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Bedside-measurements of electrical impedance tomography and functional residual capacity during positioning therapy in a case of acute respiratory failure

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Abstract

The lungs of patients with Acute Respiratory Failure (ARF) are characterized by reduced lung volume and regional heterogeneity of ventilation distribution. To improve lung volume and ventilation distribution, protective mechanical ventilation with positive end-expiratory pressure (PEEP), recruitment maneuvers, and some adjunct measures like intermittent proning have been recommended. But the continuous monitoring and management of these measures is not possible at bedside. New non-invasive monitoring tools like Electrical Impedance Tomography (EIT) and measurements of Functional Residual Capacity (FRC) by oxygen wash-in/washout have been advocated, but are not established in clinical routine. Thus, evident therapy algorithms are not yet available. The aim of this case study was to describe the ability of EIT and FRC measurement to detect changes in regional ventilation and lung volume in an ARF patient, who was treated by alveolar recruitment maneuver and intermittent prone position. An increase in FRC was observed in parallel of gas exchange improvement immediately after the recruitment. During prone position, FRC decreased constantly while a redistribution of ventilation among dorsal lung regions was detected by EIT. These two tools were compared but without a gold standard. The reported case shows that EIT and FRC measurements are two different methods, which are difficult to compare. As they do not present a good correspondence, the respective results may be under or over estimated but the measures indicated some tendencies. Nevertheless the combination of both could be a meaningful monitoring supplementation in the respiratory therapy of ARF patients.

Key words: EIT, FRC, lung recruitment, monitoring, PEEP, prone position

Introduction

The lungs of patients with Acute Respiratory Failure (ARF) are characterized by reduced lung volume and regional heterogeneity of ventilation distribution [1]. Atelectasis in dorsal lung regions is characteristic of ARF patients [2]. Patients with ARF usually have to be treated with mechanical ventilation. Typical procedures used to improve lung volume, ventilation distribution, and gas exchange include application of PEEP [3], intermittent recruitment maneuvers, and the patient placed in prone position [4].

Although there is a set of procedures and tools for the evaluation of ARF patients' lung function in standard clinical routine (e.g. pulse oximetry, capnometry, blood gas analysis, P/F ratio, respiratory mechanics, radiography) a dynamic proof of changes in lung volume and aeration of the lung during therapeutic procedures is not possible [5]. Thoracic computed tomography (CT) is the most sensitive method for the direct monitoring of atelectasis formation, lung volume, ventilation distribution and its inhomogeneity [6], but the disadvantages of radiation limit continuous investigations at bedside. Thus, a monitoring tool for bedside detection of lung volume changes and ventilation distribution is necessary. Hence, investigators attract notice to the non-invasive, radiation-free Electrical Impedance Tomography (EIT) and the direct measurement of Functional Residual Capacity (FRC). EIT (EIT Evaluation Kit, Dräger Medical AG, Lübeck, Germany) allows a bedside assessment of regional lung ventilation and dynamic evaluation of lung status within each breath [7]. The bedside FRC monitoring device (LUFU, Dräger Medical AG, Lübeck, Germany) uses an open breathing system to determine FRC during an oxygen wash-in/wash-out procedure [8]. EIT and bedside FRC monitoring are relatively new techniques proposed to assess ventilation distribution and lung volume but some ongoing issues related to these techniques remain. EIT is a medical imaging technique in which an image of the conductivity of one part of the body is inferred from surface electrical measurements. The objective of thoracic EIT is to generate cross sectional images of the tissue impedance distribution within the thorax. One of the most probable areas of EIT application in clinical settings is monitoring regional ventilation during mechanical ventilation [9]. We calculated the ventilation distribution in the ventral and dorsal lung region in per cent. The LUFU system estimates FRC by oxygen wash-in/wash-out, a variant of multiple breath nitrogen wash-out. A sidestream O_2-analyzer calculates FRC from the end-inspired and end-expired concentrations of O_2 during a step change of the inspired O_2 concentration. A measurement is started by increasing the FiO_2 by at least 0.1 (wash-in). After termination of the measurement FiO_2 is decreased back to baseline FiO_2 (wash-out). Reasonable accuracy and repeatability has been demonstrated during spontaneous breathing and mechanical ventilation [10,11]. We calculated the mean FRC of one wash-in and the consecutive wash-out.

