Fluoroscopic Pulmonary Densiography*

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Kourilsky and Marchal\(^1\) presented papers at the Fourth International Congress on Disease of the Chest which stated an accuracy of 90 and 95 per cent in the diagnosis of bronchogenic carcinoma by their technique of fluoroscopic densiography. They have also reported on the use of their methods as a means of differential pulmonary function study.\(^2\) This study was undertaken because their methods appeared to offer promise of recognition of localized pulmonary disease and areas of localized dysfunction.

**Method**

A photomultiplier tube with a sodium iodide crystal is exposed to the fluoroscopic beam after passage through the chest by means of an orifice 3/32 inch in diameter and 1/8 inch long. The system is centered on the x-ray tube and mounted on the patient side of the fluoroscopic screen. The output of the tube is filtered, the impedances matched, and recorded photographically by a mirror galvanometer. Improvements in the circuitry are being made so that presentation of details will be made at an appropriate stage in the work (Fig. 1).

The direct current output is measured by a damped vacuum tube voltmeter both with and without the patient. The fluoroscopic density is the percentage drop in voltage between the output with and without the patient. The variation in the output is recorded as an indication of the volume change of the chest due to respiration.

The fluoroscope is adjusted to 80 kilovolts and 1.5 milliamperes which delivers 1.5 roentgens per minute at the table top.

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The orifice is usually placed over three areas on each side. Each area is approximately two-thirds of the distance between the spine and the lateral chest wall. The areas are subclavicular, opposite the hilus, and one interspace above the diaphragm at the end of expiration. The orifice is always placed over an anterior intercostal space and, whenever feasible, over a posterior interspace. The shutters are adjusted to expose an area about two inches square. The duration of x-ray exposure is indicated by a timer. The usual examination requires about 10 minutes, or a total exposure of about 15 roentgens. Patients in the child bearing age group are given further protection by lead shielding below the diaphragms.

Calibration circuits with corrections for filters and breathing rate permit voltage measurements of the respiratory fluctuations. These fluctuations are expressed as a percentage of the output over each area. The fluctuations of one area are expressed as a percentage of the sum of the fluctuations over one side and give an estimation of the ventilation in the

FIGURE 1: Diagram of fluoroscopic densiograph.

FIGURE 2: Male, 47 years. Bilateral pulmonary cysts and blebs. Area: left upper lung. Progressive inflation and reduction of respiratory excursions during forced respiration made an additional diagnosis of pressure cyst which was confirmed at thoracotomy.
area as compared to the total for that lung. The total fluctuations for one lung as compared to the total of both lungs give an expression of the ventilation by that lung.

Time or phase relationships are displayed by simultaneous recording of respiration at the mouth and over the area by densiography. Ventilation is recorded by a spirometer or pneumotachygraph, although the latter is favored because of its low resistance and minimal inertia. Breath holding and rapid breathing permit identification of corresponding points on the recordings. The rapid breathing also shows alteration in phase and ventilation due to change of rate. A signal light blinking 60 times a minute establishes the rate.

FIGURE 3: Male, 60 years. Diffuse obstructive pulmonary emphysema. Area: Right middle, left upper and left lower. Left upper shows reduced respiration and lags of 100° (corrected) but greater excursions at 60 respirations per minute than the right middle with normal phase and the left middle with a phase lag of minus 60° (corrected).
Results

During this study 50 patients and subjects were examined. This report is based upon the last 22 examinations, during which time no major modification was made in the technique.

Patients and subjects with normal lungs showed distribution of ventilation similar to those obtained by bronchospirometry. Two patients with unilateral radiation fibrosis showed marked reduction in ventilation on the involved side (Table I).

Patients with tumors showed increased density and decreased respiratory fluctuations. One patient, whose lung was removed the day following the examination, showed definite, though reduced, ventilation in spite of a severe chronic suppurative pneumonitis, bronchiolitis, bronchitis, and bronchiectasis.

One with bilateral pulmonary cysts and blebs showed progressive inflation in the area of a large cyst which suggested positive pressure in the cyst (Fig. 2). At thoracotomy (by Kenneth L. Morris) the cyst ballooned through the incision and was removed. The patient experienced great relief of dyspnea and returned to work after three weeks.

Respiratory fluctuations in diffuse obstructive pulmonary emphysema

<table>
<thead>
<tr>
<th>No. 703 Female 61 years. Post-irradiational fibrosis of left lung (breast carcinoma).</th>
<th>Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right per cent</td>
</tr>
<tr>
<td>Bronchospirometry</td>
<td>5,375 cc./min. 75</td>
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<tr>
<td>Densiography</td>
<td>64</td>
</tr>
</tbody>
</table>

FIGURE 4: Diffuse obstructive pulmonary emphysema. Diagnosis of air sac replacement of left lower lobe was questioned (Table III).
were variable (Table II, Fig. 3) and no distinct pattern was identified. The chest x-ray film of one patient suggested a large air sac in the left lower lobe (Fig. 4). The densiogram showed good respiratory fluctuations in the left lower area with reduction in the left upper area so the diagnosis of an air sac was questioned (Table III). Thoracotomy revealed the left lobe to be extremely emphysematous with numerous blebs, but without sacs or bullae.

