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Case Report

Separate evaluation of unilateral lung function using upright/supine CT in a patient with diaphragmatic paralysis☆,☆☆

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ABSTRACT

Background: Unilateral diaphragmatic paralysis is a condition in which the unilateral diaphragm is paralyzed and elevated. Orthopnea due to lung compression by an elevated diaphragm in the supine position is common in patients with unilateral diaphragmatic paralysis. Although its symptom is posture-dependent, the effect of posture on lung function in unilateral diaphragmatic paralysis has not been studied. Computed tomography (CT) can be used to assess lung volume. However, conventional CT cannot be performed in the upright position. A pulmonary function test can be performed in both upright and supine positions. However, it cannot evaluate the function of each lung separately.

Case presentation: We report a case of a 79-year-old man with unilateral diaphragmatic paralysis. He presented with difficulty in inspiration, specifically in the supine position, and underwent both conventional supine CT and newly developed upright CT to assess the effect of posture on the function of each lung. The difference between expiratory and inspiratory lung volumes on CT in the supine position was less than that in the upright position by 46% and 4% on affected and healthy sides, respectively. We previously reported that the difference between expiratory and inspiratory lung volumes on CT correlated with inspiratory capacity on the pulmonary function test. A 46% decline in inspiratory capacity on the affected side in the supine position likely caused orthopnea in this patient.

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Conclusions: Supine/upright CT is helpful to assess the influence of posture on unilateral lung function in patients with unilateral diaphragmatic paralysis.

Introduction

Unilateral diaphragmatic paralysis is a disorder in which the unilateral diaphragm is paralyzed and elevated. Common causes are idiopathic, phrenic nerve injury due to surgery, cancer, or trauma [1]. Orthopnea due to compression of the lung by an elevated diaphragm in the supine position is a common symptom in patients with unilateral diaphragmatic paralysis [2]. Although its symptom is posture-dependent, postural changes in affected lung function in unilateral diaphragmatic paralysis have not been evaluated. We recently developed an upright computed tomography (CT) scanner to study human anatomy in the upright position [3]. The comparison between supine and upright CT volumetry enabled the quantitative evaluation of the postural change in lung volumes separately for the right and left sides. We previously reported that lung volumes on CT correlated with lung capacity on the pulmonary function test (PFT) [4]. Herein, we describe a patient with unilateral diaphragmatic paralysis who underwent supine and upright CT for assessing the effect of posture on lung function.

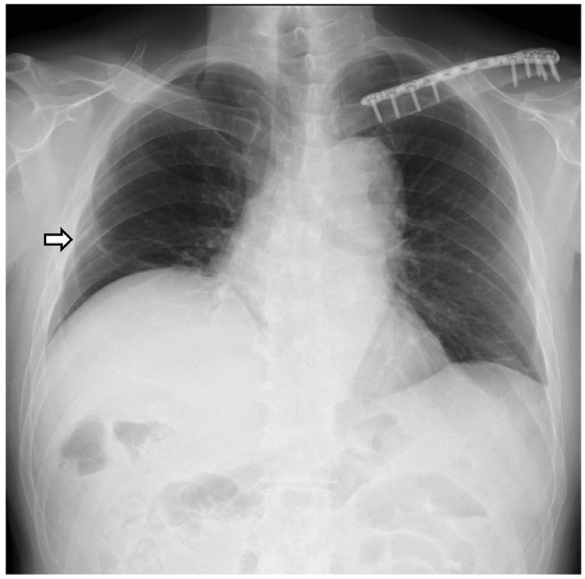

Fig. 1 – Chest X-ray in a standing position showing elevation of the right diaphragm. The arrow shows a pulmonary nodule in the right lung. A plate for the stabilization of the left clavicle fracture is observable.

Case report

A 79-year-old man with small-sized lung cancer was referred to our department. He presented with shortness of breath when lying in the supine position. Chest radiography revealed a nodular shadow in the right lung and elevation of the right diaphragm (Fig. 1). He was diagnosed with clinical stage IA2 lung cancer and idiopathic right diaphragmatic paralysis since he had no relevant medical history of diaphragmatic paralysis. A PFT in the sitting position revealed mild combined ventilatory impairment: his forced expiratory volume in 1 second was 67.7% and vital capacity was 73.3%.

