Respiratory Cycle in 90 Images

Targeted recruitment maneuvers can help to reopen collapsed areas of the lungs. However, until now suitable information for immediately determining the success of such maneuvers has not been available. **ELECTRICAL IMPEDANCE TOMOGRAPHY** (EIT) is intended to close this gap. It determines the regional distribution of ventilation in the lungs—continuously, without radiation, and directly at the patient's bedside.

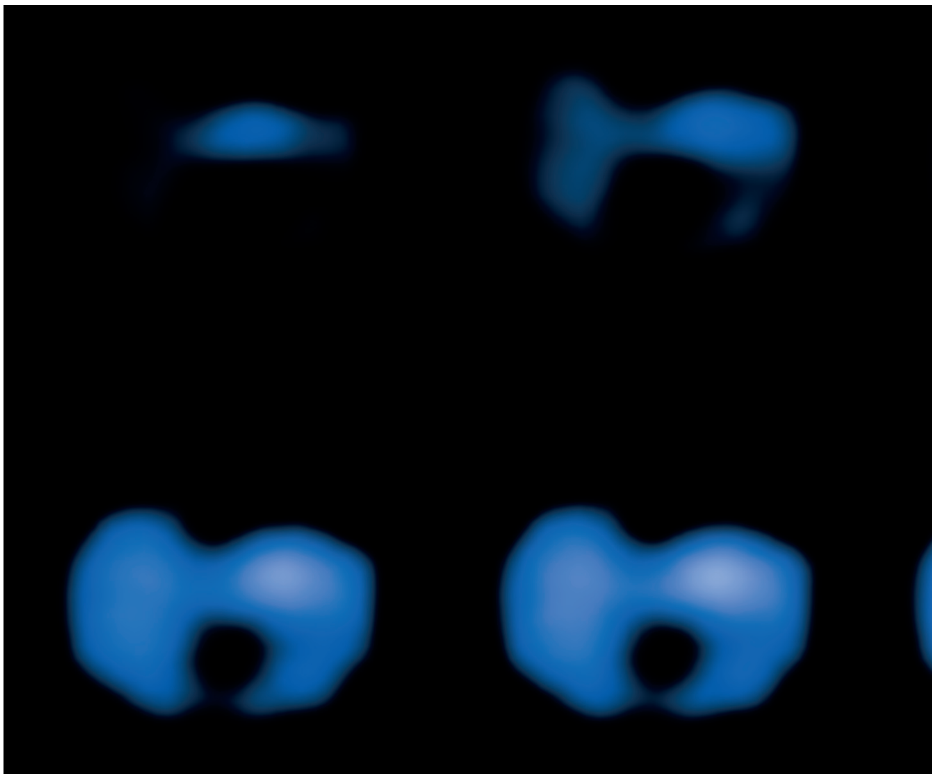
WHAT GOES ON INSIDE a person's body? In the course of time, new technical methods have provided fascinating insights that have facilitated the examination, therapy, and monitoring of patients. Pulse oximetry is a technique that enables the easy measurement of arterial oxygen saturation by measuring light absorption. A clip fastened to a finger or another part of the body determines the attenuation of certain wavelengths of light as it passes through the respective part of the body.

Although this technique was almost completely unknown 25 years ago, today it is very difficult to imagine how rescue services or an intensive care unit (ICU) could operate without it. Pulse oximetry has also established itself outside of hospitals. Amateur pilots and mountain climbers, for example, use it to help avoid altitude sickness.

The right pressure at the right time

Today experts are predicting that electrical impedance tomography, or EIT, will follow a similar path. Armed with this imaging method, it is possible to determine the regional distribution of ventilation in the lungs. "EIT has proved to be an efficient method for guiding ventilation therapy in patients with serious pulmonary diseases in such a way that consequential damage can be prevented," says Dr. Diederik Gommers, who is the vice chairman of the Adult Intensive Care Unit at Erasmus Clinical Center in Rotterdam, The Netherlands. "Especially in difficult cases where it's vital to act quickly, EIT provides us with up-to-date information that previously wasn't available." In theory, Dr. Gommers knows exactly the data he needs to treat these patients. Perhaps that's not so surprising given that he spent many years working on the research team of the experimental anesthesiologist Prof. Burkhard Lachmann. It was during this period that he codeveloped the Open Lung Concept. This concept provides important usage patterns for doctors when they have to make collapsed ("atelectatic") regions of the lungs accessible for gas exchange again by using targeted recruitment maneuvers with temporarily high ventilation pressure. These regions of the lungs are subsequently stabilized by setting optimal positive end-expiratory pressure (PEEP).

