Preoperative Pulmonary Vascular Morphology and Its Relationship to Postpneumonectomy Hemodynamics

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Rationale and Objectives: Pulmonary edema and pulmonary hypertension are postsurgical complications of pneumonectomy that may represent the remaining pulmonary vasculature's inability to accommodate the entirety of the cardiac output. Quantification of the aggregate pulmonary vascular cross-sectional area (CSA) has been used to study the development of pulmonary vascular disease in smokers. In this study, we applied this technique to demonstrate the potential utility of pulmonary vascular quantification in surgical risk assessment. Our hypothesis was that those subjects with the lowest aggregate vascular CSA in the nonoperative lung would be most likely to have elevated pulmonary vascular pressures in the postoperative period.

Materials and Methods: A total of 61 subjects with postoperative hemodynamics and adequate imaging were identified from 159 patients undergoing pneumonectomies for mesothelioma. The total CSA of blood vessels perpendicular to the plane of computed tomographic (CT) scan slices was computed for blood vessels <5 mm^2 (CSA 5 mm). This measurement expressed as a percentage of lung parenchyma area (CSA 5%) was compared to postoperative hemodynamic measurements obtained by right heart catheterization.

Results: In patients where a contrasted CT scan was used (n = 26), CSA 5% was correlated with postoperative day 0 minimum cardiac index (R = 0.37, P = .03) but not with the maximum pulmonary arterial pressures. In patients with noncontrast CT scans (n = 35), CSA 5% was inversely correlated with postoperative day 0 maximum pulmonary arterial pressures (R = 0.43, P = .03) but not with the minimum cardiac index. The preoperative perfusion fraction of the nonsurgical lung did not correlate with postoperative hemodynamics.

Conclusions: CSA of pulmonary vasculature with an area ≤5 mm^2 has potential in estimating the ability of pulmonary vascular bed to accommodate postsurgical changes in pneumonectomy.

Key Words: Pneumonectomy; hemodynamics; CSA; vasculature.

A detailed preprocedure assessment of patients undergoing lung resection has become a key component for the estimation of perioperative risk (1–3). In the case of patients undergoing pneumonectomy, the goals of this evaluation is to predict postoperative lung function, the potential for ventilatory compromise, pulmonary edema, and Acute Respiratory Distress Syndrome (ARDS) (4–6). Such patients are also at an increased risk for the development of both transient elevations of pulmonary arterial pressures (PAPs) and sustained postoperative pulmonary hypertension (7–9). Previous studies suggest that preoperative pulmonary vascular resistance and intraoperative PAPs are predictive of postoperative respiratory failure and mortality (10,11). In another example, the risk of developing postoperative pulmonary edema and ARDS was related to the preoperative distribution of lung perfusion (6,12). In aggregate, the risk for developing postpneumonectomy complications appears to be related to the ability of the nonoperative lung to accommodate an increase in blood flow to the full cardiac output. Noninvasive identification of compromised pulmonary vasculature in the nonoperative lung may reduce morbidity and mortality associated with this procedure.

Our group has previously described a semiautomated quantification method to calculate the total cross-sectional area (CSA) of the pulmonary vasculature on computed tomographic (CT) scans of the chest. The objective of these

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efforts is to develop and refine techniques to characterize vascular architecture from imaging. Using these tools, we hypothesized that those subjects with the smallest vascular CSA in the nonoperative lung as assessed by preoperative CT scans would be at greatest risk for hemodynamic compromise in the immediate postoperative period. To investigate this hypothesis, we performed a secondary analysis of clinically acquired CT scans and hemodynamic data on subjects undergoing extrapleural pneumonectomy at our institution.