By example of an ARF patient, who was treated by alveolar recruitment maneuver (RM) and prone position (P), the potential respiratory monitoring by these new techniques will be discussed. Furthermore, we describe the ability of EIT and FRC measurements to detect changes in regional ventilation and lung volume during prone position in a clinical setting.

Case summary

We report a case of a 53-year old patient with a medical history of a three vessel coronary heart disease, arterial hypertension, depression, smoking, and alcohol abuse. He was admitted to our intensive care unit after coronary artery bypass grafting. On day 4, the patient suffered from an impairment of oxygenation with a PaO_2/FiO_2 ratio of 116 mmHg due to fungal pneumonia. Chest radiography revealed bilateral alveolointerstitial infiltrates. A lung computed tomography scan showed bilateral posterior alveolar consolidations. To improve gas exchange a RM was performed (pressure controlled ventilation, PEEP 15 cmH_2O, peak inspiratory pressure 40 cmH_2O for 2 minutes) and the patient was proned. The patient was positioned prone with upper chest and pelvic support to ensure free movement of the abdomen. The patient was kept prone for 12 hours per day for 5 consecutive days. On day 13, the patient was successfully weaned from the respirator. On day 23, the patient was discharged from the intensive care unit to the ward and finally to a rehabilitation facility. We report day 4 from admission. The patient was continuously monitored by non-invasive EIT and bedside FRC measurement for 24 hours. The measurements were carried out before RM in supine position (S) (T_1), after RM (T_2), after one hour of prone position (P) (T_3), after 2 and 3 hours (T_4-T_5), after 12 hours immediately in supine position (T_6) and one hour later after reapplied RM (T_7) (data acquisition of T_6 and T_7 is similar to T_1 and T_2). Respiratory settings, hemodynamic parameters, and parameters from arterial blood gas analysis before, during and after prone position are presented in table 1.

Discussion

In our case the mechanical ventilation in combination with RM and prone position led to an improvement of oxygenation. These results are in concordance with current literature [12,13]. RM and posture therapy represent a meaningful therapeutic opportunity in a lung-protective ARDS concept. Nevertheless, RM and proning per se have different effects on the distribution of ventilation and the change of lung volume. These different phenomena can be described by EIT or FRC.

After RM (T_2) the PaO_2/FiO_2 ratio (PF-ratio) and FRC improved (Table 1). The ventilation distribution in the EIT remained unchanged – the main part of the ventilation was measured in the ventral lung portions (56%) (fig 1). After proning the FRC decreased constantly (T_3-T_5), whereas the PF-ratio dropped briefly (T_3) and then strongly increased again (T_4) remaining stable up to the end of proning. During prone position the ventilation increased in the dorsal lung portions permanently (69 to 83%). Comparing EIT findings from initial supine position and prone position a gain of ventilation in dorsal portions of the lungs can be indicated (fig 1 and 2). After continuous improvement of oxygenation in prone position, the PF-ratio remained stable also 12 hours later in supine position, whereby the FRC was on the rise again (T_6). Both parameters improved signifi-

Table 1. Respiratory and hemodynamic data (M) in supine and prone position over 24 hours. The patient was ventilated in biphasic positive airway pressure mode (BIPAP) with an inspiration-to-expiration ratio (I:E) of 1:2 and an inspiratory oxygen fraction (FiO_2) of 0.6.

