Computer-aided recognition of emphysema on digital chest radiography.

Original Citation:

Availability:
This version is available at: 2158/774318 since:

Published version:
DOI: 10.1016/j.ejrad.2010.08.021

Terms of use:
Open Access
La pubblicazione è resa disponibile sotto le norme e i termini della licenza di deposito, secondo quanto stabilito dalla Policy per l'accesso aperto dell'Università degli Studi di Firenze (https://www.sba.unifi.it/upload/policy-oa-2016-1.pdf)

Publisher copyright claim:

(Article begins on next page)
Computer-aided recognition of emphysema on digital chest radiography

Massimo Miniati\textsuperscript{a,}\textsuperscript{*}, Giuseppe Coppini\textsuperscript{b}, Simonetta Monti\textsuperscript{b}, Matteo Bottai\textsuperscript{c,d}, Marco Paterni\textsuperscript{b}, Ezio Maria Ferdeghini\textsuperscript{b}

\textsuperscript{a} Department of Medical and Surgical Critical Care, University of Florence, 50134 Florence, Italy
\textsuperscript{b} Institute of Clinical Physiology, National Research Council, 56124 Pisa, Italy
\textsuperscript{c} Unit of Biostatistics, Institute of Environmental Medicine, Karolinska Institutet, 17177 Stockholm, Sweden
\textsuperscript{d} Division of Biostatistics, Arnold School of Public Health, University of South Carolina, 29208 Columbia, SC, USA

\section{Article Info}

\begin{itemize}
\item Article history:
  \begin{itemize}
  \item Received 30 April 2010
  \item Received in revised form 12 August 2010
  \item Accepted 17 August 2010
  \end{itemize}
\item Key words:
  \begin{itemize}
  \item Emphysema
  \item Diagnosis
  \item Computed tomography of the chest
  \item Digital chest radiography
  \item Neural networks
  \end{itemize}
\end{itemize}

\section{Abstract}

\textbf{Background:} Computed tomography (CT) is the benchmark for diagnosis emphysema, but is costly and imparts a substantial radiation burden to the patient.

\textbf{Objective:} To develop a computer-aided procedure that allows recognition of emphysema on digital chest radiography by using simple descriptors of the lung shape. The procedure was tested against CT.

\textbf{Methods:} Patients (\(N=225\)), who had undergone postero-anterior and lateral digital chest radiographs and CT for diagnostic purposes, were studied and divided in a derivation (\(N=118\)) and in a validation sample (\(N=107\)).

CT images were scored for emphysema using the picture-grading method. Simple descriptors that measure the bending characteristics of the lung profile on chest radiography were automatically extracted from the derivation sample, and applied to train a neural network to assign a probability of emphysema between 0 and 1. The diagnostic performance of the procedure was described by the area under the receiver operating characteristic curve (AUC).

\textbf{Results:} AUC was 0.985 (95\% confidence interval, 0.965–0.998) in the derivation sample, and 0.975 (95\% confidence interval, 0.936–0.998) in the validation sample. At a probability cutpoint of 0.55, the procedure yielded 92\% sensitivity and 96\% specificity in the derivation sample; 90\% sensitivity and 97\% specificity in the validation sample. False negatives on chest radiography had trace or mild emphysema on CT.

\textbf{Conclusions:} The computer-aided procedure is simple and inexpensive, and permits quick recognition of emphysema on digital chest radiographs.

\textcopyright 2010 Elsevier Ireland Ltd. All rights reserved.
2. Methods

2.1. Sample

The study sample comprised 225 consecutive patients who were evaluated at the Institute of Clinical Physiology, Pisa (Italy) between June 1, 2007 and July 31, 2008. In these patients, CT of the thorax and postero-anterior and lateral digital chest radiographs were obtained for diagnostic purposes within a week of each other.

Most of the patients (85%) underwent CT for the presence of a solitary pulmonary nodule on chest radiography. The other patients had CT as part of their investigation for suspected pulmonary arterial hypertension.

For the sake of the present study, the patients were divided into two groups: (a) derivation sample (N=118), whose chest radiographs were used to develop the computer-aided procedure for emphysema recognition, and (b) validation sample (N=107), whose chest radiographs were used to test the diagnostic accuracy of the procedure.

