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The recording of FRC – is it of importance and can it be made simple?

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The oxygenation of blood is impaired in various lung diseases requiring ventilator treatment. The impairment is often associated with altered mechanical behaviour of the lung, the major finding being a reduced compliance [1]. A low compliance is interpreted as a stiffened lung due to oedema and fibrosis [1], and possibly to reduced surfactant function [2]. Many studies have been devoted to develop and refine techniques of measuring compliance and resistance of the respiratory system [3–4]. Other studies have analyzed the mechanics of the lungs in acute respiratory failure. More recently, lung compliance, or compliance of the respiratory system, has been shown to reflect the amount of normally aerated lung tissue rather than the severity of fibrosis or oedema [5]. If so, it seems to be more straightforward to measure the amount of remaining, normal lung. It is also the aerated lung that oxygenates blood and eliminates carbon dioxide from the blood. Thus, any manoeuvre that recruits lung tissue and increases the amount of aerated lung up to a normal value can be expected to improve gas exchange. In view of these considerations it may appear surprising that relatively few studies have been devoted to develop and refine techniques for bedside lung volume measurement in the mechanically ventilated patient, and to use the lung volume as a guide in the treatment of the patient and setting of the ventilator. There may be two reasons for this. Firstly, the technique of measuring lung volume, or FRC, is more complicated than a compliance recording which requires no more than the measurement of airway pressure and the insufflation volume. Secondly, the benefit of measuring FRC may not be big enough to warrant the effort. If simple enough techniques were available, more measurements would be done, reference values be collected and FRC changes by progress of disease and by various interventions be studied, resulting in a well established technique for diagnosis and follow up. A number of interesting questions can certainly be addressed regarding FRC in acute respiratory failure. Thus, how sensitive is FRC to a progress in oedema and fibrosis [3]? How rapid is the recruitment of alveoli after the application of PEEP [6]?. Does a negative fluid balance improve FRC? Can the intrinsic PEEP caused by high frequency ventilation or inversed ratio ventilation produce a different increase in FRC than a similar, externally applied PEEP? Will left heart failure affect FCR? To what extent will different body positions affect FRC in ARF, as it does in healthy subjects [7]. To what extent will changes in FRC be associated with changes in gas exchange? The reader can certainly add further questions to this list. Among the many different techniques to measure lung volume, two are dominating. One is the body plethysmography. Lung volume is measured by the application of Boyle's law, necessitating the positioning of the subject in a rigid concealed tank or plethysmograph. The technique has been used in anaesthetized subjects [8, 9] but will be difficult in the intensive care setting. The other frequently used technique is based on gas dilution principle. The subject is either rebreathing a tracer gas, e.g. Helium, in a closed circuit or the washin/washout of a tracer gas is analyzed in a multiple breath procedure. Rebreathing techniques require a gas tight circle system including the ventilator in order to reach an equilibrium of the tracer gas concentration [10–12], and this may be hard to achieve in the intubated or tracheotomized patient on mechanical ventilation. Washin and/or washout procedures are less demanding in this respect but require as much equipment and effort as the rebreathing technique [13–15]. The multiple breath nitrogen washout technique has been used since long in the lung function laboratory. The necessary change in the nitrogen concentration during the washout and washin means that the oxygen fraction will also be altered so that the patient can not be continuously ventilated with a preselected oxygen fraction. This may be a limitation in severe hypoxemia and has called for a technique which does not affect to any substantial degree the oxygen fraction during the washin/washout manoeuvre. The use of a tracer gas in minute amounts such as sulfur hexafluoride (SF6), has solved this problem and enables FRC measurements without any practical interference with the inspired oxygen fraction [16]. Other non-toxic, biologically could also be used for this purpose. The problem with any tracer gas technique, including nitrogen, is the need of a sensitive gas analyzer which should be fast enough to allow breath by breath computation of inspired or expired tracer gas flow together with a pneumotachograph. Alternatively, a bulky system can be used with collection of expired gas over a number of breaths in a bag or large spirometer and the recording of the mixed expired gas concentration together with volume measurements. The latter solution may be difficult in the intensive care unit. Gas dilution techniques, whether based on rebreathing or washin/washout, also have the inherent limitation that they can only measure the lung volume that participates in ventilation. Completely closed off lung units behind collapsed airways or mucus plugs sealing off the airway

will not be measured, and poorly ventilated regions with very long washin/washout times may also be disregarded since their contribution to the washin/washout can be difficult to detect and may disappear in the noise of the gas concentration signal. On the other hand, acute respiratory failure appears rather to be associated with lung collapse with no ventilation at all than with obstructive airways causing poor ventilation of lung units [17]. Thus, gas dilution techniques may be reasonably accurate for assessing FRC in ARDS.

The need of a simple and preferably automated technique has so far limited the acceptance of measuring FRC in the intensive care patient. In this issue of Intensive Care Medicine, a method of measuring FRC is described that, if accurate enough, may promote the use of FRC as a guide in the treatment of the patient with acute respiratory failure [18]. It is based on gas washin/washout but requires no extra analyzers than those frequently seen at an intensive care bed, i.e. O_2 and CO_2 analyzers. The technique is based on a number of algorithms, requiring dedicated computer power but this can easily be built into the ventilator. The technique is also based on a number of assumptions which need to be tested and approved. The technique is based on nitrogen washin/washout but does not measure N_2 but deducts it from the simultaneous changes in O_2 and CO_2 concentrations. No other gas than O_2, CO_2 and N_2 can therefore be present. Moreover, since O_2 analyzers presently in use (except for a masspectrometer) have slow response times the authors go one step further and deduct the O_2 concentration curve during the breath from the shape change of the CO_2 curve. The latter is measured by infrared meter which is fast enough for intrabreath analysis. However, this requires that the O_2 curve during the tidal breath is the inverse of CO_2 curve and although they are similar in normal subjects [19] this remains to be shown in patients with acute respiratory failure. Uneven distribution of ventilation/perfusion ratios and ventilatory time constants may produce different curves, e.g. in patients with obstructive lung disease.

The authors conclude that a 20% change in FRC can be detected by their technique. Will this be enough when following a patient on the ventilator? I guess so, since FRC is reduced down to below 1 l in severe ARDS, from 2.5–3 l in a normal supine subject [1, 4, 20]. An increase from e.g. 0.8 to 1.0 l or from 1.5 to 1.8 l is good enough to be detected since we want the patient to increase his FRC 3–400%! Still, it needs to be shown that the calculation of N_2 from O_2 and CO_2, and the computation of the O_2 concentration curve from the CO_2 curve are accurate enough also in various conditions of ARF. Alternatively, limits on the use of the technique must be established. This can easily be done by comparing the simplified technique with direct recordings of nitrogen as well as O_2 and CO_2 concentration curves by masspectrometry or other techniques with fast response to concentration changes. Perhaps it is not too far a guess that future ventilators will be designed not only for controlled and assisted ventilation but also for diagnosis and supervision of the respiratory and circulatory status of the patient.

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