METHODS

We evaluated a sequential cohort of patients who underwent extrapleural pneumonectomy (13) for mesothelioma between January 2008 and March 2013 at our center. Demographic and hemodynamic parameters were retrieved from both electronic- and paper-based medical records. All available CT scans of the chest performed no more than 6 months before surgery were reviewed for quantitative vascular analysis. Only those CT studies with 1 mm or thinner slices were used. A detailed description of the parameters used for image acquisition and reconstruction is available in the Appendix 1. The methods of image analysis used to calculate the vascular CSA have been previously described (14,15). Vascular analysis was performed in three anatomic locations in the lung, which would be spared from the pneumonectomy: 1 cm above the aortic arch, 1 cm below the carina, and 1 cm below the entrance of the right inferior pulmonary vein. These locations were chosen and validated to ensure reproducibility. Measures of the aggregate vascular CSA of structures <5 mm^2 were collected and normalized by the total CSA of the lung in that same slice. The final CSA 5% was calculated by using a weighted average of the three slices (average weighted by the parenchymal area of each slice). The same method was also used to compute the CSA of structures <10 mm^2 to yield the CSA 10%. All image analysis was performed using ImageJ version 1.46r (National Institutes of Health, Bethesda, MD) (16). An example and representation of the process is shown in Figure 1. Please see Appendix 1 for a more detailed description of the image analysis process.

Our STAR (Surgical Intensive Care Unit Translational Research) Center, in collaboration with the Division of Thoracic Surgery, maintains a database of all patients who underwent pneumonectomy since 2008. Institutional Review Board approval was obtained for this analysis. All subjects had a right heart catheterization in the operating room and arrived to the intensive care unit with a pulmonary arterial catheter in place for hemodynamic monitoring. The maximum PAP and the minimum cardiac index (CI) for postoperative day 0 (POD 0) were obtained from archived intensive care unit flow sheets. Only data from POD 0 were used as PA catheters were often removed on subsequent days. Perfusion scans within 1 year of surgery were also evaluated. The fraction of the total perfusion attributable to the nonoperative lung was calculated. Data are presented as means and standard deviations or medians and interquartile ranges where appropriate. Pearson correlation coefficients and their respective statistical significance were evaluated using SAS 9.3 (SAS Institute Inc, Cary, NC). For the comparison of the characteristics of the two groups, the Wilcoxon rank sum test using two-sided P values was used for continuous measurements. For the purpose of comparing categorical values a Fisher exact test was used. In all statistical comparisons, P values of <0.05 were considered statistically significant.

RESULTS

A total of 159 sequential patients who underwent pneumonectomy between January 2008 and March 2013 were identified in the database. Figure 2 provides a schematic of the review and inclusion of a subset of these subjects. Patients were excluded for inadequate preoperative imaging (n = 83) or lack of hemodynamic data (n = 13) on POD 0 leaving 61 subjects to be included in our analysis. Inadequate imaging was caused predominately by scans without adequately thin sections, usually from outside institutions. Of these 61 subjects, 26 had preoperative CT scans with intravenous contrast (I+), whereas 35 had CT scans without contrast (I−). To our knowledge, there was no specific clinical reason for why certain patients had one type of scan. The subsequent analysis was divided into two groups: patients with (I+) or without (I−) intravenous contrast enhanced CT scans.

The demographics of the cohorts, divided into the two subgroups with or without intravenous contrast enhancement, are shown in Table 1. Between the two subgroups, there was a trend toward left-sided pneumonectomies in patients with I+ CT scans, which did not reach statistical significance.

A summary of CSA calculations for both CSA 5% and CSA 10% is given in Table 4 in Appendix 1. There was a statistically significant difference in CSA 5% between the two groups (P = .001). In the subset of subjects who underwent I− CT scanning there was an inverse relationship between the CSA 5% and peak PAP on POD 0. There was no association between the CSA 5% and CI. In the I+ cohort, there was no association between the CSA 5% and the PAP but the CSA 5% was directly related to CI. These findings are illustrated in Figure 3. Similar findings were noted when using vessel CSAs of 10 mm^2 (CSA 10%), which are summarized in Table 2.

Thirty-four of the 35 patients with I− CT scans and 24 of the 26 patients with I+ CT scans had a perfusion scan available before surgery. We computed the perfusion fraction in the remaining lung as has been suggested by previous studies examining its relation to postoperative respiratory failure (6,12). This was obtained by dividing the perfusion of the unresected lung by total perfusion of both lungs. The perfusion fraction to the nonoperative lung tended to be directly related to the CSA 5% in that same lung. These trends, however, did not reach statistical significance as shown in Table 2. Similar findings were noted for CSA 10% where the correlation in the case of I− scans did reach statistical significance. The perfusion fraction