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Evaluation of postoperative lung volume and perfusion changes by dual-energy computed tomography in patients with lung cancer

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ABSTRACT

Purpose: The aim of our study was to retrospectively evaluate postoperative physiologic changes in lung cancer patients using dual-energy CT (DECT), and develop modified methods reflecting postoperative change for predicting pulmonary function.
Methods and materials: 88 patients (M:F = 64:24; mean age, 63.5 years) with lung cancer who underwent DECT and pulmonary function tests before and after operation were included. Volume and iodine values for perfusion of each lobe were quantified. The predicted postoperative FEV1 using the current method was calculated by multiplying the preoperative FEV1 by the fractional contribution of perfusion of the remaining lung. The modified method reflecting postoperative volume change was compared to the current method.
Results: Postoperative lung volume showed compensatory increases in the contralateral and remaining ipsilateral lobes, with a significantly greater increase in the ipsilateral lobe than contralateral lobe (21.8% ± 46.2% vs. 10.0% ± 20.8%, P = 0.031). Perfusion analysis showed blood volume increases in both ipsilateral and contralateral lobes without statistical differences (blood volume ratio difference, 29.2% ± 26.7 vs. 24.6% ± 16.5, P = 0.368). The performance of the modified method considering postoperative lung volume change was comparable to that of the current method in the development and validation datasets (95% CI, −24.5% to 37.1% vs. −33.3% to 22.2% and −23.6% to 32.0% vs. −31.9% to 16.0%, respectively).
Conclusions: Postoperative compensatory increases in lung volume and perfusion occur in different ways. Our modified method incorporating postoperative lung volume changes can be considered a comparable method for prediction of postoperative lung function.

1. Introduction

The preoperative evaluation of pulmonary function in patients with lung cancer under consideration for surgery is essential. This is because pulmonary function can predict the risk of both perioperative complications and long-term disability after pulmonary resection [1–3]. In patients with poor pulmonary function, the treatment of choice may change from curative resection to limited resection or chemoradiation therapy [4]. A predicted postoperative forced expiratory volume over 1 s (FEV1) of less than 30% has traditionally been considered indicative of an increased operative risk for patients undergoing lobectomy [1].

Several methods have been used to predict postoperative FEV1. Perfusion scintigraphy is the preferred imaging modality for obtaining the lobar perfusion ratio [5,6], as it can show the functioning lung status while accounting for the effects of the tumor and smoking-induced alterations on ventilation/perfusion inequalities [7,8]. However, the quantitative evaluation of lobar perfusion using scintigraphy, which has low spatial resolution and lacks anatomic lobar differentiation, means that it can be difficult to correctly estimate the postoperative function of the remaining lung following operation. Quantitative CT or perfusion MRI can be outstanding alternative modalities to perfusion scintigraphy, as they demon-

Abbreviations: BVΔ, change in blood volume ratio; DECT, dual-energy CT; FEV1, forced expiratory volume over 1 s; LVΔ, change in lung volume; PFT, pulmonary function test; SD, standard deviation.

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Table 1
The characteristics of patients in the development dataset.

	Total	Lobectomy	Bilobectomy	Pneumonectomy
Numbers	53	46	6	1
Age	63.1 (10.9)	62.9 (11.4)	62.3 (4.3)	79
M:F	39:14	33:13	5:1	1:0
Preoperative FEV1, L	2.5 (0.6)	2.6 (0.6)	2.4 (0.3)	2.28
Preoperative FEV1, % predicted	86.2 (18.8)	87.1 (18.9)	79.3 (19.9)	94
Postoperative FEV1, L	2.2 (0.5)	2.2 (0.5)	1.8 (0.3)	1.68
Postoperative FEV1, % predicted	74.6 (17.4)	76.6 (17.2)	60.5 (14.9)	70

Note— FEV1, forced expiratory volume during 1 s.
Data are presented as mean (standard deviation).

Table 2
The characteristics of patients in the validation dataset.

