The Value of Portable Chest Roentgenography in Adult Respiratory Distress Syndrome*

Comparison with Computed Tomography

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In 17 patients with adult respiratory distress syndrome, we used data derived from computed tomographic (CT) scan densitometric analysis to validate the value of portable chest roentgenograms in objectively estimating the amount of pulmonary edema. Chest roentgenograms and CT scans were taken in the same ventilatory conditions (apnea at 10 cm H2O of positive end-expiratory pressure [PEEP]); blood gas samples and hemodynamic parameters were collected at the same time. Roentgenographic analysis was undertaken by independent observers using two standardized scoring systems proposed in the literature. CT scan analysis was performed using the CT number frequency distribution and the gas lung volume (measured by helium dilution technique) to estimate quantitatively the lung density, the lung weight, and the percentage of normally aerated and nonaerated tissue. Knowing the mean CT number of the pulmonary parenchyma in a group of normal subjects, we also inferred the ideal lung weight expected in the study population and computed the excess tissue mass as the difference between actual and ideal lung weight. Both the roentgenographic scoring systems showed direct correlation with the pulmonary impairment as detected by CT scan densitometric analysis (CT number, percentage of nonaerated tissue, lung weight, and excess tissue mass; p<0.01) and inverse relation with the percentage of normally aerated tissue (p<0.01). We also found a relationship between roentgenographic scores and the impairment in gas exchange as detected by shunt fraction (p<0.05). We conclude that standardized reading of portable chest roentgenograms by means of scoring tables is a valuable tool in estimating the amount of pulmonary edema in a patient with adult respiratory distress syndrome.

The presence of diffuse alveolar infiltrates on the chest roentgenogram is a characteristic feature of the adult respiratory distress syndrome (ARDS), a clinical disorder consisting of parenchymal inflammation, permeability pulmonary edema, severe dyspnea, and refractory hypoxemia.1-3

The accumulation of fluid in the extravascular space, by replacing the gas density with a water-equivalent density, yields a progressive increase in the overall lung tissue density that is visualized on the chest roentgenogram.

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The best approach to evaluate lung edema in patients with ARDS should be the direct measurement of the amount of extravascular lung water (EVLW). However, the assessment of EVLW by indicator dilution techniques is limited by the invasiveness of the procedures and by the possible regional abnormalities in lung perfusion, leading to an underestimate of EVLW.4-5 Vascular obstructions have been, indeed, extensively reported in autopsy lung specimens from ARDS patients4 and also have been demonstrated clinically by bedside pulmonary angiography5,6 and perfusion lung scanning.7

More sophisticated techniques for lung water measurement, such as nuclear resonance8 or positron emission tomography9,10 are restricted in their application by high cost and low practicality.

Hence, at the present time, the chest roentgenogram is the only practical means available to evaluate pulmonary edema in critically ill patients.11 Chest roentgenography provides excellent information about regional distribution of lung edema and, unlike indicator dilution techniques, does not depend on active
arterial perfusion of edematous areas. Evaluation of lung density by chest roentgenography is, however, affected, to a various extent, by the degree of lung inflation, the superimposition of lung structures with different density, and the quality of the roentgenography film, especially when obtained under emergency conditions.

Furthermore, it is widely objected that the evaluation of roentgenographic findings may be affected by the subjective interpretation of the reader. With the present study, we aim to reappraise chest roentgenography as a valuable method to assess lung edema in patients with acute respiratory failure (ARF) by comparing a standardized reading of portable chest roentgenograms with the determination of lung tissue density obtained by computed tomography (CT).

**Material and Methods**

**Patient Population**

This study was conducted in the frame of a project for the study of ARDS approved by the Human Studies Committee of the Lombardia Region. Informed consent was obtained from the patients or relatives before the study.

The study group consisted of 17 patients (11 males, six females; mean age, 41 ± 18 years) with ARDS of various causes (four bacterial pneumonia; five viral pneumonia; four polytrauma; and four others [peritonitis, sepsis, pulmonary embolism,encephalitis]); there were 11 survivors and six nonsurvivors. All the patients were intubated and mechanically ventilated and had a flow-directed thermilization Swan-Ganz catheter and an arterial cannula inserted, prior to the study, for clinical reasons. No patient had a history of lung disease.