To evaluate posture-associated lung volume changes in each of the patient's lungs, we performed conventional supine and newly developed upright CT (Canon Medical Systems, Otawara, Japan; Fig. 2) [3]. This study was approved by the institutional ethics committee (No. 20180302). Written informed consent was obtained from the patient for participating in this study. Both supine and upright chest CT examinations were performed with automatic exposure control using a noise index of 24 for a slice thickness of 5 mm (tube current range, 10-350 mA). Other scanning parameters were also the same for supine and standing CT scans (peak tube voltage, 120 kVp; rotation speed, 0.5 s; slice collimation, 0.5 mm × 80; and pitch factor, 0.813). A series of contiguous 0.5-mm thick images was reconstructed using Adaptive Iterative Dose Reduction 3D (Canon Medical Systems) [4]. The patient was scanned during breath-hold, both at end-inspiration (near total lung capacity on PFT) and end-tidal expiration (near functional residual capacity on PFT), as described in a previous study [5]. Computed tomography dose index volume values for inspiratory supine, expiratory supine, inspiratory upright, and expiratory upright CT were 3.70, 3.90, 3.50, and 3.70 mGy, respectively. Values for dose-length product for inspiratory supine, expiratory supine, inspiratory upright, and expiratory upright CT were 146.2, 139.5, 142.8, 133.1 mGy cm, respectively. The effective dose estimates for inspiratory supine, expiratory supine, inspiratory upright, and expiratory upright CT were 2.05, 1.95, 2.00, 1.86 mSv, respectively, and was calculated using the dose-length product measurements and appropriate normalized coefficients reported in the literature for chest CT (0.014 mSv/mGy cm) [6]. Lung volumes were measured using a commercially available workstation (Ziostation2; Ziosoft, Tokyo, Japan). Lung volume change from expiration to inspiration (which correlated with the inspiratory capacity on PFT in our previous study) was calculated [7].

Figure 3 shows three-dimensional reconstruction images of lungs at end-inspiration and end-tidal expiration in upright and supine positions. Table 1 summarizes inspiratory and expiratory lung volumes as determined using CT in upright and supine positions. In the upright position, right and left inspiratory lung volumes were 1735 mL and 1835 mL, respectively, whereas in the supine position, they were 1179 mL and 1788 mL, respectively. Therefore, the inspiratory lung volumes in

