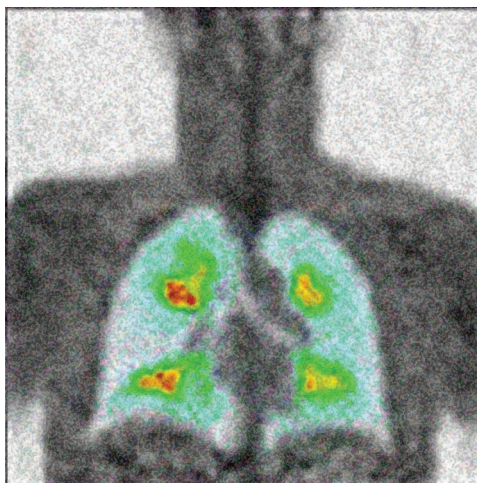


The Dark Side of the Lung

Unveiling Regional Lung Ventilation with Electrical Impedance Tomography

IN this issue of ANESTHESIOLOGY, we can read the results of a study of the distribution of lung ventilation performed with electrical impedance tomography (EIT).¹ The authors collected data during awake state and during lower limb surgery under general anesthesia in three randomized groups of surgical patients breathing spontaneously or receiving either pressure-support ventilation (PSV) or pressure-controlled ventilation. Two observations of interest emerged from the study. The first concerns the effects of the three ventilatory modes on the distribution of pulmonary ventilation. The second is the potential value of EIT monitoring during anesthesia. The study's main finding was that when patients breathe spontaneously, gas was distributed similarly in anesthetized and awake states. During pressure-controlled ventilation, on the other hand, the distribution shifted to more ventral regions of the lung, and surprisingly, this shift also occurred in patients assigned to PSV.

That atelectasis develops during general anesthesia in dependent zones is well known, and we also know that it leads to ventilation-perfusion mismatching and impaired gas exchange.² In the early 1980s, Hedenstierna's group in Sweden showed that this effect occurs both in patients breathing spontaneously and those under mechanical ventilation.³ However, Nyrén *et al.*,⁴ using single-photon emission computed tomography, recently showed that the distribution of ventilation is similar during inhalational anesthesia in spontaneous breathing and during awake state. In the critical care setting, when patients with acute lung injury are initially allowed to breathe spontaneously with airway pressure release ventilation, better cardiopulmonary function has been



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observed and patients have required ventilation support for shorter periods.⁵ It seems that when diaphragm contraction is preserved at least to some extent, it is able to generate a transpulmonary pressure that exceeds the critical alveolar pressure. This pressure is transmitted to lung regions near the diaphragm, specifically to the more caudal and dorsal zones, where alveolar collapse tends to occur; spontaneous breathing would therefore open lung units where recruitment is most useful, improving aeration.^{6,7} These observations seem to call into question the findings of Radke *et al.*¹ in patients under general anesthesia and PSV. First, certain design limitations may explain the discrepancy, given that the anesthetic techniques used and the duration of surgery were not entirely homogeneous in the authors' three patient groups. The differences, though not statistically significant in this small study, may have been clinically significant. We are referring to slight variations in the

combination of regional block techniques and general anesthesia, the amount of sufentanil administered, and the depth of anesthesia recorded. As a result, it is possible that automatic ventilator adjustments in the PSV group may have led to enough loss of ventilatory stimulus to diminish diaphragm activity. PSV levels set from 10 to 20 cm H₂O are too high to produce enough diaphragm contraction to provide spontaneous ventilation benefits.⁸ Second, spontaneous ventilation during airway pressure release ventilation has been shown to be more efficient than PSV in decreasing atelectasis in patients with acute respiratory distress syndrome, even when both ventilator modes are set at the same mean airway pressure.⁹ During airway pressure release ventilation, patients

Image: J. P. Rathmell.

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breathe spontaneously without a trigger and can control inspiratory and expiratory duration. A sinusoidal flow pattern similar to normal spontaneous breathing can therefore be maintained. During PSV, a decelerated gas flow pattern develops, and the patient's effort does not follow the same time course. For all these reasons, we suspect that the group of patients under PSV in the study of Radke *et al.* had gas distribution patterns similar to those under pressure-controlled ventilation. It is clear that the diaphragm is more effective in recruiting alveoli and driving ventilation to dependent lung zones when the patient breathes spontaneously under anesthesia.

The second point of interest of this study was the intraoperative use of EIT as a monitoring tool. EIT provides a breath-by-breath picture of ventilation without radiation. The focus of attention can be the whole lung or regions of interest, delineated by the anteroposterior and right-to-left axes of the lung.^{10–12} The processor calculates changes in electrical impedance detected during a breathing cycle by analyzing signals from an electrode belt placed around the patient's chest. Some electrodes emit electrical currents and others detect them; together the signals are used to create an image of the contents of the thorax. As gases are poor electrical conductors, impedance increases on inspiration or alveolar recruitment and decreases with expiration or alveolar collapse. Changes in impedance during the breathing cycle are transformed into images of a slice of the lung. EIT can also calculate lung volume by regions of interest. What we see is a picture of the distribution of ventilation during each cycle for each lung. We believe that such monitoring has extraordinary potential in anesthesia, as a means to facilitate the diagnosis of ventilation abnormalities or to confirm the efficacy of ventilatory maneuvers during anesthesia.

Some limitations of EIT stem from problems with the validity of the recorded data, which may be degraded if the electrode belt is moved, if there are changes in extravascular fluid in lung tissue, or if strong electromagnetic fields create artifacts. Images can also be misinterpreted. An airless state may be because of alveolar collapse, but it might also be caused by movement of the diaphragm or by pleural effusion. Furthermore, EIT cannot be used during thoracic or cardiac surgery because the belt would interfere with the surgical field. In addition, we still do not know which of the indices derived from the distribution of regional ventilation that have been described¹² would be the most appropriate to monitor during surgery.

EIT offers a way to view regional lung ventilation at the bedside, an advantage over computed tomography scanning, today's gold standard. Other pulmonary imaging alternatives (ultrasound or respiratory inductance plethysmography) are also too cumbersome or complicated to be used at the bedside. Among the portable alternatives to EIT that are being developed or are already available, one to watch is vibration response imaging. This technology creates dynamic images on the basis of vibrations recorded by sensors placed on the

patient's back. In a sense, the device consists of many stethoscopes placed serially to provide qualitative and quantitative information about regional ventilation.¹³ Vibration response imaging has mainly been used in intensive care units,¹⁴ and its potential utility in anesthesiology still needs to be assessed.

We can already begin to speak of noninvasive pulmonary image monitoring at the patient's bedside, but how might such monitoring be useful in the operating room? EIT has already been used in a few intraoperative studies (in gastric bypass¹⁵ and laparoscopic¹⁶ surgery, for example), but a great deal of ground remains to be covered. Noninvasive pulmonary imaging monitors might be able to help us optimize ventilation during anesthesia and possibly reduce the incidence of postoperative pulmonary complications, particularly in patients known to be at higher risk of death.¹⁷ The future should bring more lightweight, portable devices with feedback systems that would perform automatic adjustments to enhance alveolar recruitment, choosing the optimal positive end-expiratory pressure or tidal volume, for example.

The study by Radke *et al.*¹ is a welcome contribution to our understanding of spontaneous ventilation, calling on us to rethink conventional notions. The authors' application of EIT also suggests exciting new research possibilities. Clearly, pulmonary imaging monitors that are easy to use have arrived and will soon be commonplace in our operating rooms, revealing the dark side of the lung we have been unable to see until now. With such technology we should be able to manage ventilation during surgery with greater agility and improve patient outcomes.

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