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The relationships between tracheal index and lung volume parameters in mild-to-moderate COPD

Jung Seop Eom[a,1,2], Geewon Lee[b,1,3], Ho Yun Lee[c,4], Jin Young Oh[d,5], Sook-young Woo[e,6], Kyeongman Jeon[a,2], Sang-Won Um[a,2], Won-Jung Koh[a,2], Gee Young Suh[a,2], Man Pyo Chung[a,2], Hojoong Kim[a,2], O Jung Kwon[a,2], Hye Yun Park[a,*]

[a] *Division of Pulmonary and Critical Care Medicine, Department of Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, 81 Irwon-ro, Gangnam-gu, Seoul 135-710, Republic of Korea*
[b] *Department of Radiology, Pusan National University Hospital, 179 Gudeok-ro, Seo-gu, Busan 602-739, Republic of Korea*
[c] *Department of Radiology and Center for Imaging Science, Samsung Medical Center, Sungkyunkwan University School of Medicine, 81 Irwon-ro, Gangnam-gu, Seoul 135-710, Republic of Korea*
[d] *Division of Pulmonology, Department of Internal Medicine, Dongguk University Ilsan Medical Center, 814 Siksa-dong, Ilsandong-gu, Goyang-si, Gyeonggi-do 410-773, Republic of Korea*
[e] *Biostatistics Team, Samsung Biomedical Research Institute, 81 Irwon-ro, Gangnam-gu, Seoul 135-710, Republic of Korea*

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ABSTRACT

Background: Although elongated morphological changes in the trachea are known to be related to lung function in chronic obstructive pulmonary disease (COPD), whether the tracheal morphological changes are associated with airflow limitations or overinflation of the lung in the early stages of COPD has not yet been determined. Thus, our aim was to investigate the association of tracheal index (TI) with lung function parameters, including lung volume parameters, in COPD patients with mild-to-moderate airflow limitations.
Materials and methods: A retrospective study was conducted in 193 COPD patients with GOLD grades 1–2 (post-bronchodilator forced expiratory volume in 1 s [FEV_1] ≥ 50% predicted with FEV_1/forced vital capacity ratio ≤ 70%; age range, 40–81) and 193 age- and gender-matched subjects with normal lung function as a control group (age range, 40–82). Two independent observers measured TI at three anatomical levels on chest radiographs and CT scans.
Results: Compared with the control group, TI was reduced significantly and "saber-sheath trachea" was observed more frequently in COPD patients. Patients with GOLD grade 2 disease had a lower TI than those with GOLD grade 1. TI had apparent inverse correlations with total lung capacity, functional residual capacity, and residual volume, regardless of the anatomical level of the trachea. Even after adjustments for covariates, this association persisted.
Conclusions: TI is reduced even in mild-to-moderate COPD patients, and TI measured on chest CT shows significant inverse relationships with all lung volume parameters assessed, suggesting that tracheal morphology may change during the early stages of COPD.

1. Introduction

Chronic obstructive pulmonary disease (COPD) is a highly prevalent lung disease, with an increasing mortality rate, globally [1]. The main feature of COPD is airflow limitation, with chronic inflammation causing airway remodeling and narrowing [2]. The small airway inflammation and obstruction progressively trap air during expiration, leading to hyperinflation of the lung. This phenomenon contributes to the lung morphological changes in COPD. Recently, several studies have suggested that morphological changes occur from the early stage of COPD, showing that narrowing or disappearance of small conduction airways (2–2.5 mm)

* Corresponding author. Tel.: +82 02 3410 3429; fax: +82 02 3410 6956.
E-mail addresses: ejs00@hanmail.net (J.S. Eom), rabkingdom@naver.com (G. Lee), hoyunlee96@gmail.com (H.Y. Lee), indr71@hanmail.net (J.Y. Oh), sookyoung12.woo@samsung.com (S.-y. Woo), kjeon@skku.edu (K. Jeon), sangwonum@skku.edu (S.-W. Um), wjkoh@skku.edu (W.-J. Koh), suhgy@skku.edu (G.Y. Suh), mpchung@skku.edu (M.P. Chung), hjk3425@skku.edu (H. Kim), ojkwon@skku.edu (O.J. Kwon), kerrybe.park@samsung.com (H.Y. Park).
[1] Both these contributed equally to this study.
[2] Tel.: +82 02 3410 3429; fax: +82 02 3410 6956.
[3] Tel.: +82 051 240 7357; fax: +82 051 244 7534.
[4] Tel.: +82 02 3410 2502; fax: +82 02 3410 0049.
[5] Tel.: +82 031 961 7146; fax: +82 031 961 7969.
[6] Tel.: +82 02 3410 6499; fax: +82 02 3410 3669.

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begins from COPD grade 1 (mild) disease; static lung volumes and ventilation-to-perfusion mismatching were increased in mild COPD patients [3–5].

Numerous attempts have been made to identify the radiological parameters that reflect the morphological changes in COPD with lung function. Indeed, the extent of low-attenuation area of the lung, mean lung density, and airway wall area percentage measured or quantified by computed tomography (CT) scanning enable the assessment of the extent and distribution of both emphysema and small airway disease in COPD. These parameters are also significantly correlated with lung function parameters, even in mild COPD [6–9].

"Saber-sheath trachea" (SST) is defined as a tracheal index (TI) of less than 2/3 and TI is a radiological parameter calculated as the ratio of the transverse diameter (TD) to anteroposterior diameter (APD) in the trachea [10]. Previous studies related to SST or TI have suggested that elongated morphological changes in the trachea are related to lung function parameters in COPD [11–13]. However, whether the tracheal morphology changes are associated with airflow limitation or overinflation of the lung during the early stages of COPD has not yet been determined. Thus, the aim of the current study was to investigate the relationship of TI to lung function with lung volume parameters in patients in the early stages of COPD.