The patients in the derivation sample had a median age of 65 years (interquartile range [IQR], 56–70 years); 96 (81%) of them were males. In the validation sample, the patients' median age was 66 years (IQR, 57–73 years), and the proportion of males 56%.

Chronic obstructive pulmonary disease (COPD) was rated present on spirometry if the post-bronchodilator ratio of forced expiratory volume in 1 s (FEV1) over forced vital capacity (FVC) was less than 0.70. The severity of COPD was staged according to the GOLD guidelines from 0 (no emphysema) to 100 using the panel grading (PG) method.

The procedure begins with the extraction of the lung contours on chest radiography. Based on a preliminary study with different net-planes that are arranged at intervals of 5 between 0 and 50, and at intervals of 10 between 60 and 100. A score of 5 or less is consistent with trace emphysema, a score >30–50 indicates mild emphysema, a score >30–50 moderate emphysema, and a score >50–100 severe emphysema.

In scoring emphysema on CT, the two raters examined sagittal lung sections, and gave them the score of the standard most closely similar, or a score between two standards. The PG scores by the two independent raters were averaged.

2.3. Chest radiography

Postero-anterior and lateral digital chest radiographs (Thorax 2000, IMIX, Finland) were obtained at a standard 2-m focus to detector distance with the patients upright holding their breath at full inspiration. Each radiographic image was 2000 × 2000 pixels (198 µm per pixel) in size with a dynamic range of 12 bits. Images were obtained by the acquisition equipment in standard operational conditions, and no further post-processing was applied. Chest radiographs had the identification data removed, and were stored in DICOM format for further analysis as described below.

2.4. Descriptors of the lung shape

The procedure begins with the extraction of the lung contours in the postero-anterior and lateral chest radiographs. This is the only interactive part of the procedure that is accomplished by locating a number of knot points along the boundaries of the lungs in each radiograph. In the present study, this step was carried out by a chest physician who was blinded to clinical and CT data. The lung contours are automatically drawn by means of cubic splines (Fig. 1).

The program then identifies 4 points in the postero-anterior view corresponding to the apex and the costophrenic angle of the right and left lung, respectively (Fig. 2a). In the lateral view, the 4 points are the costophrenic angle posteriorly, the cardiophrenic angle anteriorly, the lung apex, and the maximum vertical distance of the perpendicular drawn from the line joining the costophrenic to the cardiophrenic angle (Fig. 2b). The 4 points identified on each radiograph are the corners of a polygon, the area of which is measured.

Next, on each radiograph, the program identifies 3 triangles with their base on 3 sides of the polygon and their height equal to the maximum vertical distance from the triangle base to the superjacent lung segment (Fig. 2). Each triangle is described by 3 numerical features: (i) normalized area, or the ratio of the triangle area to the total area including the polygon and triangles; (ii) height ratio, or the ratio of the triangle height to the triangle base; (iii) base ratio, or the projection of the triangle minor side on the triangle base divided by the base length.

In emphysematous lungs, the normalized area of the triangle below the diaphragms is expected to decrease due to the depression and flattening of the diaphragmatic contours associated with chronic hyperinflation. Conversely, the normalized area of the triangles under the costal and retrosternal aspects of the lungs is expected to increase.

The height ratio is a numerical index of the maximum bending of a given anatomic segment of the lung, and the base ratio indicates the position, along the triangle base, where the maximum bending occurs.

The procedure ends by creating one vector from each radiograph that includes 9 numerical features as descriptors of the lung shape. The two vectors are then fed to a neural network that operates as follows.

2.5. Neural network training and testing

A feed-forward multi-layer neural network was employed to recognize emphysema from the descriptors of lung shape on chest radiography. Based on a preliminary study with different net-
work architectures [10], we chose a neural network featuring 
18 input units, two hidden layers with 10 and 4 units respec-
tively, and a single output unit whose activation yields the 
probability that the input pattern belongs to the “emphysema” category.

The network was trained using the standard error back-
propagation algorithm with adaptive learning rate [11]. The chest 
radiographs from the derivation sample were used for the train-
ing process, adopting the “leave-one-out” approach [11]. For each 
case, the descriptors of the lung shape are the training pattern, and 
the corresponding target value is 0 for “no emphysema”, and 1 for 
“emphysema”.

After training, the performance of the neural network was tested 
in both the derivation and the validation samples using CT as the 
reference diagnostic standard. The descriptors of lung shape were 
fed to the network inputs, and the output unit returned the proba-
bility of emphysema between 0 and 1.

2.6. Statistical analysis

The scatter plot of the PG of emphysema by the two independent 
raters was tested for departure from perfect agreement by fitting 
a simple linear regression model and verifying the null hypothesis 
that the intercept is equal to zero and the slope is equal to one, 
jointly.

The prevalence of emphysema in the derivation and in the val-
ification samples was compared by Fisher exact test. Differences in 
the severity of emphysema across the two samples were assessed 
by Mann–Whitney nonparametric test. The relation between the 
severity of COPD and the severity of emphysema on CT, or the 
probability of emphysema on chest radiography, was tested for by 
Kruskal–Wallis nonparametric test.

The diagnostic performance of the computer-aided procedure 
in the derivation and validation samples was described by receiver 
operating characteristic (ROC) curves, using the area under the
Fig. 2. Descriptors of lung shape in postero-anterior (a) and lateral (b) chest radiographs. In (a) the corners of the polygon are the apex and the costophrenic angle of each lung; in (b) the corners are the costophrenic angle posteriorly, the cardiophrenic angle anteriorly, the lung apex, and the maximum vertical distance from the line joining the costophrenic to the cardiophrenic angle. The triangles have their base on 3 sides of the polygon and their height equal to the maximum vertical distance from the triangle base to the superjacent lung segment.

curves as a numerical index. Ninety-five confidence intervals (95% CI) were estimated using the bias corrected accelerated bootstrap method.

3. Results

Inter-rater agreement in scoring emphysema on CT was excellent (Fig. 3). Emphysema was diagnosed consistently by the two independent raters in 225 patients. The prevalence of emphysema was slightly but not significantly higher in the derivation than in the validation sample (43% vs 38%, p = 0.498). Similarly, there was no significant difference between the two samples with regard to the severity of emphysematous lesions on CT; the median PG score was 50 (IQR, 35–68) in the derivation sample, and 50 (IQR, 30–75) in the validation sample (p = 0.768).

ROC curves from the derivation and the validation samples are displayed in Fig. 4. Each curve is constructed using probability cutpoints between 0 and 1 at steps of 0.05. The area under the ROC curve was 0.985 (95% CI, 0.965–0.998) in the derivation sample, and 0.975 (95% CI, 0.936–0.998) in the validation sample.

We chose a probability cutpoint of 0.55 to compute the sensitivity and specificity of the procedure in diagnosing or excluding emphysema on chest radiography (Table 1).

Overall, there were 8 false negative results, 4 in the derivation and 4 in the validation sample. Their characteristics are summarized in Table 2. In these patients, the PG score was consistent with mild or trace emphysema.

Five patients turned out to be false positive, of whom 3 in the derivation and 2 in the validation sample. Two of them had COPD on spirometry (FEV1 46% and 69% predicted, respectively) but no emphysema on CT. The probability of emphysema in the 5 false positives was 0.56, 0.57, 0.57, 0.58, and 0.59.

Among the 141 patients who were diagnosed as having COPD, there was a highly significant relation (p < 0.0001) between the severity of airflow obstruction, as reflected by the GOLD stage, and the PG of emphysema on CT (Table 3). Similarly, there was a highly significant relationship (p < 0.0001) between the GOLD stage and the probability of emphysema on chest radiography (Table 3).

**Table 1**

<table>
<thead>
<tr>
<th>Number % (95% CI)</th>
<th>Derivation sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emphysema on CT</td>
<td>51/118 (43–53)</td>
</tr>
<tr>
<td>True positive on CXR</td>
<td>47/51 (80–97)</td>
</tr>
<tr>
<td>No emphysema on CT</td>
<td>67/118 (47–66)</td>
</tr>
<tr>
<td>True negative on CXR</td>
<td>64/67 (87–99)</td>
</tr>
</tbody>
</table>

**Validation sample**

<table>
<thead>
<tr>
<th>Number % (95% CI)</th>
<th>Validation sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emphysema on CT</td>
<td>41/107 (29–48)</td>
</tr>
<tr>
<td>True positive on CXR</td>
<td>37/41 (76–97)</td>
</tr>
<tr>
<td>No emphysema on CT</td>
<td>66/107 (52–71)</td>
</tr>
<tr>
<td>True negative on CXR</td>
<td>64/66 (89–99)</td>
</tr>
</tbody>
</table>

CI: confidence interval. CT: computed tomography. CXR: chest radiography.

* Based on neural network output (probability cutpoint 0.55).
Fig. 4. Receiver operating characteristic curves from derivation and validation samples. Solid circles are probability cutpoints of emphysema from 0 (top right) to 1 (bottom left) as provided by neural network output. Arrows indicate the probability cutpoint (0.55) chosen to compute sensitivity and specificity of digital chest radiography.

Fig. 5. Frequency distribution of patients in validation sample according to probability of emphysema. CXR: chest radiography. TN: true negative. FN: false negative. TP: true positive. FP: false positive.

Among the 225 patients included in the study, there was one patient only in whom emphysema and interstitial lung disease coexisted. This 68-year old male was GOLD stage 3 (FEV1/FVC 43%, FEV1 49% predicted), and had severe pulmonary arterial hypertension at right heart catheterization. The PG score of emphysema was 60, and the probability of emphysema on chest radiography 0.80. So, he was correctly classified as true positive for emphysema.

Fig. 5 shows the frequency distribution of the patients in the validation sample according to the estimated probability of emphysema on chest radiography. The computer-aided procedure provided a nearly complete discrimination between patients with and those without emphysema on CT.

4. Discussion

The recognition of emphysema on chest radiography is based on the identification of signs of hyperinflation and vascular disruption. Chronic hyperinflation is often manifested by depression and flattening of the diaphragmatic contours [6]. In the lateral chest radiograph, this determines a widening of the cardiophrenic junction such that the cardiophrenic angle is close to or greater than 90 degrees [6].

A widened retrosternal space is an additional sign of hyperinflation in the lateral view. It is defined as a space showing increased radiolucency and measuring 2.5 cm or more from the sternum to the most anterior margin of the ascending aorta [6].

In keeping with the pathology of emphysema, signs of vascular disruption or attenuation have also been described [6,12–14]. The identification of these vascular abnormalities, however, requires substantial medical expertise and is affected by the exposure of the chest radiograph. In fact, a grossly overexposed film makes the evaluation of vascular abnormalities nearly impossible.

Sometimes, it may be hard to establish whether a given diaphragmatic contour is flat. Similarly, it may be difficult to rate a retrosternal space “widened” in the presence of an unfolded ascending aorta, or “hyperlucent” if the anterior mediastinum is thickened by fibrotic tissue. We thought, therefore, to resort to a computer-aided recognition of emphysema.

Table 2

<table>
<thead>
<tr>
<th>Patient</th>
<th>COPD</th>
<th>Probability of emphysema on CXR</th>
<th>PG of emphysema</th>
<th>Type of emphysema</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yes</td>
<td>0.54</td>
<td>15</td>
<td>Centrilobular</td>
<td>Upper lobe</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>0.23</td>
<td>15</td>
<td>Bullous</td>
<td>Upper lobe</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>0.36</td>
<td>10</td>
<td>Centrilobular</td>
<td>Upper lobe</td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td>0.49</td>
<td>7.5</td>
<td>Paraseptal</td>
<td>Upper lobe</td>
</tr>
<tr>
<td>5</td>
<td>No</td>
<td>0.48</td>
<td>5</td>
<td>Paraseptal</td>
<td>Upper lobe</td>
</tr>
<tr>
<td>6</td>
<td>No</td>
<td>0.23</td>
<td>5</td>
<td>Paraseptal</td>
<td>Upper lobe</td>
</tr>
<tr>
<td>7</td>
<td>No</td>
<td>0.32</td>
<td>5</td>
<td>Paraseptal</td>
<td>Upper lobe</td>
</tr>
<tr>
<td>8</td>
<td>No</td>
<td>0.41</td>
<td>5</td>
<td>Paraseptal</td>
<td>Upper lobe</td>
</tr>
</tbody>
</table>

COPD: chronic obstructive pulmonary disease; CXR: chest radiography. PG: picture grading. Patients 1–4 are from derivation sample. Patients 5–8 are from validation sample. Of the two COPD patients, one was GOLD stage 1 (FEV1: 68% predicted), and the other GOLD stage 3 (FEV1: 46% predicted).

