

PULMONARY MONITORING: END EXPIRATORY LUNG VOLUME (EELV)

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1. METHODS FOR EELV MEASUREMENT DURING MECHANICAL VENTILATION (MV)

Functional Residual Capacity (FRC) is the volume of gas that remains in the lungs at the end of expiration, while EELV corresponds to FRC in the presence of positive end expiration pressure (PEEP). In classical physiology, the measurement of EELV can be performed through techniques based on imaging, body plethysmography or dilution of a gas tracer. Mostly due to technical reasons, EELV measurement has not become a routine monitoring tool in intensive care, but several techniques for use in patients undergoing MV have been recently described and tested, while computed tomography (CT) scan is probably the most solid standard reference for EELV measurements during MV. Wash-in or wash-out of a tracer gas (as nitrogen or oxygen) in a multiple breath maneuver seems to be well applicable at bedside, and promising techniques have been presented with acceptable accuracy and repeatability. The simple instrumentation required might increase the diffusion of EELV measurements in the clinical practice.

In 2005 Olegard et al [Anesth Analg. 2005;101(1):206-12] described a modified nitrogen wash-in/wash-out technique after a change in inspiratory oxygen fraction (FiO_2) to measure EELV in patients undergoing MV. It is based on standard monitors and nitrogen concentration is estimated from inspiratory and end-tidal plateau gas concentration values of O_2 and CO_2 . This technique has recently been implemented in a commercially available mechanical ventilator. Three years later Chiumello et al [Crit Care 2008;12(6):R150] showed that this technique has a good agreement with reference methods such as CT and helium dilution.

In 2006 Weismann et al [J Clin Monit Comput. 2006;20(4):251-60] developed a new system for EELV measurements called LUFU (acronym for Lung Function). It is based on oxygen wash-in/wash-out after a change in FiO_2 . This method is non-invasive and does not require modifications to the ventilator or interruption of the care process. Its reliability has been demonstrated in healthy subjects and volunteers with pulmonary disease [Intensive Care Med. 2007;33(5):912-6] and during control and assisted MV in intensive care units [Intensive Care Med. 2008;34(12):2235-40].

2. POTENTIAL CLINICAL APPLICATIONS OF EELV

EELV for assessment of alveolar recruitment

PEEP promotes recruitment of non aerated lung volume and therefore it increases EELV, although recruitment of previously non-aerated lung units must be distinguished from the distension of lung units that were already ventilated. As the benefits of PEEP are more significant in patients with high recruitability, a method to assess the quantity of recruited lung might improve the management of patients in MV tailoring PEEP to the individual patient needs. In clinical research PEEP-induced volume recruitment is usually assessed as the volume difference between multiple pressure-volume (PV) curves at different levels of PEEP: this approach is rather complex and seldom used in everyday practice. Using this approach, measurement of EELV might be used to reference the starting point of the curves on the volume axis [Crit Care Med. 2010;38(5):1300-7]. In this context EELV appears to be a very promising tool for evaluating alveolar recruitment.

In 2011 Dellamonica et al [Intensive Care Med. 2011;37(10):1595-604] described a method derived from bedside EELV measurements to assess PEEP-induced lung recruitment. The authors estimated recruitment as the difference between the change in EELV at different levels of PEEP (measured with nitrogen wash-in/wash-out technique) and the minimum predicted volume gain. This one is the smallest possible increase in lung volume due to the application of a PEEP and it is computed as the product of respiratory system compliance and the increase in PEEP. Estimated recruitment is well correlated with the recruited volume measured on PV curves, as a reference technique.

EELV and ventilator induced lung injury (VILI)

Strain is the lung distortion caused by tidal inflation and PEEP and it is defined as the ratio between the end expiratory inflated volume and the lung resting volume (FRC or EELV). Lung strain has been proposed as the determinant of VILI and its role in ARDS was shown by a few studies.

In 2011 Protti et al [Am J Respir Crit Care Med. 2011;183(10):1354-62] showed that in healthy pigs VILI occurs when strain exceeded a critical threshold which corresponds to an interval ranging from 1.5 to 2. In 2011 our group studied lung tissue inflammatory response to tidal deformation. Its intensity can be measured by positron emission tomography (PET) imaging of [¹⁸F]fluoro-2-deoxy-D-glucose. We found a tight relationship between metabolic activity and glucose uptake of normally aerated tissue and regional tidal volume (V_T) normalized by EELV [Am J Respir Crit Care. 2011;183:1193-1199]. In keeping with these findings Gonzàles-López et al [Intensive Care Med. 2012;38:240-247] showed that patients with ALI undergoing MV and with high levels of V_T /EELV (measured at bedside with an oxygen wash-in/wash-out

technique) exhibit an increased alveolar inflammatory response in terms of matrix remodelling and inflammation markers.

These findings have potential clinical relevance because they support the evidence that during MV EELV should be taken into account to set the appropriate tidal volume and so a lung-protective ventilation.