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# Long term EIT based compliance monitoring in COVID-19 patients

**Abstract:** The COVID-19 is a viral infection that causes respiratory complications. Infected lungs often present ground glass opacities, thus suggesting that medical imaging technologies could provide useful information for the disease diagnosis, treatment, and posterior recovery. The Electrical Impedance Tomography (EIT) is a non-invasive, radiation-free, and continuous technology that generates images by using a sequence of current injections and voltage measurements around the body, making it very appropriate for the study to monitor the regional behaviour of the lung. Moreover, this tool could also be used for a preliminary COVID-19 phenotype classification of the patients. This study is based on the monitoring of lung compliances of two COVID-19-infected patients: the results indicate that one of them could belong to the H-type, while the other is speculated belongs to L-type. It has been concluded that the EIT is a useful tool to obtain information regarding COVID-19 patients and could also be used to classify different phenotypes.

**Keywords:** Electrical Impedance Tomography, phenotype, lung compliance, COVID-19 pneumonia.

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## 1 Introduction

In November 2019, a novel coronavirus strain appeared in Wuhan, province of Hubei, China. Even if at first the outbreak was thought to be a punctual case, it did not take long for the situation to get out of control. Now, as for June 2021, more than 173 million COVID-19 confirmed cases and more than 3 million deaths have been reported by the World Health Organization (WHO) [1].

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The disease, which is caused by the SARS-CoV-2 virus, is usually transmitted by direct contact of respiratory droplets between individuals, possibly causing fever, dry cough, anosmia, and ageusia [2]. Moreover, the respiratory infection usually shows ground glass opacities in chest CTs, thus suggesting intrathoracic lung tissue abnormalities (e.g.: pneumonia).

Due to the possible lung tissue and functioning abnormalities, thorax imaging techniques may be helpful when talking about COVID-19 patients' diagnostic, treatment, and posterior recovery. Among the various imaging technologies known to date, the Electrical Impedance Tomography (EIT) could be one of the most appropriate ones to use among the infected individuals because it is non-invasive, non-ionizing, continuous and cost-effective [3].

The EIT technology is based on the injection of weak electrical currents into the patient's body to induce voltage variations around its boundaries (skin). The voltage measurements are then used to reconstruct images of the interior of the body, which are useful to perform further analyses [4].

As lung tissue differences may be measured with EIT recordings, it has been hypothesized that a preliminary differentiation of disease phenotypes may be possible. Back in 2020, Gattinoni et al. presented a first phenotype classification of COVID-19 patients, in which a distinction was made between those of H-type (high lung recruitability) and L-type (low lung recruitability) [5].

Putting all together, and in order to obtain COVID-19-related information and possible differences between patients, we conducted an evaluation on the long term regional lung compliance changes of two patients that were subjected to ventilation strategies daily. Arterial Blood Gas (ABG) analyses were also included in the research to support the EIT measurements.

# 2 Methods

## 2.1 Subject and protocol description

Two sedated and mechanically ventilated COVID-19 patients have been included in order to analyse their evolution for at least 7 days. Patient A is a 67-year-old female, with hypertension and hypothyroidism in her past medical history. Patient B is an 81-year-old woman, who was found to have hypertension. Further information concerning the subjects can be found in the next table (see Table 1):

In terms of the respiratory protocol used in the subjects, a daily alveolar recruitment manoeuvre was performed by using a Pressure-Controlled Ventilation (PCV) mode, followed with a PEEP titration strategy.

As for the recruitment phase, a stepwise 3 $cmH_2O$ PEEP increment was applied to the patients, starting from a basal PEEP of 10 $cmH_2O$, until reaching an end-expiratory pressure of 25 $cmH_2O$. At the highest PEEP, a peak intra-thoracic pressure of 40 $cmH_2O$ was reached. For the deflation phase, the same stepwise protocol with 3 $cmH_2O$ PEEP decrease had been followed until the initial PEEP was reached. In addition to the ventilation protocol, an ABG analysis was performed to each patient before and after the PEEP manoeuvre, thus enabling to calculate $pO_2$ and $pCO_2$ changes during the ventilation strategies.

**Table 1:** Characteristics of the COVID-19 infected patients.

| Patient | Gender | Age (yr) | Weight (kg) | BMI ($kg/m^2$) | Trial days |
|---|---|---|---|---|---|
| A | F | 67 | 90 | 29.7 | 7 |
| B | F | 81 | 80 | 31.2 | 12 |

## 2.2 EIT data acquisition

The EIT device that was utilized to acquire conductivity related data was the Dräger PulmoVista 500 (Dräger, Lübeck, Germany). According to the electrode positioning standards, a 16-electrode belt was positioned between the $5^{th}$ and the $6^{th}$ intercostal spaces in a transverse plane around the chest. Adjacent current injections were applied through the belt, as well as adjacent voltage measurements, at an image acquisition rate of 50 Hz, thus obtaining a high temporal resolution.

