Chapter 28

On-line Monitoring of Respiratory Mechanics

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Introduction

Respiratory mechanics play a central role in the management of critically ill patients undergoing artificial ventilation [1]. Mechanical ventilation is needed in patients with acute respiratory failure (ARF). This is a condition defined by a rapid deterioration in pulmonary gas exchange that may be due either to alterations in the mechanical properties of airway and/or tissue leading to ventilation-perfusion mismatching or shunt, or to neuromuscular insufficiency causing alveolar hypoventilation. Quantitative determination of respiratory mechanics is of crucial importance to aid the clinician to diagnose the disease underlying ARF, to assess the status and progress of the disease, to measure the effects of treatments, to tune the ventilator setting to the patient’s specific needs, and thus to minimize the risk of ventilator-induced complications, such as ventilator-induced lung injury [2].

Despite the great importance of monitoring lung mechanics in ventilator-dependent patients, these measurements are not always regularly performed, and in particular are not continuous [3]. Continuous monitoring enables the early detection of changes in patient status, thus allowing a rapid therapeutic response, as well as the evaluation of its effectiveness.

The assessment of parameters of respiratory mechanics, revealing the overall lung function, is thus of crucial importance in the intensive care unit (ICU). This process invariably involves measurement, modeling, and estimation issues [4]. The proposal of simple models based on physiological and anatomical considerations, which can be represented in terms of electrical or mechanical analogues, eased their interpretation and helped their adoption. This led to a number of distinct approaches that have useful clinical applications. However, the kind of physiopathological insight that can be obtained strictly depends on the type of applied input (frequency content, amplitude) and output (sampling site and frequency) that can be designed for the specific application [4].

The purpose of this paper is to review briefly the strengths and weaknesses of the most-common methods for monitoring respiratory mechanics. After that, we will focus on the continuous, on-line monitoring of respiratory mechanics in the ICU. Mathematical models for the on-line monitoring of respiratory mechanics during mechanical ventilation offer an attractive tool to assess the main viscoelastic parameters of the respiratory system, neither requiring additional equipment nor interfering with the ventilator settings.
Monitoring Respiratory Mechanics

Measurement of respiratory mechanics in a ventilated patient can be performed using different techniques. In the following we will assume that the patient is a relaxed, passive patient, i.e., a patient without a spontaneous respiratory activity. The methods discussed are in general also valid in active patients, although, to assess lung mechanics during spontaneous/assisted breathing, an estimate of pleural pressure is needed and can be acquired using the esophageal balloon with a minimally invasive technique.

Probably, a reliable standard technique for assessing respiratory mechanics in patients during controlled mechanical ventilation is the rapid airway occlusion (RAO) technique (Fig. 1). This technique, albeit introduced at the beginning of the century, has been gaining wide popularity in the last 10-15 years, after a series of studies that have elucidated the theoretical aspects of the technique as well as its physiological basis [5, 6].

When applied at the end of expiration it provides a measure of the static intrinsic positive end expiratory pressure (PEEP_{st}), also known as auto-PEEP. If RAO is applied just before the end of the inspiration it enables to measure most of static elastance ($E_s$) and interrupter ($R_{int}$), as well as total ($R_{tot}$) resistance, according to the following equations (see Fig. 1):

\[ E_s = \frac{P_{plat} - P_{PEEP_{st}}}{V_T} \]  
\[ R_{int} = \frac{P_{peak} - P_t}{V'} \]  
\[ R_{tot} = \frac{P_{peak} - P_{plat}}{V'} \]

where $V_T$ is tidal volume and $V'$ the flow immediately preceding the occlusion.

However, the RAO maneuver interferes with the ventilator settings, and thus it is not suitable for continuous monitoring of the patient’s status. Moreover, this technique requires either ventilators equipped with an end-expiratory occlusion button or additional equipment and skill that may not be routinely available in clinical settings.

Assessment of respiratory mechanics can also be performed using the forced oscillation technique (FOT) [7]. FOT is the application of a small oscillatory pressure at the mouth by means of an external generator. It may be applied during both spontaneous and mechanical ventilation, and it is suitable for continuous, non-invasive monitoring, since the FOT frequency is much higher than typical breathing frequencies, and hence is not interfering with patient efforts [8]. However, the technique requires specific equipment (to oppose the positive pressure generated by the ventilator) and expertise. Moreover, FOT is not suited to measure intrinsic PEEP (PEEP_{st}). PEEP_{st} reflects the end-expiratory elastic recoil of the total respiratory system due to incomplete expiration and dynamic pul-