ORIGINAL ARTICLE

**DOI:** 10.4274/nkmj.galenos.2021.36855
Nam Kem Med J 2021;9(3):238-242

# A Correlation Between Quantitative Measurement Parameters of Thorax Computed Tomography and Pulmonary Function Test: A Retrospective Study

## Toraks Bilgisayarlı Tomografi Kantitatif Ölçüm Parametreleri ile Solunum Fonksiyon Testi Arasındaki Korelasyonun İncelenmesi: Retrospektif Çalışma

Hadi SASANI[1], Levent Cem MUTLU[2]

[1]*Tekirdağ Namık Kemal University Faculty of Medicine, Department of Radiology, Tekirdağ, Turkey*
[2]*Tekirdağ Namık Kemal University Faculty of Medicine, Department of Pulmonary Diseases, Tekirdağ, Turkey*

**ABSTRACT**

**Aim:** Pulmonary functional and volumetric evaluation is routinely performed with pulmonary function test (PFT). However, volumetric evaluation is also possible in computed tomography (CT) imaging. The aim of this study is to examine the relationship between PFT and CT volumetric findings.

**Materials and Methods:** Between April 2017 and May 2020, a total of 69 patients (34 males, 35 females) having thorax CT (without any parenchymal disease) and PFT were studied retrospectively. The images and PFT examinations with an optimum quality were enrolled. In CT, the volume and density of both lungs as well as total lung volume (TLV) and total lung density (TLD) were calculated. Forced expiratory volume in 1 second (FEV1), forced vital capacity (FVC), and FEV1/FVC ratio were recorded for the assessment with CT.

**Results:** In a total of 69 patients (34 male, 49.3%; 35 female, 50.7%), the mean age was 55±14.56 years, FEV1=2.12±0.87, FVC=2.92±1.05, FEV1/FVC ratio=72.19±13.07, right lung volume=2118.06±662.36, right lung density=-806.8±68.16, left lung volume=1755.35±605.02, left lung density=-774.80±248.98, TLV=3820±1272.35 and TLD=-1597.17±295.70. FEV1, FVC and FEV1/FVC ratio showed a positive correlation with bilateral (right and left) lung volume and density ($p<0.05$).

**Conclusion:** PFT provides important quantitative pulmonary functional data that can evaluate the severity and course of diseases causing respiratory symptoms. However, in cases where PFT cannot be performed (such as Coronavirus Disease-2019), CT quantitative pulmonary volumetric evaluation can be an alternative in the evaluation of main pulmonary functions.

**Keywords:** Lung volume measurements, computed tomography, respiratory function test

**ÖZ**

**Amaç:** Pulmoner fonksiyonel ve hacimsel değerlendirme rutin olarak solunum fonksiyon testi (SFT) ile yapılmaktadır. Ancak bilgisayarlı tomografi (BT) görüntülemede hacimsel değerlendirme de mümkündür. Bu çalışmanın amacı, SFT ile BT hacimsel bulguları arasındaki ilişkiyi incelemektir.

**Gereç ve Yöntem:** Nisan 2017 ile Mayıs 2020 tarihleri arasında toraks BT (parankimal hastalığı olmayan) ve SFT yapılan toplam 69 hasta (34 erkek, 35 kadın) retrospektif olarak incelendi. Optimum kalitede görüntüler ve PFT incelemeleri kaydedildi. BT'de, her iki akciğerin hacmi ve yoğunluğu ile toplam akciğer hacmi (TLV) ve toplam akciğer yoğunluğu (TLD) hesaplandı. BT ile değerlendirme için bir saniyedeki zorlu ekspiratuvar hacim (FEV1), zorlu vital kapasite (FVC), FEV1/FVC oranı kaydedildi.