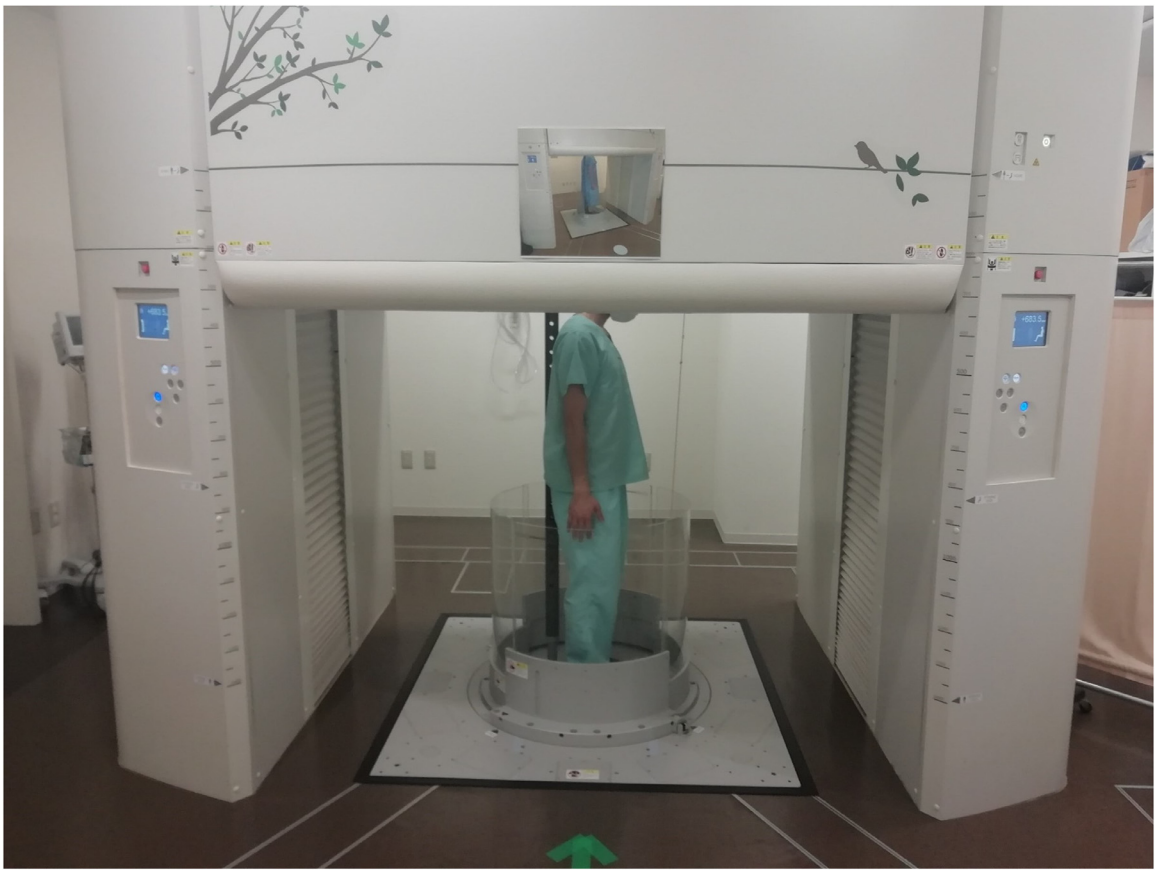

Fig. 2 – Upright computed tomography (CT) scanner. Upright CT examinations in the upright position were performed with the patient's arms down.

Table 1 – Inspiratory and expiratory volumes of lungs on computed tomography in the upright and supine positions.

	Inspiratory volume (mL)	Expiratory volume (mL)	Difference between inspiratory and expiratory volumes (mL)
Upright			
Right (affected side)	1735	1040	695
Left (healthy side)	1835	1032	803
Supine			
Right (affected side)	1179	805	374
(%change from upright)	(−32%)	(−23%)	(−46%)
Left (healthy side)	1788	1016	772
(%change from upright)	(−3%)	(−2%)	(−4%)

the supine position on the right (affected) and left (healthy) sides were 32% and 3% less than those in the upright position, respectively. The volume change from expiration to inspiration in the supine position was 46% and 4% less than those in the upright position on the right (affected side) and left (healthy side) sides, respectively. Both the 32% decline in inspiratory lung volume and 46% decline in volume change from expiration to inspiration on the right side from the upright to supine position were thought contribute to orthopnea caused by the elevation of the right diaphragm in the supine position in the patient.

We recommended surgical plication of the right diaphragm for unilateral diaphragmatic paralysis as well as wedge resection of right upper lobe for lung cancer. However, per the patient's request, he underwent wedge resection of the right upper lobe without surgical plication of the diaphragm. He was discharged on postoperative day 7 without any complications.