**FIGURE 5:** Fluoroscopic densiogram and pneumotachygram. Male, 58 yrs. Bronchogenic carcinoma of right upper lobe confirmed at pneumonectomy. Areas: right upper and middle lung "ID" and "IP" indicate the beginning of inspiration on the densiogram and pneumotachygram respectively. Over the shadow, breathing at the mouth lags breathing over the area by 180° observed or 260° corrected.
Below the shadow the densiogram lags 60° observed or 20° corrected behind the pneumotachygram. This is thought to be within normal limits.
TABLE II—FLUOROSCOPIC DENSIOGRAPHY REPORT

<table>
<thead>
<tr>
<th>Area</th>
<th>Output, V.</th>
<th>Density, %</th>
<th>Area, V.</th>
<th>Lung, %</th>
<th>Total, %</th>
<th>Rate/min.</th>
<th>Phase, °</th>
<th>Rate</th>
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TABLE III—FLUOROSCOPIC DENSIOGRAPHY

<table>
<thead>
<tr>
<th>Area</th>
<th>Right per cent</th>
<th>Left per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
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<td>Middle</td>
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<td>40</td>
</tr>
<tr>
<td>Lower</td>
<td>48</td>
<td>46</td>
</tr>
</tbody>
</table>

Right lung 59 per cent. Left lung 41 per cent.

FIGURE 6: Fluoroscopic densiogram and pneumotachygram. Female, 50 years. Normal. Area: Right lower lung. Quiet breathing and breath holding. Quiet breathing is normal but during breath holding there is an expiratory drift followed by normal recovery. Insensible respiration may account for the drift.
Patients and subjects with normal lungs have minimal phase difference between the ventilation at the mouth and over the various areas.

One patient with an extra-pleural paraffin pack and three with localized bronchogenic carcinoma showed, over the shadow or adjacent to the shadow, that the respiratory fluctuations preceded the air movements at the mouth as demonstrated by the pneumotachygram (Fig. 5).

Patients with obstructive pulmonary emphysema demonstrated a definite lag in the ventilation of some areas behind the breathing at the mouth. No pattern was developed. In some patients this lag disappeared during voluntary tachypnea; in some, air flow continued at a slow rate during breath holding, however, this may be failure of complete cessation of respiration (Fig. 6). In one the phase lag disappeared after an intermittent positive pressure breathing treatment with a bronchodilator aerosol only to reappear in another area (Fig. 7).

FIGURE 7: Fluoroscopic densiogram, spirogram and electrocardiogram. Male, 57 years. Obstructive pulmonary emphysema. Area: Left middle lung. Quiet breathing before and after intermittent positive pressure breathing, inspiration with 0.5 cc. Isoproterenol hydrochloride. A lag of approximately 180° before is normal after the therapy.
DISCUSSION

During inspiration the volume increase of the chest cavity produces stretching and thinning of pulmonary structures. This causes the fluoroscopic beam to traverse less tissue with less absorption and greater output, which is the commonly observed brightening of the lung fields. Fluoroscopic densiography is a method of recording this phenomena but with a degree of sensitivity greater than visual perception and confined to small areas. This method has been criticized on the basis that the anterior-posterior movement of the chest, being greater in the superior than in the inferior areas, would produce inaccuracies. If the lungs are perfectly elastic, the thinning of the structures will be of similar order regardless of the direction of maximum chest wall movements. In the absence of localized disease, expression of the total respiratory fluctuations of one lung as a percentage of the total of both lungs gives figures similar to those developed by bronchospirometry, that is, right 55 per cent and left 45 per cent. This suggests reliability of the data.

Fluoroscopic densiography is related only to ventilation and, unlike bronchospirometry, it gives no indication of lung function in terms of oxygen consumption. It requires neither local anesthesia, premedication nor the introduction of tubes which present a degree of obstruction to air flow and possible alteration of respiratory reflexes. The mental strain for the patient is minimal. Radiation exposure necessitates limitation of the duration and x-ray factors in this type of examination, although the exposures used are less than with most fluoroscopic examinations of the stomach. Low x-ray factors, minimal exposure during placement of the orifice, use of small shutter openings, automatic timing of exposure, radiation shielding, and calibration of the tube output are utilized to control exposure.

All measurements are made in the anterior-posterior axis. Overlapping of lobes except over the infraclavicular space, occurs so the terms “middle” and “lower” apply to areas and not to lobes. Recordings over the left lower lung areas are apt to be distorted due to mechanical compression by cardiac pulsations.

In addition to the lungs themselves, the x-ray density of the chest is affected by size, body build, muscular development and amount of adipose tissue, as well as by the distance of the orifice from the tube and patient, and to a lesser extent by the size of the shutter opening. No attempt has been made to attach significance to the absolute value of the density or the respiratory fluctuations. Breast density in the lower lung areas and well developed pectoral muscles reduce respiratory fluctuations.