	Supine		Prone				Supine	
	T1	T2	T3	T4	T5	T6	T7	T8
FRC [L]	1,81	2,6	2,4	2,22	2	1,99	2,575	3,2
PF-ratio [mmHg]	116	246	189	232	232	246	208	228
P_aCO_2 [mmHg]	38,5	47,5	57,1	53,1	51,1	51,2	51	48,5
$etCO_2$ [mmHg]	33	42	48	51	55	46	41	43
P_{peak}/PEEP [mbar]	28/14	20/10	20/10	20/10	20/10	20/10	20/10	20/10
$PEEP_i$ [mbar]	15	12	12,3	13,3	10,8	10,5	12	11,5
C_{res} [mbar/ml]	43	42	45	42	46	46	61	54
V_T [ml]	600	420	450	420	460	460	610	540
HF [min^{-1}]	66	65	64	65	63	67	66	67
MAP [mmHg]	73	64	80	77	80	77	66	65
CVP [mmHg]	22	16	22	16	20	15	10	10

FRC, functional residual capacity; P_aO_2/FiO_2, arterial partial pressure of oxygen/inspired oxygen fraction; P_{peak}, peak airway pressure; PEEP, positive end-expiratory pressure; V_T, tidal volume; HR, heart rate; MAP, mean arterial pressure; CVP, central venous pressure; 1 mbar equals 1.02 cm H_2O

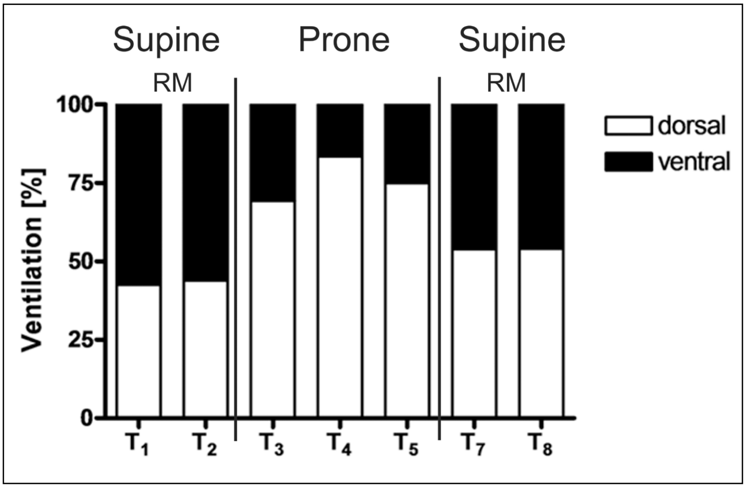

Figure 1: EIT monitoring during positioning maneuvers. The amounts of ventilation in the ventral and dorsal lung regions are presented in per cent. (T_1-T_2: supine, T_3-T_5: prone, T_6-T_7: supine).

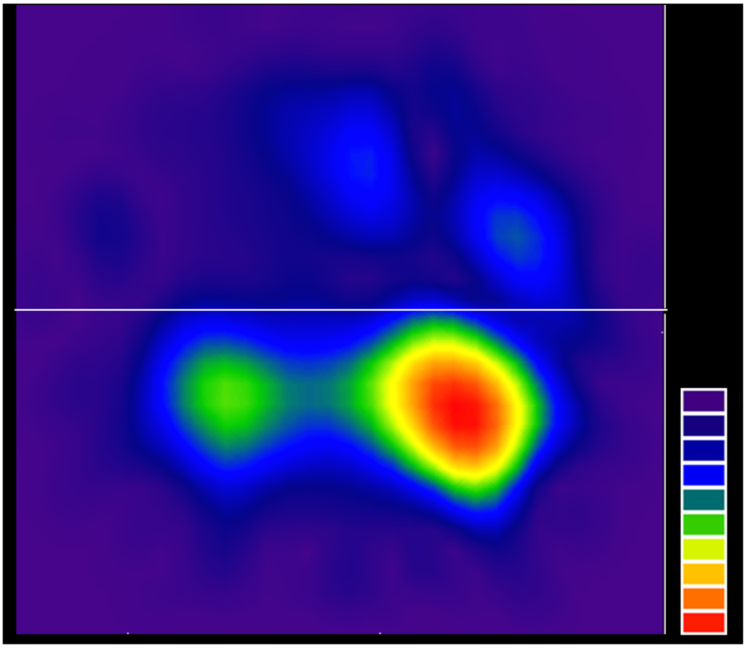

Figure 2: Colour-scaled functional EIT image. It shows impedance changes in prone position (T_4) referring to the initial reference data set in supine position before RM (T_1). EIT data at T1 is defined as baseline data. (Min: minimum of impedance/ventilation change; Max: maximum of impedance/ventilation change). There was a gain of ventilation in the dorsal parts of the lungs due to prone position.