2. Materials and methods

2.1. Study population

The Samsung Medical Center Institutional Review Board approved the analyses of the clinical and imaging data. The requirement for patient consent was waived given the retrospective nature of this study.

Data from patients who underwent pre- and post-bronchodilator lung function tests and received lung volume tests, including total lung capacity (TLC), functional residual capacity (FRC), and residual volume (RV), at Samsung Medical Center (a 1960-bed, university-affiliated, tertiary referral hospital in Seoul, South Korea) between April 2008 and March 2010 were used. There were 325 patients who had a post-bronchodilator forced expiratory volume in 1 s (FEV_1)/forced vital capacity (FVC) ratio of 70% or less with $FEV_1 \geq 50\%$ predicted and available chest radiographs and CT scans within 3 months from spirometry. Of these patients, we excluded 132 subjects with any medical condition or disease that may affect the tracheal diameter, such as a mediastinal mass or previous tracheostomy ($n = 12$), a history of physician-diagnosed asthma or respiratory disorder other than COPD ($n = 68$), a history of previous thoracic surgery ($n = 21$), and a progressive systemic disease other than COPD that predicted poor overall prognosis ($n = 31$). In total, 193 mild-to-moderate COPD patients were included in the COPD group; 115 patients (59.6%) with Global Initiative for Chronic Obstructive Lung Disease (GOLD) grade 1 (mild, $FEV_1 \geq 80\%$ predicted) and 78 (40.4%) with grade 2 (moderate, $50\% \leq FEV_1 < 80\%$ predicted) [14].

All COPD patients underwent a CT scan in a stable state, without acute exacerbation of COPD. Of the 193 COPD patients, 21 had lung nodules less than 3 cm in diameter, which had a negligible influence on lung function and tracheal diameter. Of the patients who had lung function test results available, including lung volume results and available chest radiographs and CT scans within 3 months from the lung function tests during the same study period, 193 control subjects with a normal lung function (FEV_1/FVC > 70%, FEV_1 > 80% predicted, and FVC > 80% predicted) and no lung parenchymal or mediastinal abnormalities other than benign lung nodules or T1N0M0 non-small-cell lung cancer on CT scans were matched 1:1 to those in the COPD group based on age (±2) and gender.

2.2. Pulmonary function test and CT data acquisition

Spirometry was performed using Vmax 22 (SensorMedics, OH, USA) and lung volume parameters were measured by a whole body plethysmograph using Vmax 20 + V62J (SensorMedics, OH, USA) according to criteria established by the American Thoracic Society [15]. All CT images were obtained in the full inspiratory state and CT scans were performed with varying scanners; eight-detector scanner (LightSpeed Ultra, GE Healthcare), 16-detector scanner (LightSpeed 16, GE Healthcare), 40-detector scanner (Brilliance-40, Philips Medical System), and 64-detector scanners (Aquilion 64, Toshiba Medical System, Tokyo, Japan or Lightspeed VCT, GE Healthcare, Waukesha, Wis). Images of the whole thorax were acquired with the following CT parameters: 120 kV voltage, 150–200 mA tube current, 2.5 mm or less section thickness, 0.5–0.6 s tube rotation, and 1.25 mm or 0.625-mm detector collimation. Coronal reformation of the images was performed with a section thickness of 2 mm. Effective radiation dose was 5 mGy. Axial CT images were displayed in mediastinal window setting (width, 400 HU; level, 20 HU) and lung window setting (width, 1500 HU; level, −700 HU) on monitors with a picture archiving and communication system workstation (Centricity 2.0, General Electric Medical Systems Integrated Imaging Solutions, MT. Prospect, IL, U.S.A.).

2.3. Measurement of TI and the definition of SST

To measure TI, CT scans and chest radiographs were reviewed independently by two observers, one radiologist and one pulmonary physician who were both blinded to the lung function tests. Three different levels were used to calculate TI, based on previous reports [10–13,16–18], and each observer measured tracheal diameters (APD and TD) at all three levels using both chest radiographs and CT axial imaging as follows: (1) at the upper margin of the aortic arch (AA), (2) 1 cm above AA, and (3) 2 cm above AA. At each level, APD was defined as the greatest diameter from the middle of the posterior membrane to the anterior margin of the trachea, and TD was defined as the greatest vertical diameter of APD on axial CT imaging (Fig. 1). A lateral chest radiograph was used for APD measurements, while TD was measured on a posteroanterior chest radiograph at each level of the trachea (Fig. 2). TI was calculated from the measured tracheal diameters as a ratio of TD to APD on both chest radiographs and CT. SST was defined as a TI < 2/3.

2.4. Assessment of COPD phenotype

CT findings were classified as showing either the airway- or emphysema-dominant phenotype. The extent of emphysema was calculated by the percent (%) low-attenuation proportion of the total lung area at the upper, middle, and lower lung zones, and airway abnormalities were evaluated in terms of bronchial wall thickening, bronchial wall irregularity, bronchiectasis and centrilobular nodules. Bronchial wall thickening was defined by the ratio of the inner diameter to the outer diameter of the lumen of less than 0.8 and extensive involvement. Bronchiectasis was considered present according to the visibility of a bronchus in the outer one-third of the lung or a diameter of the inner lumen greater than that of the accompanying pulmonary artery; the finding was regarded as positive if more than 50% of a segment was affected. Centrilobular nodules were considered present if more than 50% of a segment was affected. Moderate-to-severe emphysema with none-to-mild airway abnormalities on CT scans was considered to be the emphysema-dominant type, while none-to-mild emphysema