**Experimental Procedure**

The patients were studied after a mean of 4 ± 3 days (range, 1 to 11 days) after the onset of full-blown respiratory failure as indicated by the intubation time. All the patients were kept in paralysis (pancuronium bromide) and intravenous anesthesia (Pentanyl, thiopental sodium) was given throughout the study.

The chest roentgenograms were taken in the intensive care unit (ICU) during apnea with the lung inflated at 10 cm H₂O positive end-expiratory pressure (PEEP), in the supine position. Portable chest roentgenography equipment was used (Toshiba); the electron power ranged between 48 and 56 kV according to the patient's size; the exposure time was kept below 0.2 s, while the distance between the focus and the film plane was 120 cm.

Within 1 to 2 h of the chest roentgenograms, the patients were transferred to the Radiology Department to undergo the CT scan (Pfizer AS/EO CT scanner). The exposures were taken at 120 kV, 50 mA, and 5 s. Slice thickness was 9 mm and the dimensions of the pixels of the reconstruction matrix were 1.5 × 1.5 mm × 9 mm. The system was previously calibrated by a suitable phantom.

Before the CT scan, the mechanical ventilation was delivered at the same parameters used in ICU before the chest roentgenogram (i.e., FiO₂, 0.6 to 1.0, according to clinical conditions; tidal volume, 10 ml kg⁻¹; respiratory rate, 16 to 22 beats per minute; square wave form; inspiratory-expiratory ratio, 1:1; inspiratory pause, 0; PEEP, 10 cm H₂O).

The first level of exposure was above the carina (apex), the second was approximately at the hilum (hilum), and the third was above the diaphragm (base). Every exposure was performed with the patient in apnea at 10 cm H₂O PEEP, as during chest roentgenograms.

**Physiologic Parameters**

The functional residual capacity (FRC) was measured at atmospheric pressure by helium dilution technique, while the compliance of the total respiratory system (TSCL) was measured by a supersyringe through step-by-step inflation-deflation (100 ml step) and the volume pressure curve was then drawn manually.

The lung volume at 10 cm H₂O PEEP was computed adding to the measured FRC the volume computed on the inflation limb of the V/P curve to reach 10 cm H₂O pressure.

Blood samples, arterial (arterial cannula) and mixed venous (Swan-Ganz catheter), were taken after the CT scan and analyzed for gas tensions (Pao₂, Paco₂, IL 1312 pH/Blood Gas Analyzer) and oxygen saturation (IL CO-Oximeter 283). The right-to-left shunt fraction (Qsp/Qt) was computed according to the standard formula.

The mean pulmonary artery pressure (PAP) and the mean pulmonary capillary pressure (WP) were measured by transducers (Bentley Trantec) and recorded by monitor (128 Kontron); cardiac output (CO) was measured in triplicate by thermilization (CO-Edwards) and cardiac index (CI) was computed.

**Table 1—Roentgenographic Scoring of Lung Edema in ARF**

<table>
<thead>
<tr>
<th>X-Ray Finding</th>
<th>Score A*</th>
<th>Score B†</th>
</tr>
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<tbody>
<tr>
<td>Right-sided cardiac enlargement with bulging of main pulmonary artery</td>
<td>2,4</td>
<td>Normal</td>
</tr>
<tr>
<td>Hilar abnormalities (size and density)</td>
<td>1,2</td>
<td>Pulmonary vascular congestion</td>
</tr>
<tr>
<td>Air bronchogram</td>
<td>2,4</td>
<td>Mild</td>
</tr>
<tr>
<td>Lung density increase</td>
<td></td>
<td>Moderate</td>
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<table>
<thead>
<tr>
<th>X-Ray Finding</th>
<th>Score</th>
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</thead>
<tbody>
<tr>
<td>Hazy</td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>1,2</td>
</tr>
<tr>
<td>Peripheral</td>
<td>2,4</td>
</tr>
<tr>
<td>Central and peripheral</td>
<td>3,6</td>
</tr>
<tr>
<td>Patchy</td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>2,4</td>
</tr>
<tr>
<td>Peripheral</td>
<td>5,10</td>
</tr>
<tr>
<td>Central and peripheral</td>
<td>7,14</td>
</tr>
<tr>
<td>Extensive white density</td>
<td>20</td>
</tr>
</tbody>
</table>