**Bulgular:** Toplam 69 hastada (34 erkek, %49,3; 35 kadın, %50,7) ortalama yaş 55±14,56 yıl, FEV1=2.12±0,87, FVC=2,92±1,05, FEV1/FVC oranı=72,19±13,07 sağ akciğer hacmi=2118,06±662,36, sağ akciğer yoğunluğu=-806,8±68,16, sol akciğer hacmi=1755,35±605,02, sol akciğer yoğunluğu=-774,80±248,98, TLV=3820±1272,35 ve TLD=-1597,17±295,70 idi. FEV1, FVC ve FEV1/FVC oranı bilateral (sağ ve sol) akciğer hacmi ve yoğunluğu ile pozitif korelasyon gösterdi ($p<0,05$).

**Address for Correspondence:** Hadi SASANI MD, Tekirdağ Namık Kemal University Faculty of Medicine, Department of Radiology, Tekirdağ, Turkey
**Phone:** +90 282 250 74 55 **E-mail:** hsasani@nku.edu.tr **ORCID ID:** orcid.org/0000-0001-6236-4123
**Received:** 20.12.2020 **Accepted**: 10.07.2021

**Sonuç:** SFT, solunum semptomlarına neden olan hastalıkların ciddiyetini ve seyrini değerlendirebilen önemli kantitatif pulmoner fonksiyonel veriler sağlar. Ancak, SFT'nin yapılamadığı durumlarda (koronavirüs hastalığı-19 gibi) BT kantitatif pulmoner hacimsel değerlendirme, ana pulmoner fonksiyonların değerlendirilmesinde alternatif bir yöntem olabilir.

**Anahtar Kelimeler:** Akciğer hacmi ölçümleri, bilgisayarlı tomografi, solunum fonksiyon testi

## INTRODUCTION

The lung volumes are routinely evaluated by using pulmonary function tests (PFTs) in which total lung capacity (inspiratory volume), static expiratory volumes and dynamic volumes [absolute and relative forced expiratory volume in 1 second (FEV1)] can be assessed. However, the measurement of unilateral or regional lung volumes is difficult in PFT[1].

Lung volumes include tidal volume [(TV); the change in lung volume during normal breathing], inspiratory reserve volume (an extra volume that can be breathed in at the end of normal TV inspiration), expiratory reserve volume (an extra volume that can be breathed out at the end of normal TV expiration), and residual volume (a volume remaining in the lungs at the end of a maximum expiration). Vital capacity is the volume change between the end of a maximum inspiration and the end of a maximum expiration. Functional residual capacity is the volume remaining in the lungs at the end of normal expiration. Total lung capacity is the total volume in the lungs[2].

Computed tomography (CT) of thorax is a modality of choice which is widely used for the evaluation of either mediastinal or pulmonary parenchymal diseases, it provides indices reflecting regional density and it is capable to measure the density or volume of anatomical structures and lungs[1,3].

PFTs are used in combination with imaging in the follow-up of patients with diffuse lung disease. There are some studies in the literature investigating the correlation between PFT and CT in the patients with chronic obstructive pulmonary disease (COPD)[4-7], interstitial lung disease (ILD) or pulmonary fibrosis[8,9], lung transplantation[10], after bronchial valve treatment[11], rheumatoid arthritis[12], lung cancer[13] and in those with scoliosis[14].

In this paper, we aimed to evaluate PFT and CT volumetric results in normal population and whether CT volumetric values could be a good predictor for the assessment of PFT specially in extraordinary situations such as coronavirus disease-2019 (COVID-19), in which PFT is impossible to be performed.

## MATERIALS AND METHODS

### Study Population

Between April 2017 and May 2020, a total of 69 patients (34 male, 35 female) with any indication, who had thorax CT examination without any pulmonary disease and who had PFT, were scrutinized retrospectively.

Patients without a history of malignancy, chronic disease and lung parenchymal disease (infiltration, consolidation, tumor etc.), those CT images with good quality and inspiration, those at the age of 18 years or above, and those having PFT, were enrolled in the study.

Inclusion criterion was being subjects with normal spirometric values.

