The respiratory muscle pump in emphysema after single-lung transplantation

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ADVANCES IN ORGAN PRESERVATION, surgical techniques, immunosuppression, and antibiotic therapy now make single-lung transplantation (SLT) a viable and worthwhile therapeutic option. Adult SLT recipients are principally associated with diagnoses of advanced chronic obstructive pulmonary disease/emphysema (48%) and idiopathic pulmonary fibrosis (31%) (3). Following SLT both health-related quality of life (7) and survival prospects (3) appear improved. However, SLT creates a unique and complex physiological situation. Within the pleural cavity is now a native lung (often emphysematous) and transplanted lung (“normal”) where the volume of the graft is significantly decreased relative to the native lung (6). Important questions arise from these differences in lung size and the subsequent lung-to-lung interactions. Specifically, does the presence of two lungs with differing sizes and mechanical properties affect chest wall mechanics and respiratory muscle function?

With respect to respiratory mechanics, the hyperinflated native lung and the graft have an imbalance in the extent and rate of inflation and emptying (9), which would require asymmetrical expansion of the chest wall and displacement of the mediastinum. Indeed, computerized tomography studies show that with human SLT there is significant displacement of the mediastinum toward the transplanted lung (2, 4, 6) where the angle of mediastinal shift is highest at residual volume (~33°) and lowest at total lung capacity (~20°). The displacement of the mediastinum likely arises, in part, from an imbalance between the elastic recoil pressure of the transplanted and native lung. Assuming that neural drive to the diaphragm remains intact following the SLT, part of the asymmetry in ventilation could be also attributed to asymmetrical displacement of the diaphragm on the native side relative to the transplanted side.

In a canine model of unilateral emphysema, it has been shown that phrenic nerve stimulation results in a less negative airway opening pressure (∆Pao; which in the absence of airflow reflects pleural pressure) in the emphysematous lung relative to the control lung (8). Why is the ability of the diaphragm to lower ∆Pao preserved on the nonemphysema side? Diaphragm length was measured with sonomicrometry with no differences (delta length) between the emphysema-lung apposed hemidiaphragms relative to the normal lung-apposed hemidiaphragm. From this, it appears that the changes to lung shape and mechanical properties have an effect on diaphragm function where the pressure-generating capacity is unequal between the hemidiaphragms. The cause of the interpulmonary difference in ∆Pao was attributed to a difference in the mechanical efficiency of the hemidiaphragms on the basis of lung surface measurements. However, other contributing factors for the discrepancy in ∆Pao were not assessed.

In this issue of the Journal of Applied Physiology, De Troyer et al. (5) provide an important advance in our understanding of how SLT could affect the mechanics of the diaphragm. It was hypothesized that the interpulmonary difference in ∆Pao was the result of a different shortening of the two halves of the diaphragm. To address this they used single-lung inflation to simulate unilateral emphysema in anesthetized dogs. With animals positioned in a computed tomographic (CT) scanner, individual lungs were inflated and the phrenic nerves were stimulated while the endobronchial tubes were occluded. A major strength of this study was the CT-derived determination of muscle displacement and length of the two hemidiaphragms (midcostal region) and radius of curvature. They found that with unilateral lung inflation the pressures developed by the diaphragm are asymmetric. As such, it appears that single lung inflation (as a model of SLT) induces shortening of both hemidiaphragms, but the degree of shortening on the inflated side is much greater than the noninflated side. Said differently, the initial resting length is shortened by the inflation but the delta shortening during stimulation is less on the inflated side. Moreover, it was shown with CT that the asymmetry of contraction is largely explained by a differential effect of inflation on the length and curvature of the two hemidiaphragms.

As with most good studies, the generation of further questions is often as important as the main findings. The study by De Troyer et al. is no exception. It is, of course, difficult to extend the findings from acute animal studies to human SLT recipients, but some comment is warranted. Given the increased life expectancy of SLT recipients it stands to reason that they would be able to increase their participation in the activities of daily living (e.g., walking, climbing stairs) as well as structured exercise programs. What are the consequences of SLT on dynamic lung volumes and the mechanics of the diaphragm with exercise? There is some evidence that SLT patients develop expiratory flow limitation and dynamic hyperinflation with exercise. For example, Murciano et al. (12) found that during exercise SLT patients became flow limited and complained of dyspnea of progressively increasing severity. The native lung, which was probably flow limited at rest, presumably became severely hyperinflated at relatively low levels of exercise. So, during exercise in SLT there appears to be a high propensity for expiratory flow limitation and reduced expiratory time, leading to lung hyperinflation (via gas trapping) and consequent increases in end-expiratory lung volume (EELV). The rise in EELV places the patient on the less compliant region of the lung’s pressure-volume relationship, which in turn increases elastic and threshold loads on the inspiratory muscles leading to an increased work of breathing/sense of effort. The rise in EELV in the native lung during exercise would enhance the difference in length between the two hemidiaphragms. As such, the hyperinflation associated with SLT likely requires the inspiratory muscles to contract from a shorter length, meaning that the muscular force required to ventilate the lungs is substantially increased during exercise.

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Does SLT and the associated shift in mediastinum have an effect on cardiac function? The heart and the lungs are both situated within the intrathoracic space and consequently the heart is exposed to respiratory-related changes in intrathoracic pressure (PITHP). It is inevitable therefore that changes in the volume of one will influence the other. With each inspiratory descent of the diaphragm, PITHP is reduced and the lungs expand. This lowered PITHP is also transmitted across the walls of the right atrium, promoting right atrial filling and widening of the right atrial transmural pressure. This means that cardiac preload and afterload are a function of intracardiac pressure and also PITHP and lung surface-cardiac fossa pressure. The transmural wall stress across the blood vessels within the abdominal compartment and rib cage are also subjected to respiratory-induced swings in PITHP. How do two lungs of different sizes and mechanical properties along with asymmetrical contraction of the diaphragm affect the functioning of the heart and vascular system under exercising conditions where both ventilation and cardiac output are obliged to increase simultaneously? This may be an important consideration as it is often underappreciated that the act of respiration has a significant effect of venous return (10, 11) and on the splanchnic circulation (1).

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

REFERENCES