For the reconstruction of raw EIT images from the voltage measurements, the time-difference GREIT [6] algorithm was used.

## 2.3 Compliance image construction

To obtain tidal-variation functional EIT (TV-fEIT) images, the lung contour was determined first. A threshold value of 20 % was applied to the global ventilation signal, and all values below the threshold were discarded. As slightly different lung contours were obtained for different PEEP values, the final lung region that was used was created by combining all the lung contours obtained through all the PEEP steps of the manoeuvre. The TV-fEIT images were obtained by calculating the differences between end-inspiratory and end-expiratory points of the global ventilation signal.

Considering that local tidal variations are highly correlated with intrathoracic impedance variations [7], pixelwise compliance can be estimated as follows (see eq 1).

$$\boldsymbol{C_{px}} = \frac{\boldsymbol{\Delta Z}}{\boldsymbol{P_{plat} - PEEP}} \quad (1)$$

Where $\Delta Z$ is the intrathoracic impedance variation, and $P_{plat}$ is the plateau pressure inside the airways. Once this relation is applied to all the pixels of the TV-fEIT images, EIT-based compliance maps can be displayed.

To be able to analyse the patients' reaction to the recruitment manoeuvres, differences between the last PEEP step and the initial PEEP step have been calculated by subtracting the respective compliance maps.

# 3 Results

The compliance maps clearly show different patterns on the evolution of both patients, suggesting that patient B reacted better than patient A to the alveolar recruitment manoeuvres.

In the case of patient A, it seems that the best lung compliance is found on the first day of recordings. After the first day, a progressive deterioration seems to take over, until the last day in which the lung compliance improved (see Figure 1). In terms of arterial blood gases, patient A suffered a gradual daily increase in the $pCO_2$, while his $pO_2$ values drastically decreased (see Figure 2), reaching a point at which no oxygenation improvement is visible (day 6).

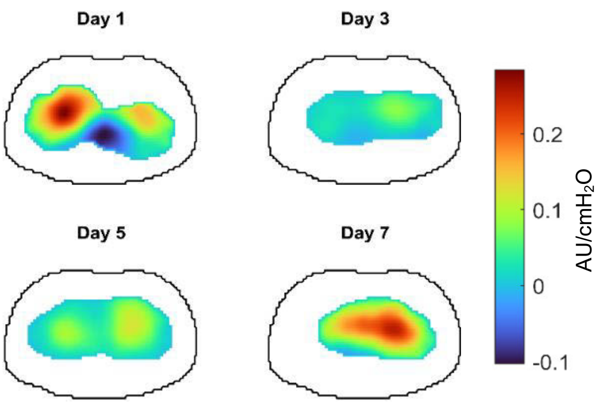


**Figure 1:** EIT based compliance maps belonging to patient A.

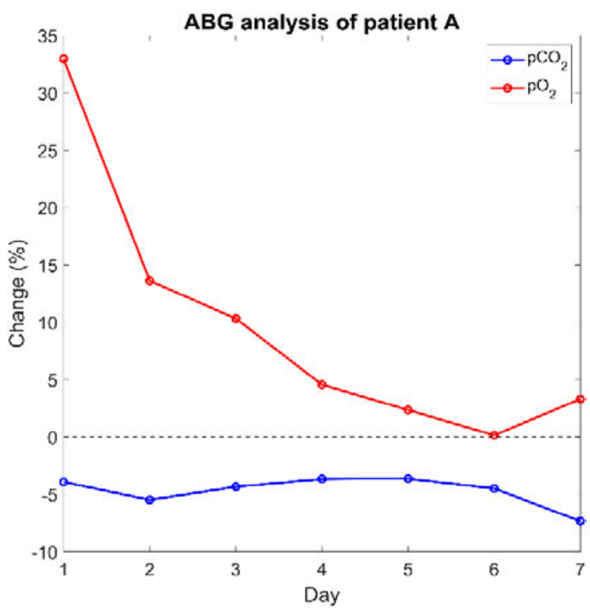


**Figure 2:** ABG evolution of patient A during the recording days.

On the other hand, more homogeneous lung compliance maps can be found for patient B, who generally shows higher overall compliances (see Figure 3). Regarding the arterial blood gas analyses, it is impossible to identify any trend in the $pO_2$, even if the data from the last 4 days suggest a clearly identifiable deteriorating tendency. Moreover, the $pCO_2$ gradually increases during the recording days (see Figure 4), which is a sign of poor lung ventilation.