Exclusion criteria were as follows:

1) Subjects who had undergone thoracic surgery,

2) Subjects who had a CT finding of pneumothorax, pleural effusion, pneumonia, emphysema, ILD, chronic bronchitis, bronchiectasis, lung bullae, lung abscess, or lung mass, lung neoplasm,

3) Patients with insufficient breathing or CT image quality, having parenchymal disease, being less than 18 years old and those not having PFT were excluded from the study.

4) Active smokers and ex-smokers.

Patients' information was obtained from the hospital's data system.

CT images were achieved from picture archiving and communication system (PACS) and PFTs were obtained from the hospital data system.

This study was approved by the university/local human research ethics committee and all procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Tekirdağ Namık Kemal University, Non-Invasive Clinical Research Ethics Committee approved the study protocol (approval number: 2020.148.06.10).

### Study Protocol

Non-enhanced CT examinations of 70 patients with any indication were included in the study. A 128-row multi-detector CT scanner (Aquilion™ Prime; Canon Medical Systems) was used for CT scanning. Field of view (FOV) of the whole chest was scanned from the lung apex to the diaphragm with a single breath-hold. The patients were lying in supine position on the table of the device and the arms were above the head.

CT acquisition was done by the following parameters: the current of 100-250 mAs modulated by personal body mass index (BMI) dose; tube voltage of 100 140 kV and collimation of 0.5 mm x 80, gantry rotation time of 0.35 sec, pitch factor of 0.813, FOV: 20x20 cm, slice thickness 1 mm and slice interval 0.8 mm.

### Imaging Assessment

Obtained CT images were transferred to PACS (Sectra 7.0, Sectra AB, Linköping, Sweden) and were analyzed at a workstation (Vitrea 2 workstation; Vital Images, Canon, Minnetonka, MN, USA). The assessment was done by an eight-year experienced radiologist.

By using semi-automated pixel-based image segmentation method (region growing algorithm) and manual drawing tools in the workstation, the volume and density of both lungs as well as total lung volume (TLV) and total lung density (TLD) were calculated. The range of density thresholds in semiautomatic segmentation were between -1062 HU and -138 HU (Figure 1).

### PFT Assessment

PFT assessment was performed by using a device (MasterScreen PFT System; Jaeger, VIASYS Healthcare, Hoechberg, Germany) of spirograms having the largest FEV1 and forced vital capacity (FVC), selected from at least two technically acceptable spirometric measurements being used in the analysis.

PFT examinations with good quality and sufficiency were included. The values of FEV1, FVC, FEV1/FVC ratio were recorded for the assessment with CT. Also, the values of weight, height and BMI were noted. The median interval between PFT and CT was 1 day (range: 1-2 days). There was no therapeutic application or any applied procedure that might have affected the results.

### Statistical Analysis

All data were analyzed using a statistical package program (SPSS version 17.0; SPSS, Inc., Chicago, IL, USA). The variables were investigated using visual (histograms, probability plots) and analytical methods to determine whether they were normally or not normally distributed. Investigating the associations between non-normally distributed and/or ordinal variables, the correlation coefficients and their significance were calculated using the non-parametric test (Spearman correlation test). A 5% type-1 error level was used to infer statistical significance.

## RESULTS

### CT Volumetric Image

Obtained deep breath-hold CT images were evaluated at the workstation (Vitrea 2 workstation; Vital Images, Canon) in multi-plane reconstruction and three-dimensional view, calculating the volume and density in post-process analysis (Figure 1).

### Descriptives of the Study

In a total of 69 patients (34 males, 49.3%; 35 females, 50.7%), the mean values of the calculated parameters were as follows: mean age=55±14.56 years (range: 18-86), FEV1=2.12±0.87 (range: 0.66-4.09), FVC=2.92±1.05 (range: 1.03-5.46), FEV1/FVC ratio=72.19±13.07 (range: 35.30-99.44), right lung volume (RLV)=2118.06±662.36 (range: 712.73-3668.26), right lung density=-806.8±68.16 (range: -904.20 to-574.70), left lung volume (LLV)=1755.35±605.02 (range: 357.06-3310.28), left lung density=-774.80±248.98 (range: -918.30 to 654.10), TLV=3820±1272.35 (range: 1378.95-6418.38) and TLD=-1597.17±295.70 (range: -1822.50 to 630.00).