	Total	Lobectomy	Bilobectomy	Pneumonectomy
Numbers	35	32	1	2
Age	64.1 (7.0)	64.2 (7.1)	56	65.1 (2.0)
M:F	25:10	22:10	1:0	2:0
Preoperative FEV1, L	2.5 (0.5)	2.5 (0.5)	2.7	2.6 (0.3)
Preoperative FEV1, % predicted	86.3 (16.0)	87.2 (16.2)	71.0	80.0 (9.0)
Postoperative FEV1, L	2.2 (0.4)	2.2 (0.4)	2.1	1.9 (0.1)
Postoperative FEV1, % predicted	74.5 (14.7)	76.1 (14.3)	57.0	58.5 (4.5)

Note— FEV1, forced expiratory volume during 1 s.
Data are presented as mean (standard deviation).

strate greater assessment accuracy [9–11]. Recently, Chae et al. [11] demonstrated that dual-energy CT (DECT), which provides images presenting the status of the lung perfusion at a specific time point, allowed more accurate prediction of postoperative FEV1 in patients with lung cancer, than did perfusion scintigraphy. However, the currently used methods for calculating postoperative FEV1 do not take postoperative volume and perfusion changes in the residual lung into consideration. It is possible that postoperative compensation may occur in relation to the expansion of the remaining lung [12], with a resulting change in ventilation and perfusion status. Volume reduction effect after lobectomy can also occur with underlying emphysematous lung which could also lead to improvement of postoperative FEV1 [13]. Although these effects could be variable from patient to patient, current method could lead to underestimation of postoperative FEV1. This issue is of clinical relevance to appropriate therapeutic decision making in patients with marginal pulmonary reserve.

To confirm the effects of postoperative physiologic change on FEV1, the postoperative changes in volume and perfusion in the residual lung require investigation. However, to our knowledge, there are only a few published studies on postoperative lung volume or perfusion changes which are generally animal studies, or contain small numbers of patients or mainly focused on patients with chronic obstructive pulmonary disease [12,14–17].

Therefore, the purpose of our study was to retrospectively evaluate postoperative physiologic changes in lung cancer patients using DECT, and develop modified methods reflecting postoperative change for predicting pulmonary function.

2. Materials and methods

This retrospective study was approved by our institutional review board, and the requirement for written informed consent was waived.

2.1. Study population

2.1.1. Development dataset

Patients who underwent preoperative and postoperative perfusion CT evaluation with standard lobectomy or pneumonectomy for non-small cell lung cancer between July 2010 and November 2014 were selected from a single center database of a tertiary hospital. Of the initial 73 patients identified, 20 were excluded because of additional wedge resection in the ipsilateral lobe (n = 15), pre- or postoperative radiation therapy (n = 3), and lack of a postoperative pulmonary function test (PFT) (n = 2). Finally, 53 patients (mean age, 63.1 years ± 10.8; range, 39–79 years) were included in this study. There were 39 men (mean age, 63.3 years ± 11.4; range, 42–79 years) and 14 women (mean age, 61.5 years ± 9.3; range, 39–72 years).

All of the patients underwent PFT and DECT prior to the surgery, and at least 4 months after the surgery. According to the study of Brunelli et al., postoperative FEV1 increases until at least 3 months post-surgery. Therefore, a follow-up PFT after more than 3 months is thought to be appropriate for analysis [18]. The mean interval period between preoperative evaluation and operation was 10.9 days ± 10.3 (range, 1–49 days; median, 7 days) for DECT, and 20 days ± 17.9 (range, 1–115 days; median, 18 days) for PFT. The mean interval period between postoperative evaluation and operation was 201.8 days ± 86.3 (range, 144–345 days; median, 174 days) for DECT and 188 days ± 73.9 (range, 138–339 days; median, 161 days) for PFT. Table 1 summarizes the characteristics of patients in the development dataset.

2.1.2. Validation dataset

We assessed the performance of the modified formula for prediction of postoperative FEV1 using a separate validation cohort from the same center, but covering a different period. Thirty-five patients who underwent surgery from 2009 to 2010 were included, according to the same inclusion criteria as mentioned above. These patients, previously studied in determining the usefulness of DECT for predicting postoperative pulmonary function following partial or complete lung resection [11], were evaluated for changes in lung volume and perfusion after resection and evaluating the performance. Table 2 summarizes the characteristics of the patients in the validation dataset.

2.2. CT protocol

CT scans were obtained for all patients using the same dual source CT system (SOMATOM Definition; Siemens Healthcare, Forchheim, Germany) in the dual energy mode (80 and 140 kV).