However, the practical implementation of this method had long proved to be difficult. "For the doctor to ventilate with the right pressure at the right time," explains Gommers, "he or she has to know pretty quickly how the various regions of the lungs respond to the individual recruitment maneuvers." That has not been possible up until now



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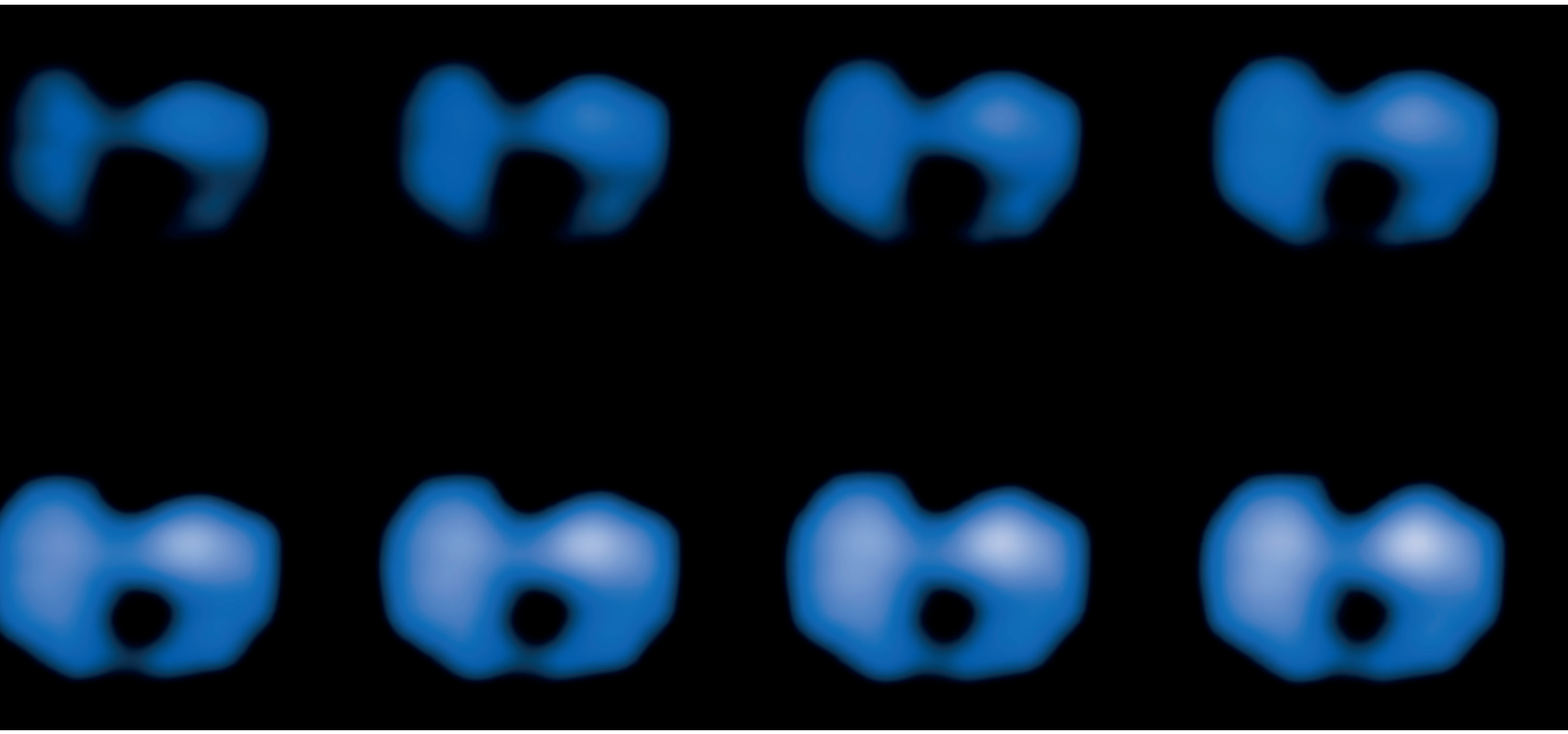
Some of the 90 images of a respiratory cycle: White indicates the best-ventilated

because no suitable method has been available. Although computed tomography (CT) provides a very detailed tomographic image of the lungs, the patient must first be transported from the ICU to the CT department—often a difficult and complex procedure. In addition, it is not possible to carry out continuous measurements because this method uses x-rays. Consequently, physiological processes such as respiration cannot be portrayed dynamically.

