Fast and Slow Compliance:
Time, in Addition to Pressure and Volume,
is a Key Factor for Lung Mechanics

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Introduction

Static lung mechanics are considered state of the art in spite of the fact that they only provide a narrow view and do not represent the mechanical behavior of the lung during on-going tidal ventilation. Static measurements are usually cumbersome to perform and are uncommon in clinical practice. There is now ample proof of the importance of choosing a protective ventilatory strategy, which has been defined as ventilating with pressures between the lower and upper inflection point (LIP, UIP) \[1, 2\]. Determination of these two inflection points demands static or at least quasi static measurements. The definition of true static conditions is that a sufficiently long end-inspiratory and end-expiratory pause is used to not only stop gas flow in the airways, but also equilibrate visco-elastic forces of the lung tissue. It has been shown that this equilibration time is short and the tracheal pressure decreased as little as \( \sim 2 \, \text{cmH}_2\text{O} \) during the five seconds after instigation of an end-inspiratory pause \[3\]. This pressure fall is small compared to the pressure fall that occurs within milliseconds immediately after closing the inspiratory valve of the ventilator. The initial pressure drop is a result of obtaining no-flow conditions in the patient’s airways and the time is correlated to the endotracheal tube and patient airway resistance (\( R \) in \( \text{cmH}_2\text{O}/\text{L/s} \)), the breathing circuit compliance (\( C \) in \( \text{L/cmH}_2\text{O} \)) and the flow immediately before closing the valve:

\[
t = \text{time constant} = R \times C
\]

In a typical case, the breathing circuit has a compliance of \( 0.5 \times 10^{-3} \, \text{L/cmH}_2\text{O} \) and a tube resistance of \( 6 \, \text{cmH}_2\text{O}/\text{L/s} \) which gives a time constant of 3 ms. In this case the flow will decrease by 95% in three time constants, i.e., \( \sim 10 \, \text{ms} \). After a minimal time, the pressure in the ventilator and in the alveoli will be equalized, disregarding the visco-elastic forces, that will lag behind through the breath during tidal ventilation. During a long end-inspiratory pause the visco-elastic forces will cause the pressure in the alveoli to fall as compared to the pressure immediately after closing the inspiratory valve and vice versa during a prolonged end-expiratory pause.

Thus, there are different time perspectives regarding lung mechanics: dynamic measurements, no-flow measurements, measurements including equilibrated visco-elastic forces, and finally measurements including time needed for opening collapsed lung units.
Fast Compliance

Three different methods have been proposed for determining the pressure-volume relationship during tidal ventilation, i.e., fast compliance: The slice method [4, 5], the dynostatic algorithm (DSA) [6, 7], and the stress index [8, 9]. The slice method and the DSA both give an alveolar pressure volume curve during on-going ventilation.

The Slice Method

The slice method is a three step procedure where first the tracheal pressure is calculated from the ventilator pressure and flow and an algorithm for the endotracheal tube resistance and then a tracheal pressure-volume loop is obtained. For reasonable precision of the measurements the pressure volume loop is divided into six slices and the least square method is applied for each slice to give a compliance value for each slice from the bottom to the top of the tidal volume. Thus, this method has the capacity of calculating volume-dependent compliance breath by breath: fast compliance. The advantage of the method is that it is based on easily available data for computation and can be used in both volume and pressure control ventilation. The disadvantage is that tube resistance may differ from the algorithm values in clinical practice and that the end parts of the breath – at the bottom and at the top are difficult to calculate with good precision. Also, any inflection point will be pre-positioned between the slices irrespective of where it is in reality.

The Dynostatic Algorithm

The DSA is based on direct tracheal pressure measurements for obtaining a tracheal pressure-volume loop. Assuming that the expiratory and inspiratory resistances at the same inspiratory and expiratory volume are reasonably similar, the alveolar pressure can be calculated by using the equation of motion at a number of isoplanes of the tracheal pressure-volume loop and an alveolar pressure-volume curve can be obtained displaying the ‘fast’ volume-dependent compliance breath by breath. The advantage of the DSA is that it is independent of tube resistance and also of changes in the resistance of the airways during inspiration and expiration. Also, the pressure-volume curve can show the correct position of any inflection points as it is based on at least twenty isovolume planes for each breath. A further advantage is that it can be used in both volume and pressure control mode. The disadvantage is that it demands a tracheal pressure line inserted through the tube, but this is at the same time an advantage as the pressure in the trachea can be measured without interrupting ventilation, i.e., peak tracheal pressure and intrinsic positive end-expiratory pressure (PEEP) can be monitored continuously.

The Stress Index

The stress index method is not a method that directly results in a conventional pressure-volume curve as it calculates the shape of the inspiratory pressure-time curve during on-going volume control ventilation according to the formula: