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Paired maximum inspiratory and expiratory plain chest radiographs for assessment of airflow limitation in chronic obstructive pulmonary disease

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ABSTRACT

Background: The usefulness of paired maximum inspiratory and expiratory (I/E) plain chest radiography (pCR) for diagnosis of chronic obstructive pulmonary disease (COPD) is still unclear.
Objectives: We examined whether measurement of the I/E ratio using paired I/E pCR could be used for detection of airflow limitation in patients with COPD.
Methods: Eighty patients with COPD (GOLD stage I = 23, stage II = 32, stage III = 15, stage IV = 10) and 34 control subjects were enrolled. The I/E ratios of frontal and lateral lung areas, and lung distance between the apex and base on pCR views were analyzed quantitatively. Pulmonary function parameters were measured at the same time.
Results: The I/E ratios for the frontal lung area (1.25 ± 0.01), the lateral lung area (1.29 ± 0.01), and the lung distance (1.18 ± 0.01) were significantly ($p < 0.05$) reduced in COPD patients compared with controls (1.31 ± 0.02 and 1.38 ± 0.02, and 1.22 ± 0.01, respectively). The I/E ratios in frontal and lateral areas, and lung distance were significantly ($p < 0.05$) reduced in severe (GOLD stage III) and very severe (GOLD stage IV) COPD as compared to control subjects, although the I/E ratios did not differ significantly between severe and very severe COPD. Moreover, the I/E ratios were significantly correlated with pulmonary function parameters.
Conclusions: Measurement of I/E ratios on paired I/E pCR is simple and reproducible, and can detect airflow limitation in patients with severe and very severe COPD.

1. Introduction

Airflow obstruction and air trapping in patients with chronic obstructive pulmonary disease (COPD) are generally investigated using pulmonary function tests [1]. However, pulmonary function tests have certain limitations for investigating the localization of impairments or the correlations between function and motion associated with the muscles, bones and joints of the thorax, and the lung tissues, diaphragm and heart when compared with radiologic or pathologic approaches [2–4]. Among radiologic modalities, chest computed tomography (CT) scan is an extremely useful method for investigating the presence, distribution, sites, sizes and numbers of emphysematous lesions as areas of low attenuation and bronchial wall thickening, and the findings are well correlated with pulmonary function parameters [5–8]. However, the cost and radiation exposure associated with CT are problematic.

In a primary care setting, plain chest radiography (pCR) is performed routinely for detection of morphological lung abnormalities and for obtaining useful information for management of patients with respiratory diseases, and it is also safer, cheaper and easier to

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Table 1
Characteristics of study participants.

	COPD (n = 80)	Control (n = 34)	p value
Age, yr	70.3 ± 0.8	64.7 ± 1.8	0.001
Gender, female/male	9/71	12/22	0.006
Body mass index, kg/m^2	21.5 ± 0.3	22.8 ± 0.5	0.006
Smoking status, Cu/Ex/No	27/53/0	6/7/21	<0.001
Smoking index, pack-years	54.9 ± 3.1	18.4 ± 5.3	<0.001
GOLD stage, I/II/III/IV	23/32/15/10	N/A	
Pulmonary function parameters before bronchodilation			
FVC, L	3.2 ± 0.1	3.3 ± 0.1	0.714
%FVC predicted, %	101.1 ± 2.0	106.1 ± 2.0	0.040
FEV_1, L	1.6 ± 0.1	2.6 ± 0.1	<0.001
%FEV_1 predicted, %	64.0 ± 2.8	107.9 ± 2.7	<0.001
FEV_1/FVC, %	47.5 ± 1.7	78.9 ± 0.9	<0.001
RV/TLC, %	40.6 ± 1.5	32.5 ± 1.8	0.004
DLco/V_A, %	2.8 ± 0.2	3.9 ± 0.3	0.005
I/E ratios determined by morphometric analysis of pCR			
PAF areas of lung field	1.25 ± 0.01	1.31 ± 0.02	0.023
RLL areas of lung field	1.29 ± 0.01	1.38 ± 0.02	0.009
Lung distance	1.18 ± 0.01	1.22 ± 0.01	0.038

Cu: current-smokers, DLco: lung diffusion of carbon monoxide, Ex: ex-smokers, FEV_1: forced expiratory volume in 1 s, FVC: forced vital capacity, GOLD: Global Initiative for Chronic Obstructive Lung Disease, No: nonsmokers, RV: residual volume, TLC: total lung capacity, VA: alveolar volume, PAF: postero-anterior frontal, and RLL: right-left lateral.

perform than CT scan. It is well known that the posterioanterior and lateral pCR views have high sensitivity and specificity for detection of pulmonary emphysema, demonstrating depression and flattening of the diaphragm with blunting of the costophrenic angles, irregular hyperlucencies with hyperinflation and vascular attenuation of the lung fields, an abnormally increased retrosternal space, and a sterno-diaphragmatic angle of >90° [2,3,9,10]. However, the usefulness of pCR for detection of pulmonary function abnormalities such as airflow obstruction and air trapping is still unclear. In the present study, we hypothesized that the ratios of the changes in area and/or distance of the lung fields from the inspiratory to expiratory phase on pCR might be correlated with the severity of airflow obstruction or air trapping in the lungs. Our aim was to investigate whether the ratios of the areas and distance of the lungs in paired maximum inspiratory and expiratory (I/E) pCR would allow detection of airflow obstruction and air trapping in patients with COPD.

2. Methods and materials

2.1. Subjects

Eighty patients with stable COPD aged >40 yr and 34 control subjects (6 current, 7 ex-, and 21 nonsmokers) without airflow obstruction were selected at Kurume University Hospital (Fukuoka, Japan) between April 2010 and December 2012. All subjects were healthy volunteers as controls who provided written informed consents. We recruited the healthy volunteers by using posters and social media. The characteristics of the participants are shown in Table 1. Individuals who had congenital thoracic abnormalities such as funnel chest and scoliosis, or phrenic nerve paralysis and pleural effusion were carefully excluded. Individuals who had conditions such as cerebrovascular, cardiac, neuro-muscular or psychological abnormalities, or other chronic respiratory diseases were also excluded, as these conditions could potentially affect the results of pulmonary function tests.

2.2. Study protocols

After supplying written informed consent, each participant gave information about existing medical conditions, medical history, and smoking habits [smoking status and Brinkman Index (pack-years)]. Paired maximum I/E pCR before bronchodilation and pulmonary function tests before and after bronchodilation were performed on the same day. The study was conducted in accordance with the Good Clinical Practice guidelines and approved by the Ethics Committee of Kurume University (approval no. 8091, March 31st, 2010).

2.3. Pulmonary function tests

The forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1) were measured with an electrical spirometer (Chestgraph Jr. 101, Chest Co., Tokyo) before and 30 min after administration of a bronchodilator (sulbutamol, 400 μg; GSK, Tokyo, Japan), in accordance with the recommendations of the American Thoracic Society [11]. Residual volume (RV) and total lung capacity (TLC), and the lung diffusion capacity for carbon monoxide (DLco) and alveolar volume (V_A), were also measured before bronchodilation using the helium-dilution and single-breath method, respectively [12,13]. The frequency of RV/TLC and DLco/VA has been accepted for analysis of air-trapping and the diffusion capacity index, respectively [6].

2.4. Definition and severity of COPD

Diagnosis and staging of COPD were in accordance with the Global Initiative for Chronic Obstructive Lung Disease (GOLD) guidelines [1], and included a post-bronchodilation FEV_1/FVC ratio of <0.7, and pre- and post-bronchodilation reversibility of FEV_1 of <200 mL and <12%, respectively. GOLD stages I, II, III, and IV COPD were defined as %FEV_1 predicted >80%, <50% %FEV_1 predicted <80%, <30% %FEV_1 predicted <50%, and %FEV_1 predicted <30% after bronchodilation, respectively [1].

2.5. Plain chest radiography and morphometric analysis

In this study, we used two different items of computed pCR equipment: PRERIO-U (Fuji Co., Tokyo, Japan) and KXO-80G (Toshiba Co., Tokyo, Japan) with a 180-cm focus-to-detector (film) distance, operated at 110 kV and 200 mA. Four images were acquired successively for each participant using the same computed pCR instrument. Postero-anterior frontal (PAF) and right-left lateral (RLL) views were acquired in the maximum I/E breath phases, with the subject in a standing position. To measure the areas of the PAF and RLL lung fields (Fig. 1A) and the distance between the apex and base of the right lung field on PAF views (Fig. 1B), the digitalized pCR images were analyzed using a computed color image analysis software system (WinRoof® version 5.0; Mitani Co., Fukui, Japan) [14]. The areas of the PAF and RLL lung fields were polygonally surrounded to include the mediastinal and cardiac shadows, and the inner thoracic and diaphragm shadows were traced by hand using an electronic pen, because the overlapped parts of lung, mediastinums, and heart independently could not recognize in two-dimentional pCR techniques (Fig. 1A). The distance between the apex and base of the right lung field on PAF views (point E to F in Fig. 1B) was measured as follows. First, three vertical lines through point A (the corner of the costophrenic angle), point B (the corner of the cardiophrenic angle), and point C (the central point between points A and B) were drawn parallel to the center line of a spinous process of a thoracic vertebra (vertebral line). Secondly, a horizontal line perpendicular to the vertebral line was drawn through point D (lung apex). Finally, the intersection points of the lines through point C, and the diaphragm line and point D, were expressed as points E and F, respectively. We designated the distance of the lung as the distance from point E to point F.