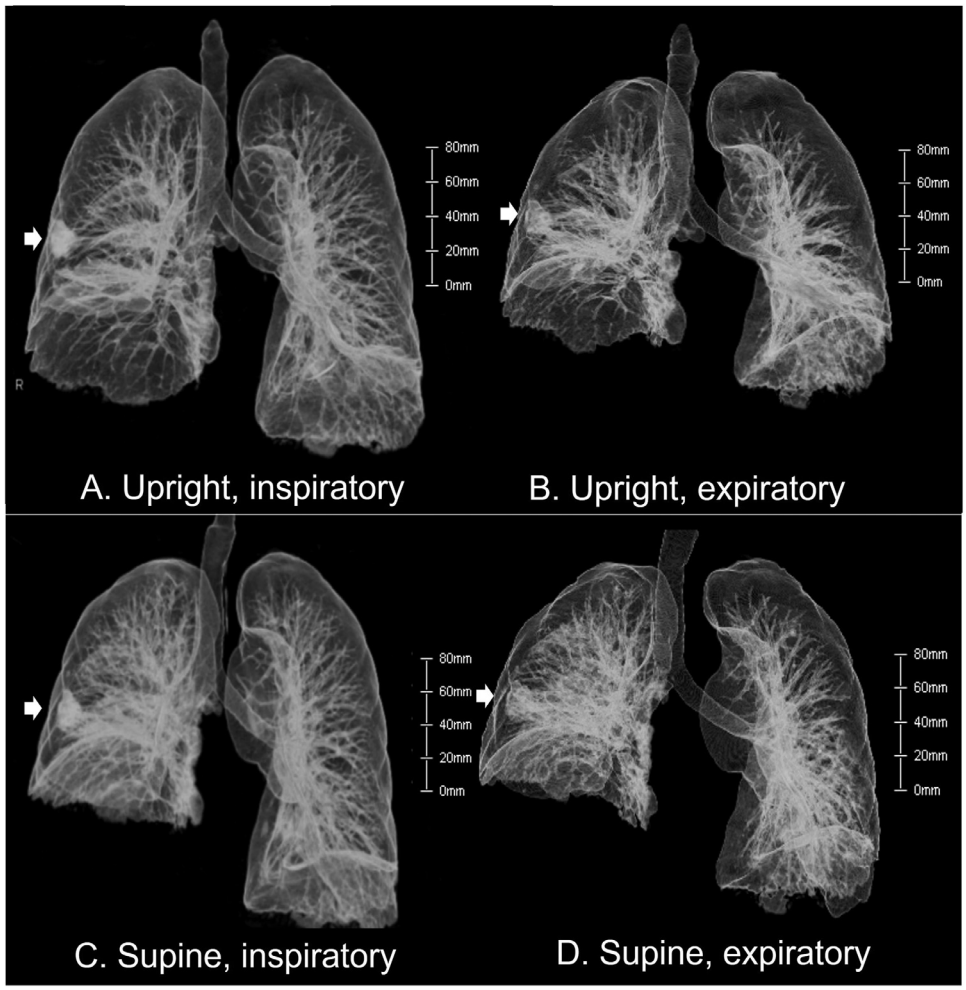

Fig. 3 – Three-dimensional reconstruction images (frontal view) of the lungs. (A) deep inspiration in the upright position, (B) end-tidal expiration in the upright position, (C) deep inspiration in the supine position, and (D) end-tidal expiration in the supine position. The arrow indicates primary lung cancer in the right upper lobe.

Discussion

We recently developed an upright CT scanner for evaluating human anatomy in the upright position [3]. A comparison of supine and upright CT volumetry enabled the separate quantitative evaluation of postural changes on lung volumes on both the right and left sides. In our previous study of 32 asymptomatic volunteers, right (10.3% increase) and left (11.6% increase) lung volumes were significantly greater in the standing than supine position [8]. Moreover, we previously reported the correlation between CT volumetric lung volumes at end-inspiration and end-tidal expiration and lung capacity via PFT in 100 asymptomatic volunteers [7]. The Pearson's correlation coefficients used to compare total lung volumes via inspiratory CT in supine and standing positions and total lung capacity via PFT were 0.83 and 0.93, respectively. Further, r values used to compare lung volume changes from expiration to inspiration on CT in supine and standing positions versus inspiratory capacity on PFT were 0.53 and 0.62, respectively. Therefore, lung volume assessed by supine/upright CT volumetry co-related with lung capacity on PFT.

To our knowledge, this is the first report of a patient with unilateral diaphragmatic paralysis who underwent both upright and supine CT. A PFT is widely used for assessing the severity of diaphragmatic paralysis [2], and can be performed both in the upright and supine positions [9]. However, PFTs cannot be used to separately evaluate the function of each lung. For patients with unilateral diaphragmatic paralysis presenting as orthopnea, combined upright and supine CT volumetry could be an effective method for quantitatively assessing postural-associated lung volume change on affected and healthy sides and for evaluating the impact of unilateral diaphragmatic paralysis on the functioning of an affected lung. Surgical plication of the diaphragm is the treatment of choice for symptomatic diaphragmatic paralysis [2,9]. The effect of posture on lung volume is important information when considering surgical plication of the diaphragm in patients with unilateral diaphragmatic paralysis who present with orthopnea.

Patient consent statement

Written informed consent was obtained from the patient to publish this case report entitled "Separate evaluation of unilateral lung function using upright/supine CT in a patient with diaphragmatic paralysis" and any accompanying images in *Radiology Case Reports*.

Availability of data and materials

All data generated or analyzed during this study are included in the published article. Further enquiries can be directed to the corresponding author.

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