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Respiration and the Airway

RESPIRATION AND THE AIRWAY

Perioperative assessment of regional ventilation during changing body positions and ventilation conditions by electrical impedance tomography

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Abstract

Background: Lung-protective ventilation is claimed to be beneficial not only in critically ill patients, but also in pulmonary healthy patients undergoing general anaesthesia. We report the use of electrical impedance tomography for assessing regional changes in ventilation, during both spontaneous breathing and mechanical ventilation, in patients undergoing robot-assisted radical prostatectomy.

Methods: We performed electrical impedance tomography measurements in 39 patients before induction of anaesthesia in the sitting (M1) and supine position (M2), after the start of mechanical ventilation (M3), during capnoperitoneum and Trendelenburg positioning (M4), and finally, in the supine position after release of capnoperitoneum (M5). To quantify regional changes in lung ventilation, we calculated the centre of ventilation and 'silent spaces' in the ventral and dorsal lung regions that did not show major impedance changes.

Results: Compared with the awake supine position [2.3% (2.3)], anaesthesia and mechanical ventilation induced a significant increase in silent spaces in the dorsal dependent lung [9.2% (6.3); $P<0.05$]. Capnoperitoneum and the Trendelenburg position led to a significant increase in such spaces [11.5% (8.9)]. Silent space in the ventral lung remained constant throughout anaesthesia.

Conclusion: Electrical impedance tomography was able to identify and quantify on a breath-by-breath basis circumscribed areas, so-called silent spaces, within healthy lungs that received little or no ventilation during general anaesthesia, capnoperitoneum, and different body positions. As these silent spaces are suggestive of atelectasis on the one hand and overdistension on the other, they might become useful to guide individualized protective ventilation strategies to mitigate the side-effects of anaesthesia and surgery on the lungs.

Key words: atelectasis; electrical impedance; electrodes; perioperative period; respiration, artificial

During general anaesthesia, gas exchange is impaired because of a mismatch of the regional distribution of ventilation and perfusion.[1] The main pathogenic mechanism is the development of atelectasis in dorsal dependent lung areas and overdistension

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Editor's key points

- Electrical impedance tomography was used to assess regional changes of lung ventilation in patients undergoing robot-assisted radical prostatectomy.
- The silent spaces (which receive little or no ventilation) of the lungs were increased by mechanical ventilation, by capnoperitoneum, and by Trendelenburg's positioning.
- Electrical impedance tomography may be useful in identifying the silent spaces, which may suggestive of atelectasis of the lungs.

in ventral non-dependent lung areas.[2] Given that artificial ventilation can cause harm to healthy lungs, protective ventilation strategies have been advocated.[3]

As the complexity and duration of laparoscopic procedures have increased over the years and are expected to increase even more (robot-assisted prostatectomy in the deep Trendelenburg position is only one example), bedside tools capable of identifying the consequences of therapeutic interventions with sufficient sensitivity and specificity could allow optimization of ventilation strategies for such settings.

The working principle of electrical impedance tomography (EIT) is the measurement of changes in resistance of the lung against the flow of alternating electrical currents applied to the thorax during breathing. This resistance of a medium to alternating current is called impedance. Electrical impedance tomography reconstructs functional images with high temporal resolution based on the assessment of impedance changes during the respiratory cycle. In this way, regional ventilation can be seen continuously at the bedside. Stretched lung tissue poses higher impedance to electrical current than non-stretched lung tissue. The variations of impedance during the breathing cycle seen in EIT are therefore the result of changes in tissue stretch.[4] For these changes, the term 'relative stretch' is used. Given that in poorly ventilated lungs or in areas of the lungs that are not ventilated or stretched at all, the change in impedance during the ventilation cycles is reduced compared with well-ventilated areas, EIT might be used as a monitoring device for guidance of lung-protective ventilation during surgery. However, its practical use is strongly dependent on parameters allowing clear and reliable interpretation of those pathophysiological changes. Therefore, we quantified regional changes in pulmonary impedance, defining lung areas with impedance changes of <10% of the maximum as 'silent spaces'.[5]