FEV1, FVC and FEV1/FVC ratio showed a positive correlation with bilateral (right and left) lung volume and density ($p<0.05$), but there was no correlation with TLV and density ($p>0.05$). Demographic and laboratory data of the study population are shown in Table 1.

## DISCUSSION

Results of the present study, which are compatible with the literature[10,11,13,15], suggest the positive correlation between

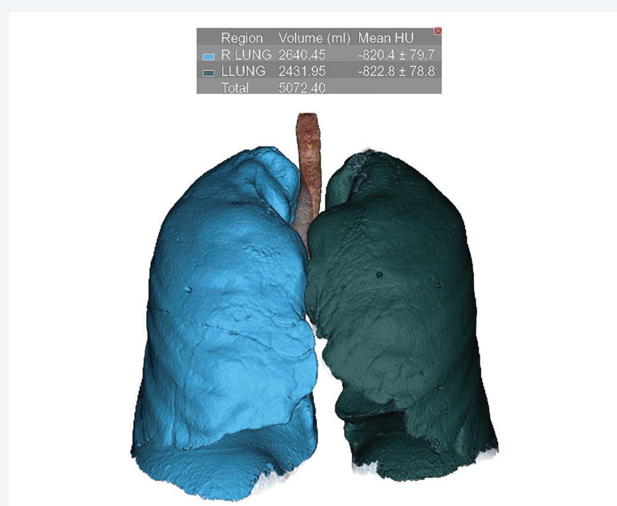


**Figure 1.** A 3D reconstructed CT image shows the volume and density of right and left lungs as well as total lung values

*CT: Computed tomography*

**Table 1. Demographic and laboratory data of the study population**

| Parameters | Values |
|---|---|
| **Age (mean)** | 55±14.56 years |
| **Gender** | Male: 49.3% (n=34)<br>Female: 50.7% (n=35) |
| **Smoking habits** | None |
| **FEV1** | 2.12±0.87 |
| **FVC** | 2.92±1.05 |
| **Right lung volume** | 2118.06±662.36 mL |
| **Right lung density** | -806.87±68.16 HU |
| **Left lung volume** | 1755.35±605.02 mL |
| **Left lung density** | -774.80±248.98 HU |
| **Total volume** | 3820±1272 mL |
| **Total density** | -1597.17±295.70 HU |

FEV1: Forced expiratory volume in 1 second, FVC: Forced vital capacity

PFT (FEV1, FVC) and CT pulmonary volumetric and density parameters.

In the study by Kauczor et al.[1], the correlation of the total lung capacity (TLC) with the inspiratory CT volume was found to be higher (r=0.89) than with the expiratory CT volume (r=0.8). They underestimated TLC by 12% having a good correlation with static lung volumes (r=0.89). Using expiratory helical CT, they overestimated residual volume by 850 mL (r=0.77)[1].

Pelzer and Thomso.[16] studied the calculation of regressions for respiratory airflow conductance against age and height from measurements made by body plethysmography in 82 normal subjects aged 17-82 years. The mean coefficient of variation in plethysmographic thoracic gas volume in repetitive testings on the same day was found to be 3.8% and 10% in repeated testings on separate days[16].

Despite the highest image resolution and quantification facilities in CT, there are some pros and cons in assessment. The supine position in CT scans can result in an underestimation of the actual lung volume as compared to body plethysmography, which may be due to a submaximal inspiration in the supine position[17]. In the study by O'Donnell et al.[18], an average upright vs supine reduction in vital capacity was found to be less than 3%. Therefore, the results from the lung volumes measured by CT modality cannot be compared directly to those from other techniques. In addition, there is a radiation exposure for the patient in CT.