Functional residual capacity (FRC) is also of only limited use when it comes to assessing the success of targeted recruitment maneuvers. This is because FRC measurements reflect the entire lung rather than what is happening in a particular region of the lung as the result of the maneuver. With this method, the gas volume remaining in the lungs following a normal expiration at rest is measured at regular intervals. EIT, like FRC, provides information about end expiratory lung volume, but with the added benefit that EIT provides information about the response to recruitment maneuvers in specific regions of the lungs. In other words, FRC provides a doctor with clues, whereas EIT provides additional information and more specific guidance.

16 electrodes measure resistance

EIT provides a means of analyzing ventilation distribution in the lungs—the data is continuously displayed as images, waveforms, and parameters. To do so, it uses the fact that the air content influences the bioelectrical properties of pulmonary tissue. The more air that is contained in the pulmonary tissue, the greater is the electrical resistance, >



regions, black the nonventilated regions. Blue regions are in between these two states.

The display is the window into the lungs: It shows respiratory function at a glance in intuitively identifiable colors.

> which in this case is specifically referred to as "impedance."

In order to determine this impedance, Dräger has developed a solution in which 16 electrodes are first placed around the patient's chest. Tiny electrical currents are then applied to the body through one electrode pair and the resulting voltages at the remaining electrode pairs are measured. These voltages change in relation to the amount of air present in the patient's chest. Because the position at which the current is applied to the body during an EIT rotates around the chest, the voltage measurement locations also change. As is the case with CT images, the measured values obtained after one 360-degree rotation can be used to compute a tomographic image that provides information about the distribution of air inside the chest (in the dorsal and ventral lung regions).

But that is by no means the end of the story. To resolve the change in the distribution of air with respect to time, EIT requires more than just a single snapshot. Instead—depending on the settings—30 images are captured every second and respiration is continuously displayed as a dynamic image. One respiratory cycle lasting approximately three seconds generates a sequence of 90 images that show the ventilation distribution in the lungs in an intuitively understandable manner with the help of color coding.

The three colors selected (black, blue, and white) represent the ventilation of the lungs at a specific point in time in the individual regions of the lungs. White represents the regions that are best ventilated; nonventilated regions are black. The blue areas represent regions that are in a transitory phase between black and white or vice versa. Finally, arranging the images chronologically results in an informative, dynamic image showing how these areas grow and recede in rhythm with the patient's respiration.

"This provides us with completely new insights into what is happening inside the patient's lungs," says Dr. Gommers when he is asked to describe his experience with EIT prototypes from Dräger. "What's more, thanks to the highly sensitive equipment we are able to optimize the fine adjustment of the ventilator directly at the patient's bedside."

Software is an important factor

It is the software that converts the measured data into comprehensible images which make the solution so usable. It was necessary to develop algorithms that condition the measured data so that only the relevant changes in bioimpedance as a result of ventilation are considered. In other words, such things as changes in the resistance between the electrodes and the skin don't play a role. Other disturbance variables, such as cardiac activity, can be subtracted so that the healthcare personnel can concentrate on the processes relevant to ventilation. The software also had to be written in such a way that the measured data can be continuously analyzed and visualized in real time bedside without delay. This was an important prerequisite, as any demand for off-side analysis would substantially diminish the practical benefits of EIT.

Professor Ola Stenqvist, an anesthetist at Salhgrenska University Hospital in Göteborg, Sweden, has been following the advancements in this area very closely. He first became acquainted with the concept of EIT in the mid-1990s and has been a Dräger development partner since 2002. And because Dräger already offers a user-friendly solution with its current EIT prototype, it is conceivable that he—just like his colleague Dr. Gommers—would like to use EIT for more than just research purposes in the future.

The intensive care community is eagerly anticipating the introduction, in 2010, of a commercial EIT solution from Dräger. Says Stenqvist: "I believe that this product will represent a great advance in daily clinical practice as far as treating mechanically ventilated patients is concerned." **Frank Grünberg**