*Each lung is scored separately: score range, 0 to 52 (Pistolesi).
†The right and left lungs were divided into a total of six regions: two upper, two lower, and two peripheral regions: score range, 0 to 300 (Halperin).
Table 2—Image Analysis

<table>
<thead>
<tr>
<th>Normal Value</th>
<th>Patient Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>(n = 7)</td>
<td>(n = 17)</td>
</tr>
<tr>
<td>Mean CT No.</td>
<td>−699 ± 11</td>
</tr>
<tr>
<td>Normally aerated tissue, %</td>
<td>77 ± 3</td>
</tr>
<tr>
<td>Poorly aerated tissue, %</td>
<td>16 ± 2</td>
</tr>
<tr>
<td>Nonaerated tissue, %</td>
<td>7 ± 1</td>
</tr>
<tr>
<td>Mean lung weight, g kg⁻¹</td>
<td>19 ± 2</td>
</tr>
<tr>
<td>Score A</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>(scaled 0-52) Range</td>
<td>12-48</td>
</tr>
<tr>
<td>Score B</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>(scaled 0-390) Range</td>
<td>130-365</td>
</tr>
</tbody>
</table>

The CT number reflects the physical density, i.e., the ratio between the volume of gas plus the volume of gas plus the volume of tissue, and being the total amount of gas present in the lung known by an independent measurement (FRC by helium dilution), we could estimate the lung tissue weight (considering the specific weight of the lung tissue = 1) rearranging the following equation:

\[ \text{Volume of Gas} = \frac{\text{CT Number of Air} - \text{CT Number of Water}}{\text{Mean CT Number of the Whole Lung}} \]

Moreover, knowing the CT frequency distribution, the weight for each compartment (normally aerated, poorly aerated, and non-aerated) was computed. The lump weight, computed as above, includes the lung structural mass, the blood, and the EVLW.

The normal expected values (ideal lung weight) for a given patient were computed according to the above equation by substituting as gas volume the expected normal FRC (according to the equation proposed by Ibanez and Rauck\(14\) for supine and paralyzed patients), and substituting as mean CT number the mean CT value we found in normal subjects at atmospheric pressure. (It is worth emphasizing that the dispersion of CT number, in normal individuals, is very narrow. See Table 2).

The percentage of increase in lung tissue mass (excess tissue mass) was then computed as the difference between actual and expected normal lung weight indexed to the latest.

Statistical Analysis

The results are reported as mean ± standard deviation. Coefficients of linear correlation and regression lines were calculated according to standard methods.

Results

Physiologic and Imaging Parameters of the Study Population

Some of the most relevant gas exchange, lung mechanics and hemodynamic parameters of the patient population at the time of the study are summarized in Table 3. These parameters were taken with the patient in paralysis and anesthesia during mechanical ventilation with PEEP of 10 cm H₂O.

The gas exchange parameters are consistent with

<table>
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<tr>
<th>Table 3—Physiologic Parameters</th>
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<tr>
<td>Qsp/Qt</td>
</tr>
<tr>
<td>Mean ± SD</td>
</tr>
<tr>
<td>0.40 ± 0.15</td>
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</tbody>
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Portable Chest Roentgenography in ARDS (Bombino et al)
moderate to severe ARDS, according to previously published criteria.52,34

The quantitative data derived from CT scan analysis are reported, in average, in Table 2, as well as the mean score obtained by the two roentgenographic scoring procedures (A and B). Reference values obtained in seven normal subjects are added for comparison.

Figure 1 shows a typical ARDS imaging study, as detectable by portable chest roentgenogram and CT scan, with the patient in the supine position and the same degree of lung inflation (during apnea, 10 cm H2O PEEP).

Chest Roentgenography Scoring System

The intraobserver variability averaged 6.1 percent (range, 0 to 22 percent) and 6.7 percent (range, 0 to 19 percent), considering score A, and 5.8 percent (range, 0 to 23 percent) and 9.6 percent (range, 1 to 31 percent) considering score B.

