Collateral damage assessment for endobronchial lung volume reduction

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Lung volume reduction surgery improves symptoms, lung function, and mortality in selected groups of patients with advanced emphysema (5). However, the uncertainty of individual outcomes and associated morbidity and mortality has limited utilization of this major surgical procedure. There is substantial interest in potentially safer, nonsurgical alternatives. Many of these methods attempt to make the lung smaller by occluding bronchi with one-way valves that allow egress for gas or secretions but block air entry (3, 9, 10). The intent is to allow absorption atelectasis in emphysematous lung units distal to the occluders.

Pilot trials of these devices have shown promise, with modest improvements in lung function, exercise capacity, and symptoms, and relatively low rates of serious complications (3, 7, 9–11). However, one surprising finding is that only a minority of patients develop radiographically visible atelectasis (3, 7, 10, 11). While atelectasis is not an absolute requirement for improved symptoms, the improvements in pulmonary function and exercise capacity are greatest in those patients who develop it (3).

The failure of emphysematous lobes to collapse, despite occlusion of their bronchi, is attributed to the low collateral resistance in emphysema. Collateral resistance is often less than airway resistance in these patients, and collateral channels frequently cross incomplete interlobar fissures (2, 4, 6, 8). Gas may thereby continue to enter these lung regions at rates exceeding its rate of absorption. A technique to predict which patients or which lobes have high collateral resistance and are likely to become atelectasic could guide patient selection and procedural planning.

In this issue of the *Journal of Applied Physiology*, Aljuri and Freitag demonstrate a new method to estimate collateral resistance (1). They validate the methodology in a bench-top study and then demonstrate its ability to predict the development of radiographically atelectasis in 11 patients undergoing endobronchial lung volume reduction. Their method is both simple and clever and more easily applied to patients than other methods (4, 8). They simulate the placement of a one-way (expiratory) valve in the target bronchus using a valve and catheter system inserted through a bronchoscope and temporarily sealed in the airway. Then, while the patient breathes spontaneously, they measure pressure just distal to the one-way valve and flow through the catheter. Gas is inhaled into the occluded region only via collateral channels. That gas is then exhaled in parallel through both collateral channels and the catheter. They show mathematically that the gas flowing out through the catheter is the net flow through collateral channels and the airways/catheter, with the resistances acting in series. The pressure measured in their catheter is atmospheric pressure during expiration (when the one-way valve opens directly to the room) and reflects the pressure in the distal capacitance regions during inspiration (when the one-way valve is closed and the subtended airways behave like an extension of the catheter). The pressure in the catheter averaged across the entire respiratory cycle divided by the flow averaged across the respiratory cycle calculates, in a bit of mathematical legerdemain, to equal the sum of the airway, catheter, and collateral resistances. It is an unusual way to consider mean values. The catheter flow during inspiration is zero, and the catheter pressure during expiration is zero, but, nevertheless, the entire respiratory cycle duration is used to calculate the means. It seems a little like calculating my average commuting speed by dividing the distance I drive to work by 24 h. However, the math works, and the lumped resistance is calculated correctly. Figure 1 below is a further simplification of the authors’ Fig. 1A. It demonstrates the essential elements of their model and may assist the reader to understand the technique.

Their bench-top study shows an excellent correlation between the resistance of their “collateral channels” measured independently by classical methods and by their new technique. In the clinical study, the method makes resistance measurements that are bimodally distributed between patients who go on to develop atelectasis or fail to do so after endobronchial lung volume reduction. However, a few differences between the two studies bear emphasis. The bench-top model allows the resistance of the airways/catheter system and the

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**Fig. 1. Simplified theoretical framework for the measurement of collateral resistance during spontaneous breathing.** $P_c$, pressure in the capacitance units distal to the catheter seated in the airway; $P_{cath}$, pressure at the catheter opening, which equals $P_c$ during inspiration and zero during expiration; $Q_{cath}$, catheter flow, which occurs only during expiration and is zero during inspiration; $Raw$, series resistance of the catheter plus airways; $R_{coll}$, resistance of collateral channels. Inspiration and expiration are represented by movement of the piston, indicated by the double-headed arrow. $R_{coll} + Raw = mean \frac{P_{cath}}{Q_{cath}}$, if both $P_{cath}$ and $Q_{cath}$ are averaged across the whole respiratory cycle, even though each equals zero during inspiration or expiration. See Fig. 1 and APPENDIX of Aljuri and Freitag (1).

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collateral channel to be measured separately. Thus the correlation between the collateral resistance, as measured two different ways, lies on the line of identity. Furthermore, the metal tubes chosen to represent collateral channels have resistances much greater than the “airway” resistance. This also optimizes the accuracy of the technique, since the lumped resistance would be dominated by the collateral resistance. In patients, components of the lumped resistance cannot be parsed. In addition, collateral resistance is close to or less than airway resistance in emphysema (4, 8) and likely falls as disease severity worsens. This impairs the signal-to-noise ratio of the technique.

However, even if the quantity that is being measured in these patients is not precisely collateral resistance, the technique holds great clinical promise. In the small group of patients reported here, there is wide separation of resistance values between patients who do and do not develop atelectasis. Whatever quantity this technique is measuring, it appears to have predictive value and identifies atelectasis-prone patients with much better discrimination than any other baseline physiological measure shown in the authors’ Table 1. The methods can probably be further simplified and standardized to facilitate validation in larger numbers of patients at multiple centers.

If “collateral damage” is part and parcel of emphysema, collateral resistance will fall as emphysema becomes more severe. This is suggested by the trends in Table 1 of Aljuri and Freitag (1): the patients who developed atelectasis had baseline lung function that tended to be less abnormal than the other patients. This is unfortunate news for the future of these endobronchial methods. It suggests that the most severely emphysematous lobes may be the ones least likely to collapse. It also suggests that there may be only a range of emphysema severity that is amenable to this sort of therapy. The most severely diseased patients, those least suited to major surgery, may also be least likely to benefit from endobronchial occlusion.

The good news is that these endobronchial techniques will rewrite the risk-to-benefit ratio of lung volume reduction. A nonoperative approach decreases risk. Preprocedural assessment of collateral resistance may increase benefit. That serves the goal of precisely targeting the best patients, with no collateral damage.

REFERENCES