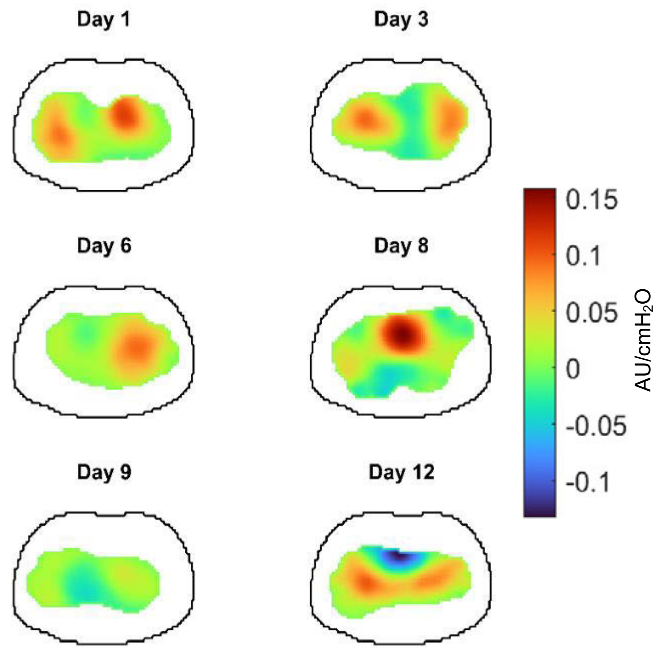


**Figure 3:** EIT based compliance maps belonging to patient B.

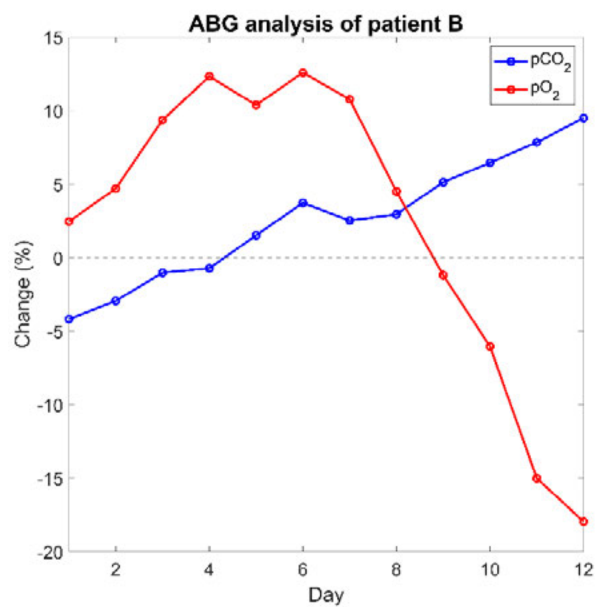


**Figure 4:** ABG evolution of patient B during the recording days.

# 4 Discussion

In this report an analysis of COVID-19 infected patients' lung compliance evolution has been performed. Since the disease is relatively new, this analysis is one of the pioneers in the field, which is thought to be able to help in the clinical decision making of infected patients.

In our study, we found that the two patients that were analysed behaved differently to the PEEP manoeuvres, thus suggesting that patient A might belong to the L-type due to the low regional lung compliance, while the patient B could be classified as an H-type because of the more stable and higher overall one. Furthermore, the possibility of a phenotype transition from L-type to H-type should also be mentioned for patient A, due to the change in compliance that can be appreciated in Figure 1. In patient B, a possible ventilation-perfusion mismatch is suspected because of the progressive deterioration that was observed in ABG test results, but the compliance stayed relatively high.

Even if long-term EIT data was available for each patient that was analysed, the number of patients was one of the main drawbacks of the research.

The usage of a single parameter (e.g.: lung compliance) to possibly classify different phenotypes is clearly insufficient. Even if the CT scan is still used as a golden standard to diagnose COVID-19 patients, the EIT has been proven to be an effective option to monitor possible disease changes in the patients, since its development during the time has been reported to be fast.

Further research with newly measured EIT data, along with the combination of different parameters, will help to better understand the evolution of the disease in different types of patients.

# 5 Conclusion

The EIT technology is a valid tool to provide useful information regarding COVID-19 patients and their respective types of disease progression (L-type and H-type), allowing the monitoring and assessment of the regional lung behaviour, suggesting possible transitions between phenotypes, and even being able to suggest ventilation-perfusion mismatches in the recordings together with other methods.

**Author Statement**

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