Original Investigation

Cardiovascular Computed Tomography Findings after Pneumonectomy: Comparison to Lobectomy

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Rationale and Objectives: To identify and compare cardiovascular findings on computed tomography (CT) scans after pneumonectomy (PNX) with those after lobectomy (LOBX).

Materials and Methods: Pre- and postoperative CT scans from 25 PNX patients were retrospectively analyzed and compared to those from 30 LOBX patients. The diameter of the main pulmonary artery (PA) and its ratio to the ascending aorta (PA/Ao) were determined. Cardiac morphometry values were ascertained by measuring maximum diameters of the right and left ventricle on axial (RV_{axial}, LV_{axial}) and four-chamber ($RV_{4\text{-}ch}$, $LV_{4\text{-}ch}$) views. RV_{axial}/LV_{axial} and $RV_{4\text{-}ch}/LV_{4\text{-}ch}$ ratios were calculated. Vessel stumps were evaluated for thrombosis.

Results: After PNX, PA (31.1 ± 5.8 mm vs 28.7 ± 5.4 mm, $P = 0.003$), PA/Ao (0.97 ± 0.15 vs 0.86 ± 0.12, $P = 0.0001$), and cardiac morphometry values significantly increased (RV_{axial} 43.6 ± 7.4 vs 39.4 ± 7.1, $P = 0.029$; $RV_{4\text{-}ch}$ 41.1 ± 6.3 vs 37.6 ± 5.7, $P = 0.041$; RV_{axial}/LV_{axial} 1.18 ± 0.27 vs 1.03 ± 0.22, $P = 0.04$; $RV_{4\text{-}ch}/LV_{4\text{-}ch}$ 1.17 ± 0.21 vs 1.02 ± 0.16, $P = 0.03$). There were no significant differences between right and left PNX. One case of PA stump thrombosis was identified after right PNX. LOBX resulted in a significant increase in PA (30.6 ± 4.3 vs 28.7 ± 3.5, $P = 0.005$) and PA/Ao (0.90 ± 0.09 vs 0.85 ± 0.10, $P = 0.017$), whereas cardiac morphometry values were not significantly changed compared to baseline values. No vessel stump thrombosis was observed after LOBX. In comparison to LOBX, all ascertained values were significantly elevated after PNX.

Conclusions: Morphologic alterations of the cardiovascular system following PNX can be identified on CT scans. Alterations are more distinct after PNX compared to LOBX.

Key Words: Computed tomography; lung surgery; pneumonectomy; lung cancer.

INTRODUCTION

Pneumonectomy (PNX) has various early and late effects on the cardiovascular system that are based on displacement of the heart and major vessels (1,2), altered hemodynamics in vessel stumps (3,4), increased perfusion to the remaining lung tissue (5), and elevated vascular resistance (6,7). In about 40% of patients after PNX these effects were shown to induce pulmonary hypertension (PH), that is, resting mean pulmonary artery pressures (PAP) exceeding 25 mmHg with concomitant dysfunction and remodeling of the right ventricle (8,9).

Doppler echocardiography was found to be useful in the evaluation of patients undergoing PNX as the right ventricular function and morphology as well as PAP can be assessed noninvasively (1,5,10).

As a result of PNX, early modifications demonstrated by echocardiography include a progressive increase in systolic PAP that starts at the end of the first week after surgery, inducing a dilation of the right ventricle that becomes significant 6 months postoperatively (1,5,9,10). Reported values for mean systolic PAP range from 27.3 ± 9.3 mmHg to 40.5 ± 12.5 mmHg 6 months after PNX (1,5,9) and 33.4 ± 7.9 mmHg to 34.1 ± 14 mmHg (1,9) 1 year following PNX, respectively. Furthermore, patients with systolic PAP exceeding 35.5 mmHg 1 year postoperatively were shown to be at higher risk of a suboptimal clinical outcome (9).

However, computed tomography (CT) studies addressing alterations of the cardiovascular system after PNX are missing. Therefore, the purpose of the present study was (1) to retrospectively evaluate chest CT scans from PNX patients for morphologic modifications of the heart and main pulmonary vessels and (2) to identify measurements that may be valuable for further prospective evaluation as clinical outcome indicators. These would be useful as CT scans are routinely

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performed in patients after PNX, especially in those after surgery for malignancy.