The interobserver variability averaged 9.2 percent (range, 0 to 28 percent) and 6.1 percent (range, 0 to 17 percent) for score A and B, respectively.

As shown in Figure 2, the two scoring systems were significantly correlated in linear fashion over the entire range of score assigned.

Relationship between Chest Roentgenography and CT Scan Analysis

All the variables derived by the quantitative CT scan analysis were significantly associated with the standardized roentgenographic readings. Figure 3 shows the relationship we found between CT scan density and the scores A and B. The roentgenographic scores A and B were also directly related to the fraction of nonaerated tissue and inversely related to the fraction of normally aerated tissue, as shown in Figures 4 and 5, respectively.

Finally, both the lung weight (expressed in g kg⁻¹)

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**Figure 1.** Portable chest roentgenogram and CT scan (apex, hilum, and basis) appearance in a patient with ARDS due to peritonitis. Roentgenographic scores were 44 (range, 12 to 48) for score A and 349 (range, 130 to 965) for score B. CT scan analysis showed a percent of nonaerated tissue of 65.6 percent, while the normally aerated tissue was 11 percent. The mean lung weight for body weight was 56.76 g, four times the normal value. The shunt fraction in this patient was 44 percent.

**Figure 2.** Relationship between the two roentgenographic scoring systems (see Table 1).
and the excess tissue mass were strictly related to the scores A and B according to the following equations:

- Mean Lung Weight = 9.72 + 1.12 Score A \( (r=0.71, p<0.001) \)
- Mean Lung Weight = -5.39 + 0.19 Score B \( (r=0.75, p<0.001) \)
- Excess Tissue Mass = -0.36 + 0.07 Score A \( (r=0.69, p<0.01) \)
- Excess Tissue Mass = -1.40 + 1.84 Score B \( (r=0.74, p<0.001) \)

**Imaging and Physiologic Parameters**

Both the parametric (CT scan) and nonparametric (roentgenographic scores) data were related to the severity of ARDS evaluated by the impairment in gas exchange. The nonaerated tissue, as detected by CT scan, and both A and B scoring values were in fact significantly correlated with the shunt fraction \( (Q_{sp}/Qt) \):

- \( Q_{sp}/Qt \) vs percent nonaerated tissue \( r=0.61, p<0.05 \)
- \( Q_{sp}/Qt \) vs score A \( r=0.61, p<0.05 \)
- \( Q_{sp}/Qt \) vs score B \( r=0.53, p<0.05 \)

**DISCUSSION**

During the last few years, we used data derived from CT scan analysis to investigate the mechanisms...
by which the application of a PEEP may affect gas exchange in ARDS patients (recruitment of lung zones expressed as decreased lung densities) and to relate the CT scan data to the mechanical properties of the diseased lung. The population in this study is part of that larger group of ARDS patients in whom a portable chest roentgenogram in standardized condition was performed for comparison with CT scan image.

The clinical value of chest CT scan as a diagnostic tool in pulmonary medicine is surely not in discussion and received considerable attention in the last years. Routine portable chest roentgenograms still have the greatest application in the assessment of lung impairment in critically ill patients, and the information derived from comparison of roentgenograms is used daily to evaluate the occurrence of new parenchymal infiltrates or pleural effusions or in emergency situations (tension pneumothorax, hyperinflation, etc); a CT scan is necessary when the clinical course diverges from the roentgenographic findings, and it is still limited in its applicability because of the cost and mainly because of the cumbersome transport of a critically ill patient to the CT room.

Both CT scan and chest roentgenography give us information about densities, their distribution pattern (morphology), and their entity. One of the hallmarks of ARDS definition, the roentgenographic appearance of diffuse parenchymal infiltrates, has been questioned by CT scan studies performed by our group and others that pointed out a prevalent localization of lung densities in the dependent zones of the lung with preservation of regions with near-normal gas/tissue ratio. However, the topography of densities seems not to affect the sensitivity of the scoring systems in detecting the overall lung impairment as shown in Figure 1 where a four times increase in lung weight compared with normal value (as computed by CT scan data) correlates with comparable high roentgenographic scores.