* Based on neural network output.
The proposed method is entirely based on the identification of abnormalities in the lung shape that are brought about by chronic hyperinflation. It does not rely on linear measurements, such as lung height or width, that are related to body build and gender, and have limited value in either diagnosing or excluding emphysema on chest radiography [13].

Our method makes use of simple descriptors that measure the bending characteristics of the lung profile on the postero-anterior and lateral chest radiographs. Such descriptors are applied to train a neural network to assign the chest radiographs a probability of emphysema between 0 and 1. A probability >0.55 makes a diagnosis of emphysema very likely, whereas a probability <0.55 makes the diagnosis very unlikely (Table 1 and Fig. 5). Below this cutpoint, mild emphysema may occasionally be found. The sensitivity and specificity attained with our method are in all similar to those reported by experienced physicians [2].

In the patients with established COPD, we found a significant relationship between the severity of airflow obstruction and the severity of emphysema on CT (Table 3). This is in keeping with the notion that severe emphysema is a major determinant of airflow limitation in COPD patients [5]. We also found that the probability of emphysema on chest radiography is strongly related to the GOLD stage (Table 3), the higher the probability of emphysema the greater the degree of airflow obstruction. It should be made clear, however, that the algorithm we propose cannot be used to predict COPD because airflow obstruction may occur in the absence of structural emphysema.

The procedure described requires a minimal interaction in extracting the lung contours from the postero-anterior and lateral chest radiographs. This step needs no particular expertise, and is carried out in less than 2 min. Then, the program returns at once the probability of emphysema.

Now that filmless technology is available in many hospitals worldwide, the computer-aided method can be used for the online evaluation of emphysema on digital chest radiographs. Our method can also be applied in epidemiological surveys to assess the prevalence of emphysema in samples of the general population, should digital chest radiography be incorporated in the diagnostic workup.

The present study has some limitations. First, the method we developed requires that the lung boundaries be clearly discernible in both the postero-anterior and lateral chest radiographs. So, any disorder that obscure the lung profile, such as large pleural effusion or extensive lung consolidation, will hamper the radiologic recognition of emphysema.

Second, the procedure we propose is not expected to assess precisely the extent and regional distribution of emphysema, nor to identify the type of emphysematous lesions. Such features are better evaluated by CT.

Third, we used a semi-quantitative method to assess emphysema on volumetric CT. Such method was developed by the pathologists for the very purpose of establishing whether emphysema is absent, mild, moderate, or severe [9], and was utilized to assess emphysema on axial CT [5,15–17]. Since volumetric CT allows three-dimensional image reconstruction, it facilitates the application of the PG score that was originally described in lung specimens cut along the midsagittal plane [9].

Over recent years, quantitative assessment of emphysema on CT has been introduced, based on the measurement of the relative lung area (volume) with attenuation coefficients below a given threshold [3]. Such an approach is aimed at overcoming the inherent subjectivity of visual estimates of emphysema [3].

As of now, there is no consensus regarding the actual threshold to be used, nor it is clear what is the upper limit of the relative lung area (volume) below a given threshold which identifies the transition from a normal to an emphysematous lung. Therefore, we preferred to apply an old-fashioned but well-established approach.

### 5. Conclusions

In summary, we propose a computer-aided method that allows online recognition of emphysema on digital chest radiographs. This method could be advantageously used in clinical practice for it is simple and inexpensive, and requires no special expertise. Its application may cut down the costs of the diagnostic procedures for emphysema and minimize the radiation burden to the patient.

### Conflict of interest

The authors have no financial, personal, or professional interest that may have influenced the study design, the analysis and interpretation of data, or the writing of the report.

### Funding

This work was supported by funds from the National Research Council of Italy, and the Department of Medical and Surgical Critical Care, University of Florence, Italy. The funding sources had no role in the study design, the collection, analysis, or interpretation of data, the writing of the report, or the decision to submit the paper for publication.

### Acknowledgments

The authors wish to thank Dante Chiappino and Daniele Della Latta for helping in the collection of data, and Luca Serasini for excellent technical assistance. Permission was obtained from those who are acknowledged.

### References