Similar to the current study, Tanabe et al.[7] investigated the associations of airway tree to lung volume ratio on CT with combination of PFT in 147 patients with COPD. The percentage ratio of the airway tree volume (AWV%) in the right lung lobes to RLV was calculated. In their study, the airway tree in the left lung was not included due to the fact that cardiac motion artefacts could affect the segmentation of this area. They found FEV1 to be 61%±20, FEV1/FVC=51%±13. AWV% decreased as the COPD spirometric grade increased. AWV% was more closely correlated with FEV1 and ratio of residual volume to TLC. Their study showed a correlation between RLV, RLV/predicted TLC (pTLC), AWV%, AWV/pTLC and FEV1, FEV1%, and RV/TLC. They concluded that AWV%, an easily measurable CT biomarker, could explain the clinical effects of airway-lung interaction in COPD patients[7].

In our study, there were similar correlation findings of PFT parameters with lung CT density-volumetry, compatible with the literature[5,7,11,19]. TLV and TLD in the current study were found to be 3820±1272.35 and -1597.17±295.70, respectively. In the literature, TLV was reported between 3380±1010 and 4668±1192 mL[10,19]. The difference in the volume values may be probably related to patient selection. Lung volumes decrease with age and gender. Since our patient group was relatively old, the values may have been low.

Density is also an important parameter in the evaluation and categorization of the pathologies [e.g. ILD, pulmonary infection, acute respiratory distress syndrome (ARDS)]. For ILD, the proportion of the lung volume with attenuation of -700-200 HU (a threshold of -700 HU)[20]; for the detection of ground-glass opacity, attenuation values from -800 to -500 HU[21]; for ARDS, lung proportion with attenuation between -1000 and -900 HU can be used. While a lung proportion with attenuation between -900 and -500 HU is defined as normally aerated, the lung attenuation above -500 HU is a poorly aerated or nonaerated area[22]. In our study, the densities of RLV, LLV and TLV, calculated by semi-automated algorithm in the workstation, were -806.8±68.16, -774.80±248.98, and -1597.17±295.70, respectively.

## Study Limitations

There were some limitations of this study. Depending on the retrospective nature of the study, CT images were obtained only in deep breath phase (inspiration) in correlation with lung volumetric evaluation as pre-FEV1 volume and there were not expiratory phase images on CT examination. Therefore, in PFT evaluation, only some parameters including FVC, FEV1/FVC ratio were meaningful. In the current retrospective study, while CT was a static and PFT was a dynamic examination, total lung capacities were calculated in both of them and the correlation of both examinations (CT, PFT) was done. In the study population, diffusing capacity of the lung for carbon monoxide was not studied.

## Conclusion

PFT provides important quantitative pulmonary functional data which are able to clarify pathologic conditions responsible for respiratory symptoms and to evaluate the severity and course of diseases. However, in the cases for which PFT cannot be done, such as COVID-19, CT quantitative pulmonary volumetric assessment can be an alternative in the evaluation of main pulmonary functions. Using the calculated volumes and densities, we need reference values that can be compared in order to make a decision about the patient. For this purpose, we can use the reference values of the spirometry.

### Ethics

**Ethics Committee Approval:** Ethic permission was obtained from the Tekirdağ Namık Kemal University, Non-Invasive Clinical Research Ethics Committee (approval number: 2020.148.06.10).

**Informed Consent:** Retrospective study.

**Peer-review:** Externally peer-reviewed.

### Authorship Contributions

Concept: H.S., Design: H.S., L.C.M., Data Collection or Processing: H.S., L.C.M., Analysis or Interpretation: H.S., L.C.M., Literature Search: H.S., Writing: H.S., L.C.M.

**Financial Disclosure:** The authors declared that this study received no financial support.

**Conflict of Interest:** The authors declared that there is no conflict of interests.

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