No attempt was made to have a more uniform population, and the variability between physiologic parameters can be due to different timing in the evolution of the illness at the moment of the study (1 to 11 days from intubation) and accounts for the different degree of lung impairment, as assessed by CT scan (Tables 2 and 3). The physiologic parameters in Table 3 describe the degree of functional deterioration in gas exchange, pulmonary mechanics, and hemodynamics, while the comparison with a normal population in Table 2 suggests the degree of "structural" impairment as detected by CT scan analysis, with a two times increase in lung weight in our population when compared with the mean value in seven volunteers comparable for age and anthropometric parameters.

To assess the objective value of the scoring systems proposed to evaluate the amount of pulmonary edema, we decided to keep the two readers completely unaware of the clinical history and course, as well as of physiologic and CT scan data, to avoid possible biases due to patient knowledge. The low intraobserver and interobserver variability points out that a scoring system can enhance the semiquantitative value of chest roentgenography, leaving less subjectivity in the evaluation of lung impairment. Others used arbitrary grades of pulmonary infiltrates to quantify lung edema on chest roentgenograms; conversely, the scoring systems we used are based also on the recognition of specific findings correlated to the presence of edema that are graded and contribute to the final score assigned to the chest roentgenogram under examination. This may enhance the ability of the
reader to detect small changes in the roentgenogram, leading to less misinterpretation of the lung impairment. Both the scoring systems evaluated in this study seem to agree in the estimation of the degree of pulmonary edema (Fig 2), despite the different procedure used in the analysis of the chest roentgenograms.

The use of data from CT scan image analysis for the validation of roentgenographic scores has its rationale in the objective quantification of lung impairment assessed by CT scan density analysis. The regressions in Figures 3, 4, and 5 show a good correlation between CT scan data and roentgenographic scores. However, we have to point out that the scatter of data points in these regression lines can reflect some of the limitations of the semiquantitative methods in chest roentgenography readings (overestimation of density in the supine position or underestimation of density in an area with relative hyperinflation, for example). On the other hand, CT scan analysis does not allow differentiation of densities due to EVLW and consolidation or blood pooling.

A previous work comparing roentgenographic detection of pulmonary edema with the assessment of EVLW by thermal-dye dilution technique concluded that the chest roentgenogram does not give a good estimation of lung edema. The authors made the a priori statement that EVLW measurements by thermal-dye dilution gives the real assessment of the amount of pulmonary edema. To assess the actual EVLW in a given lung, the thermal-dye indicator is supposed to "see" all the areas of the parenchyma under investigation. If perfusion does not occur in some zones, as described in ARDS lung, these are excluded from analysis leading to an underestimation of the amount of pulmonary edema. Conversely, the high diffusibility of the thermal indicator may lead to a overestimation of edema due to the possibility of "reading" the blood distal to microemboli as extravascular.

In the same article, the authors did not find any correlation between "functional" deterioration, as assessed by the degree of Qsp/Qt, and the assessment of EVLW by thermal-dye dilution technique. In our study, both the roentgenographic scores and the CT-derived data were correlated to the degree of gas-exchange impairment of the diseased lung. However, our patient population was more uniform than that reported in the other article, all of our patients having noncardiogenic pulmonary edema, and we cannot infer from our data that this would apply to other patients with ARF not due to ARDS. Pistolesi et al., in fact, developed different scoring procedures for cardiogenic and noncardiogenic pulmonary edema.

The good correlations we found between the roentgenographic scores and both the actual lung weight and the excess tissue mass computed by CT scan analysis led us to the conclusion that the sensitivity of standardized chest roentgenographic readings in detecting the amount of pulmonary edema is at least as good as CT scans.

In a recent workshop about lung water measurement techniques, the conclusion was that at this time, chest roentgenography is still the "reference standard which other lung water content methods are compared." Chest roentgenographic readings with scoring systems may enhance the accuracy, sensitivity, and reproducibility in detecting pulmonary edema. It is important to record for any patient the condition in which the chest roentgenogram has been done and standardize those technical parameters (distance from the focus, intensity, time) that can enhance the reproducibility of roentgenograms. This would be the starting point in performing a comparison between sequential chest roentgenograms and other techniques to study the evolution of pulmonary edema.

REFERENCES