Phase differences between air flow in different areas of the lung result in flow of air from one area into another, termed “pseuduff,” and may contribute to the sequential ventilation of Fowler. Such uneven ventilation produces inefficiency in ventilation and is strongly suggested by these observations. The phase differences observed were so extreme as to question their validity. Phase differences produced by the circuitry were recognized, measured and phase differences due to a rib or scapula moving into and out of the field were considered, but it was impossible to show that such artefacts produced the phase abnormalities. A columnating orifice was tried but rib movement made such violent fluctuations that it was abandoned.

It is difficult to explain the phase differences by the analogies, described by Olsen, between acoustical air flow systems composed of pressure, resistance and inerterance, and mechanical and electrical systems. The change in phase between quiet breathing and voluntary tachypnea suggests that these factors are pertinent. To explain the phase alterations solely on the basis of lung compliance or obstruction is of doubtful accuracy. Obstruction to air flow in a subject, and compliance and air flow resistance differences in models, produce phase alteration, as shown by Otis, but not to the extent observed in this study.

The lesions seen in the patients with reversal of lag were characterized by extreme stiffness or minimal compliance. These relatively unyielding masses may transmit pressures an advantage over bronchospirometry. This observation suggests that an additional factor exists, that is, the transmission of pressure through the lung parenchyma by continuity of lung architecture and its contents. This factor may act in addition to the factors effecting phase relationship of the air flow system and account for the extreme phase differences observed.

SUMMARY

A preliminary report is presented of fluoroscopic densiography as a method of pulmonary function study which approaches measurements of pulmonary ventilation over small areas of the lungs. After passage through the chest, the x-ray beam is transferred into electrical energy, modified and recorded on a strip chart.

Fluoroscopic density is expressed as a percentage of the x-ray absorption. Respiratory fluctuation in an area is expressed as a percentage of the transmitted x-ray by the chest in that area. The fluctuation may be expressed as a percentage of the total fluctuation of one lung. The total fluctuation of one lung may be expressed as a
percentage of the total of both lungs. These densities and fluctuations are altered in disease.

Time relations between air flow at the mouth and the respiratory fluctuations show phase relationships varying from normals of zero lags as high as 140 degrees in obstructive pulmonary emphysema and the opposite of lesser degree in bronchogenic carcinoma.

This preliminary study suggests that fluoroscopic densiography may offer a valuable addition to pulmonary function studies in normal and disease states and may contribute diagnostic criteria.

RESUMEN

Se presenta una comunicación preliminar sobre la densografía como método de estudio de la función pulmonar que tiende a obtener medidas de la ventilación pulmonar sobre áreas pequeñas del pulmón. Después de pasar a través del tórax el haz de rayos X, se transforma en energía eléctrica que se modifica y se registra en una gráfica. La densidad fluoroscópica se expresa como un porcentaje de la absorción de Rayos X. La fluctuación respiratoria en un área se expresa como porcentaje de los rayos X transmitidos por el tórax en esa área. La fluctuación puede expresarse como un porcentaje de la fluctuación total de un pulmón puede expresarse como un porcentaje del total de ambos pulmones. Estas densidades y fluctuaciones están alteradas en la enfermedad.

Las relaciones de tiempo entre la corriente de aire en la boca y las fluctuaciones, muestran relaciones de fase variando desde normales de cero hasta puntos tan altos como 140° grados de emísisma obstructivo y lo opuesto en menor grado en el carcinoma bronquiogénico. Este estudio preliminar sugiere que la densografía puede ofrecer un agregado valioso a los estudios de la función pulmonar en los estados normal y patológico y puede contribuir a formar un criterio diagnóstico.

RESUME

L'auteur présente un rapport préliminaire sur la densigraphie radioscopique comme procédé d'étude de la fonction pulmonaire. Cette méthode permet de mesurer la ventilation pulmonaire sur de petites zones des poumons. Après passage à travers le thorax, le rayon X est transformé en énergie électrique, modifié et enregistré sur bande.

La densité radioscopique est exprimée en pourcentage d'absorption radiologique. La modification respiratoire dans la zone est exprimée en pourcentage des rayons transmis par le thorax dans cette zone. La modification peut être exprimée comme le pourcentage de la modification totale du poumon. La modification totale d'un seul poumon peut être exprimée comme un pourcentage de la modification totale des deux poumons. Ces densités et modifications sont altérées dans les cas pathologiques.

Les rapports de temps entre le débit de l'air mesuré à la bouche et ces modifications respiratoires montrent des coefficients variant de la normale (zéro) à des retards atteignant 140 degrés dans l'emphysème pulmonaire obstructif et au contraire à un degré peu élevé dans le cancer bronchique.

L'étude préliminaire permet de penser que la densigraphie radioscopique peut offrir un procédé valable supplémentaire pour l'étude de la fonction pulmonaire dans les états normaux et pathologiques et peut contribuer à apporter des éléments de diagnostic.

ZUSAMMENFASSUNG


Diese vorläufige Untersuchung lässt die Erwartung zu, dass die Leuchtschirmdensographie sich als ein wertvoller Zuwachs erbietet für Lungenfunktionsprüfungen bei normalen und bei krankhaften Befunden und dass sie diagnostische Kriterien erbringen kann.

REFERENCES