There is still clinical uncertainty regarding how to assess regional inhomogeneity in aeration induced by mechanical ventilation and perioperative treatment at the bedside. We hypothesized that changes in the distribution of regional lung impedance as represented by the centre of ventilation (CoV) and the amount of silent space within the dorsal and ventral lung areas quantified by EIT could represent the expected pathophysiological changes in aeration. Therefore, we aimed to document systematically the effects of induction of anaesthesia with cessation of spontaneous breathing and implementation of mechanical ventilation, of perioperative changes in body positioning (Trendelenburg position) in combination with application of capnoperitoneum, and of the reversal of these manoeuvres on EIT findings, and to compare them with global parameters of oxygenation and lung mechanics.

Methods

This study was performed within the framework of a larger two-centre observational trial focusing on lung function after robot-assisted prostatectomy (NCT02066246). With approval by the local ethics committee of the Medical Board Hamburg (PV374) and after obtaining written informed consent, 40 patients undergoing robot-assisted prostatectomy were included. Exclusion criteria were patients with known chronic obstructive pulmonary disease or bronchial asthma. Patients with sleep apnoea, with ASA risk classification IV or more, and those with BMI >35 kg m^{-2} were also excluded.

We used an EIT device (*Swisstom BB²*; Swisstom, Landquart, Switzerland) with 32 textile-embedded electrodes placed around the chest along the sixth intercostal space. The accuracy and precision of the device were evaluated previously.[6] The primary outcome measurements of the present study, namely the changes in electrical impedance, were acquired at a scan rate of 46 Hz. The individual's height and weight determined the appropriate image reconstruction matrix.[7] Electrical impedance tomography images, containing 64×64 pixels, were created by a modified GREIT algorithm.[8] We selected the regions of interest (ROI) within the chest contours of the right and left lung based on three-dimensional thoracic models, which were created from computed tomography (CT) scans (see Supplementary material, Fig. S1).[9] Tidal EIT images from 10 consecutive breaths were created by determining, for each pixel, the change in impedance between the end of inspiration and the preceding end of expiration.

Using changes of impedance within both lung ROIs only, we then calculated silent spaces in the dorsal and the ventral lungs. However, given that EIT is usually used in the supine, semi-recumbent position, in which gravity exerts its action on the dorsal lung tissue within the EIT plane, this gravity dependence of the dorsal silent spaces was expressed by the term 'dependent silent space' (DSS), whereas in this context the term 'non-dependent silent space' (NSS) was used for the ventral lungs. Silent spaces were determined based on the CoV and 'relative stretch', as depicted in Figs 1 and 2. In an attempt to characterize the functional state of the lungs at the regional level, the median value for each one of the EIT-derived breath-wise parameters was calculated and expressed as a percentage value. The CoV is a previously described parameter to express the geometric focal point of overall ventilation as a single digit in per cent.[10 11] The vertical position of the CoV is then expressed as a percentage of the anterior–posterior extension of the identified lung region, where 0% refers to ventilation occurring in the most ventral lung region and 100% in the most dorsal part.[12]

Impedance changes during tidal breathing within the ROIs were measured as the difference between the end of inspiration and the end of the preceding expiration (Fig. 1), whereby the global impedance change resulting from the breathing-induced changes in the electrical properties of all lung regions (the relative deformation or stretch of the lung tissue during tidal breathing according to Nopp and colleagues)[4] within the EIT plane represented the tidal volume.

For the above impedance changes to be displayed as tidal images, their pixel values needed to be categorized and colour coded. Therefore, the amplitude of the pixel within the image showing the maximal impedance change or stretch during breathing served as a 100% reference (Z_{total}). This amplitude was then divided by 10, which resulted in 10 different amplitude categories (c_1–c_{10}). Depending on its amplitude, each pixel within the lung ROIs was then assigned to one of these categories.

In order to determine the relative contribution, as a percentage, of each one of the 10 stretch categories to the overall tidal volume (Vt_{total}), the amplitude of each pixel within a given category was multiplied by its relative tidal stretch. From these values, a 10-bar histogram was created, whereby the sum of all 10 categories equalled the total impedance change of the tidal breath (Fig. 1).