total uptake of both lungs before the test. This observation is in accordance with the hypothesis that during unilateral positive pressure an important deviation in the blood flow towards the normally breathing lung occurs. The ventilation of the latter increases in a smaller proportion than the oxygen uptake with the corresponding improvement of the respiratory equivalent. Phenomena practically equivalent to the above mentioned appear when the unilateral intrapulmonic positive pressure is produced with oxygen instead of nitrogen.

We have regularly observed that the excessive absorption of oxygen in one lung, when the opposite ventilates nitrogen at atmospheric pressure, is greatly reduced when the pressure in the latter increases. This phenomenon is explained by the fact that the ventilation of a lung with nitrogen causes a “washing” of the oxygen from the alveoli and from the

FIGURE 8: 26 year old woman, with right retroclavicular cavity; see text.
blood, and an equivalent amount of oxygen must be absorbed by the oxygen breathing lung. This loss of oxygen is greatly reduced by the positive pressure, and this is also in accordance with the hypothesis that the mentioned positive pressure causes an important reduction of the circulatory flow in the compressed lung.

The importance of the bronchspirometric tracings, from the point of view of a quantitative determination of the blood flow deviation, is reduced due to the fact that the positive pressure can cause hypoventilation in the compressed lung, which could itself force increased oxygen uptake in the opposite lung without the corresponding shunt of the blood flow. We ignore at what point our experimental conditions may increase the mechanical work of breathing and consequently the oxygen requirements of the patient.

SUMMARY

A description is given of a method of blood shunt from a particular lung area towards the remaining pulmonary parenchyma, through local hypertension obtained by connecting the bronchus of the area under study with an atmosphere of positive pressure of 25 cm. of water or less.

The blood flow reduction, in the areas which undergo positive pressure, was demonstrated by means of angiopneumography on 10 patients: four normal, and six with unilateral pulmonary tuberculosis. Therefore, this technique permits estimate of the potential functional value of the remaining parenchyma.

As a complementary work, on a total of 40 subjects (6 normal and 34 patients with unilateral pulmonary tuberculosis), we have studied the alterations in the spirometric tracing of an oxygen breathing lung at atmospheric pressure, when the other lung was ventilated in open circuit with nitrogen at atmospheric or positive pressure or with oxygen at positive pressure.

RESUMEN

Se pasan brevemente en revista los métodos descritos hasta el momento para el estudio de la función de los dos pulmones por separado.

Se describe un método de derivación sanguínea desde un área pulmonar determinada hacia el restante parénquima pulmonar, por medio de la hipertensión localizada obtenida al conectar el bronquio del territorio estudiado con una atmósfera de presión positiva (de hasta +25 cm. de agua).

La disminución del flujo sanguíneo, en los territorios sometidos a la presión positiva, ha sido demostrada por medio de la angioneumografía en 10 pacientes: 4 normales y 6 con tuberculosis pulmonar unilateral. Esta

*We have tried to complement the bronchospirometric experiments with oxymetric tests, that would have enabled us to evaluate the pulmonary blood flow variations. In fact the lowered arterial oxygen saturation (due to the blood shunt and to the oxygen ejection), which takes place during the unilateral ventilation with nitrogen at atmospheric pressure, would have had to disappear or greatly decrease during the unilateral positive pressure breathing, the effects of which are exactly the elimination of the blood flow from pulmonary compressed sections. We have used, with this aim, Milikan’s anoxia photometer, model 17-410, manufactured by Coleman Instr. Inc., but a serious defect in the instrument, which could not be repaired in our country, made it impossible to use this test.
técnicas da así la posibilidad de apreciar el valor funcional potencial del parenquima restante.

Se discuten las ventajas y los inconvenientes del método descrito.

Como investigación complementaria, en un total de 40 pacientes (6 normales y 34 con tuberculosis pulmonar unilateral), se ha buscado de estudiar las modificaciones que se producen en el trazado broncospirométrico de un pulmón que respira oxígeno a presión atmosférica, cuando el otro pulmón es ventilado en circuito abierto con nitrógeno a presión atmosférica o a presión positiva, o con oxígeno a presión positiva.

RESUME

Les auteurs donnent la description d'une méthode qui permet de créer un shunt sanguin à partir d'une zone pulmonaire particulière vers le reste du parenchyme pulmonaire. Il est obtenu grâce à une hypertension locale due à la connection de la bronche à la zone en observation sous pression positive de 25 cm. d'eau au moins.

La réduction du débit sanguin dans les zones sous pression positive fut démontrée au moyen de l'angiopneumographie chez 10 malades: quatre sains, et six atteints de tuberculose pulmonaire unilatérale. C'est pourquoi ce procédé permet d'estimer la valeur fonctionnelle potentielle du reste du parenchyme.

Comme étude complémentaire, sur un total de 40 sujets (6 normaux et 34 atteints de tuberculose pulmonaire unilatérale) les auteurs ont étudié les modifications du tracé spirométrique de la respiration pulmonaire oxygénée à la pression atmosphérique normale alors que l'autre poumon était ventilé en circuit ouvert avec azote à la pression atmosphérique ou en pression positive ou avec oxygène en pression positive.

ZUSAMMENFASSUNG

Es wird eine Beschreibung gegeben über eine Methode eines Blut-Shunts eines bestimmten Lungenbezirkes dem übrigen Lungengewebe gegenüber, und zwar durch eine örtliche Hypertension auf dem Wege über die Verbindung des Bronchus des zu untersuchenden Bezirkes mit einer Atmosphäre eines positiven Druckes von 25 cm Wasser oder weniger.


Als ergänzende Arbeit haben wir an insgesamt 40 Personen (6 normalen und 34 mit einseitiger Lungentuberkulose) die Veränderungen in den spirometrischen Aufzeichnungen untersucht an einer mit Sauerstoff befeuerten Lunge unter atmosphärischem Druck, wenn die andere Lunge in einem offenen Kreislauf ventiliert wurde mit Stickstoff unter atmosphärischem oder positivem Druck oder mit Sauerstoff unter positivem Druck.

REFERENCES