Because echocardiographic findings were shown to be dependent upon the amount of resected pulmonary vascular bed (1,5), we further aimed to compare our results to CT findings of patients who underwent lobectomy (LOBX).

MATERIALS AND METHODS

Data Analysis

Data from PNX and LOBX patients were collected retrospectively between 2006 and 2014. The need for informed consent was waived by the local ethics committee. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Indications for PNX and LOBX are listed in Table 1. Inclusion criteria were the following: contrast-enhanced CT before and after PNX or typical LOBX, absence of heart failure, absence of severe emphysema, and lung fibrosis or known pulmonary arterial hypertension (the latter can falsify measurements of pulmonary vessel diameters) (11,12).

In 25 patients undergoing PNX and 30 patients undergoing LOBX, adequate CT scans were available for analysis. The first follow-up CT after surgery was used for the comparison of pre- and postoperative scans. All imaging studies were performed at our institution using 16- and 64-row CT scanners (Brilliance, Philips Healthcare, Best, The Netherlands). Data analysis was performed independently by two experienced radiologists with 4 and 5 years of experience in reading chest CTs. Each investigator was blinded to the results of the other investigator during data analysis. Means of both measurements were accepted as corresponding data and used for statistical analysis.

TABLE 1. Patients' Characteristics

	Pneumonectomy	Lobectomy
Male	17	17
Female	8	13
Mean age at surgery (range)	61.3 (40–73)	64.3 (46–81)
Right	11	Upper lobe 14 Lower lobe 2 Middle lobe 4
Left	14	Upper lobe 6 Lower lobe 4
Indication		
Bronchogenic carcinoma	19	25
Metastases from extrapulmonary malignancy	2	3
Pleural empyema	1	—
Bleeding from pulmonary artery aneurysm	—	1
Tuberculosis	1	—
Bronchial carcinoid tumor	1	1
Lung abscess	1	—

Thoracic Vessels

CT scans were viewed on a mediastinal window (level 30/width 400 Hounsfield units). The diameter of the main pulmonary trunk was measured on the axial slice that showed its maximum diameter; the diameter of the ascending aorta (Ao) was determined on this slice as well (Fig 1a). The length of the pulmonary artery (PA) stump was measured from its distal end to a line drawn from the border of the main PA (Fig 1b) (13). PA stumps and pulmonary vein stumps were evaluated for thrombosis.

Cardiac Morphometry

Maximum RV_{axial} and LV_{axial} diameters were identified on axial sections between the free ventricular wall endocardium and the interventricular wall, and RV_{axial}/LV_{axial} ratios were calculated (Fig 1c). Four-chamber views were reconstructed using a previously described approach (14). $RV_{4\text{-}ch}$ and $LV_{4\text{-}ch}$ diameters were identified as the maximal distances between the ventricular endocardium and the interventricular septum, and $RV_{4\text{-}ch}/LV_{4\text{-}ch}$ ratios were calculated (Fig 1d).

Statistics

Statistical analysis was performed using GraphPad Prism version 6 (GraphPad Software, La Jolla, CA). Values are reported as the mean and standard deviation unless otherwise specified. Normal data distribution was ascertained using the D'Agostino-Pearson omnibus normality test. A paired Student *t* test was performed for the comparison of pre- and postoperative imaging series. An unpaired Student *t* test was used for all other comparisons. The Mann-Whitney rank-sum test was used for the comparison of non-normal distributed data. Bland-Altman analyses were performed for the assessment of interobserver agreement. A P value <0.05 was considered as statistically significant.

RESULTS

PNX

The first follow-up CT scan was performed after a median of 13 weeks (range 3–34 weeks) after surgery. Morphometric data of PNX patients are summarized in Table 2. Main PA diameter and its ratio to the ascending aorta (PA/Ao) significantly increased. Cardiac morphometry revealed significantly increased diameter of the RV and its ratio to the LV diameter on both axial sections and reconstructed four-chamber views. Postoperative changes seen before and after the median follow-up time of 13 weeks did not differ significantly (PA 31.2 ± 5.2 mm vs 31.0 ± 6.6 mm, $P = 0.93$; PA/Ao 1.03 ± 0.13 vs 0.90 ± 0.14, $P = 0.16$; RV_{axial} 44.0 ± 7.0 mm vs 43.2 ± 8.2 mm, $P = 0.83$; $RV_{4\text{-}ch}$ 41.6 ± 6.3 mm vs