cantly by a RM (T_7), whereas no change in the ventilation distribution occured. This case study presents data collected from two monitoring tools that have been brought to the clinical arena as additional tools for the evaluation and treatment of patients with ARF. Obviously, there is a discrepancy between FRC data indicating a gain of lung volume after RM and EIT data showing almost no change of ventilation distribution (T_1, T_2). In ventilated ARF patients ventilation is not devided homogeneously [14]. So, changes in lung volume do not necessarily contribute to impedance changes in the same direction, because it is unclear how the current pattern is influenced by the inhomogeneous status of lung tissue in the cranio-caudal axis. Furthermore, EIT represents a single thoracic slice of spatial resolution with a cranio-caudal diameter of 7-10 cm. Nevertheless, EIT has been shown to reliably assess regional ventilation distribution as compared with CT in an experimental lung injury model [7]. FRC measurements have been advocated to guide respiratory therapy [15]. But as no individual FRC is known, increased FRC values due to RM or a higher PEEP, may also indicate hyperinflation. Therefore, absolute values of bedside FRC measurements are of less interest than their trend or change. So, an improvement of lung volume (FRC measurements) and oxygenation due to the application of PEEP and RM (T_1, T_2) with no change of ventilation distribution (EIT measurements) can probably indicate either a global lung recruitment or overdistension. To differentiate between recruitment and overdistension FRC can be combined with lung mechanics. On the other hand, a decreased FRC may indicate a potential for alveolar recruitment (T_3-T_5). In prone position, there was a slight decrease of FRC, which still remained higher as prior to RM in supine position (table 1). This could be due to inadequate sedation, amount of spontaneous breathing, or an insufficient application of PEEP (10 cm H_2O). After repositioning into the supine position ventilation distribution was homogeneous, whereas the ventilation distribution after RM revealed unchanged like prior to proning. Nevertheless, it is speculative if the discrepancy between EIT and FRC measurements depends on the grade of already recruited and non-recruited lung tissue.

The reported case shows that EIT and FRC measurements are two different methods, which are difficult to compare. But EIT and FRC measures indicate some promising tendencies, even if particularly a CT scan may permit to understand lung volume changes in such a patient. It can be seen as a limitation of the case study that no gold standard, e.g. computed tomography, was used. As both tools did not present a good correspondence, the respective results may be under or over estimated. It is speculative and not the aim of the presented case if EIT and FRC measurements change independently and do not have any correspondence or if the results are just a consequence of a variability of one individual. Nevertheless, it could be pointed out that both EIT and FRC measurements have their characteristic point of view on RM and PEEP or prone position. Usually measured variables, like oxygenation or lung mechanics cannot predict these informations on lung volume or ventilation distribution. The clinical relevance of EIT in the assessment of RM or even the EIT-guided application of PEEP cannot be completely answered by this case report. The FRC seems to be insensitive compared to the phenomenon of overdistension and should always be regarded with other parameters. Probably, it is a better indicator for lung derecruitment. The EIT indicates the effects of the posture therapy continuously. Especially, additional parameters like lung mechanics and PF-ratio should always be taken into considerations especially in cases of heterogeneous lung injury in ARF patients. Finally, both used tools are novel techniques with ongoing development. Prior to becoming a routine tool for clinical use, more studies in the clinical setting need to be conducted. The main focus of future research should be to find standardized evaluation algorithms, indices and fault-tracings to easily quantify EIT data and implement FRC measurements in order to assess the progress of a therapy or the immediate impact of adjusted ventilator settings.

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