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### Computed Tomography in ARDS

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##### Technical Aspects

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Acute Respiratory Distress Syndrome (ARDS) is a generalised inflammation of the lung parenchyma, caused by different underlying diseases. It is characterised by diffuse pulmonary infiltrates, decreased respiratory system compliance and severe hypoxaemia (Ware 2000). Although important advances have occurred in the therapy of ARDS, mortality due to this syndrome remains extremely high (Phua et al. 2009). CT scanning could be useful for defining the pathophysiology of ARDS and guiding possible therapeutic strategies.

#### Gas/Tissue Ratios

CT scans are able to give insight onto the quantitative relationship between gas and tissue in the lungs. CT scans produce digital images consisting of voxels, i.e., volume elements that attenuate the radiation according to the atomic number of the substance and the density of their contents. The unit of the CT number scale is named Hounsfield Unit (HU). Per convention, distilled water has a CT number of 0 HU, air a value of -1000 HU, and bone +1000 HU. Due to a linear relationship, a voxel with a CT number of -500 HU has 50% of its volume corresponding to gas and 50% to tissue. Assuming that the density of tissue is 1 g/cm<sup>3</sup>, the total lung mass can be also calculated using CT scanning.

#### Aeration Compartments

Voxels, they can be grouped into the

- Hyperaerated (-1000 to -900 HU);

- Normally aerated (-900 to -500 HU);
- Poorly aerated (-500 to -100 HU); and
- Nonaerated compartments (-100 to -100 HU).

The determination of such compartments can be useful to understand and follow the effects of ventilation strategies in ARDS. Figure 1 illustrates the distribution of aeration compartments in a CT scan of a pig at low and high PEEP levels.

#### **Tidal Hyperaeration, Recruitment and Reaeration**

In ARDS, tidal hyperaeration, i.e. the increase of the hyperaerated compartment, has been shown to correlate closely with overdistension (Rouby et al. 2003).

Accordingly, changes in aeration status of non-aerated and poorly aerated regions may reflect tidal reaeration and/or recruitment in such patients (Gattinoni et al. 2006; Carvalho et al. 2008).

#### **Few Slices or Whole Lung Computed Tomography?**

Cumulative exposure to ionising radiation has been associated with increased risk of cancer (Griffey and Sodickson 2009). Thus, investigators have suggested to limit the lung CT scans to only one slice at the base level, i.e. near to the diaphragm, or to three slices, namely at the apex, hilus and base levels. According to Lu et al. (2001) both the one and the three slice methods lead to an overestimation of PEEP-induced recruitment in ARDS due to overrepresentation of the more recruitable upper lobes. However, a single CT scan slice, which is taken at the base of the lungs may underestimate PEEP-induced recruitment (Rouby et al. 2003).

#### **CT Scan and the ARDS lung**

CT scan has modified our view of ARDS pathophysiology and the management of ventilatory strategies (Rouby et al. 2003; Caironi et al. 2006; Gattinoni et al. 2006).

The lung in ARDS is characterised by a marked increase in lung tissue and a massive loss of aeration. The lower lobes are essentially nonaerated, whereas the upper lobes may remain normally aerated, despite a substantial increase in regional lung tissue. The overall lung volume and the cephalocaudal lung dimensions are reduced primarily at the expense of the lower lobes, which are externally compressed by the heart and abdominal content when the patient is in the supine position. Two opposite radiologic presentations, corresponding to different lung morphologies, can be observed in CT scans: focal and diffuse. When a positive airway pressure is applied to patients with focal loss of aeration, poorly aerated and nonaerated lung regions are recruited, whereas lung regions that are normally aerated at zero end-expiratory pressure tend to be rapidly overinflated, increasing the risk of ventilator associated lung injury. Patients with diffuse loss of aeration in CT scans may have recruited lung zones with less hyperinflated areas.

#### **CT Scan and the Diagnosis of ARDS**

Several clinical definitions of ARDS have been proposed after its original description by Ashbaugh et al. (1967):

- a) The American-European consensus conference definition (Bernard et al. 1994),
- b) The “Dehli” score (Ferguson et al. 2005),
- c) The Murray lung injury score (Murray et al. 1988), and
- d) the “time dependent” definition (Villar et al. 2008).

Recently, the accuracy of these definitions has been addressed using the finding of diffuse alveolar damage on autopsy (Ferguson et al. 2005), with disappointing results. Thus, the correct identification of ARDS is still an open issue. Obviously, an inappropriate definition of ARDS may lead to biased results of clinical trials and lead to the rejection of therapies that might be useful.

Recent evidence suggests that the determination of lung weight by CT scan at PEEP 5 cmH<sub>2</sub>O is useful to better define those patients who have higher degrees of oedema, alveolar collapse and higher risk of death (Gattinoni et al. 2006). Patients with lower lung weight seem to respond less to recruitment manoeuvres as compared to patients with higher lung weight.

Given that lung oedema is the hallmark of ARDS, patients who have lower lung weight possibly react differently to ventilation strategies and should be either excluded from clinical trials, or at least evaluated separately.

## CT and the Origin of ARDS

Acute respiratory distress syndrome may result from a direct (ARDSp) or indirect (ARDSexp) insult to the lung parenchyma and the pathophysiology of the disease may differ according to the type of the insult (Rocco and Pelosi 2008).

Different studies have identified differences between ARDSp and ARDSexp in CT scans. Goodman et al. (1999) reported that in ARDSexp, ground-glass opacification was more than twice as extensive as consolidation. In contrast, in ARDSp a balance between ground-glass opacification and consolidation was observed. The authors also found differences in the regional distribution of the densities. In ARDSexp ground-glass opacification was greater in the central (hilar) third of the lung than in the sternal or vertebral third. In ARDSexp ground-glass opacification was evenly distributed across the lungs. Furthermore, the presence of air bronchograms and pneumomediastinum were prevalent in ARDSp, while emphysemalike lesions (bullae) were comparable in both groups.

According to Rouby et al. (2000), ARDSp is more frequently associated with diffuse and patchy loss of aeration in CT, whereas ARDSexp is more commonly accompanied by lobar loss of aeration.

## CT Scans for Ventilator Settings in ARDS

ARDS requires a multifactorial therapy, including the specific therapy for the underlying disease, interventions in some of the molecular pathways leading inflammation or coagulation abnormalities and supportive therapies, mainly mechanical ventilation. CT scan may be useful to identify patients who will require “ultra-low” tidal volumes, i.e. lower than 6 mL/kg. Ultra-low tidal volumes can minimise stress and strain, but may require extracorporeal CO<sub>2</sub> removal.

CT scan may also be used to detect patients with higher or lower potential of lung recruitment. Gattinoni et al. (2006) evaluated 68 patients with ARDS by means of whole-lung CT scans at 5 cm H<sub>2</sub>O PEEP and at 45 cm H<sub>2</sub>O airway plateau pressure. Moreover, to assess the effects of the application of higher PEEP, they obtained a further CT scan of the whole lung at 15 cm H<sub>2</sub>O PEEP. Thereby, those authors could identify patients responding to the recruitment manoeuvre and higher levels of PEEP. Our group suggested recently that the use of CT might be included in algorithms to identify patients with higher or lower recruitment and possible individual mechanical ventilation setting of tidal volume, recruitment and PEEP, as well as the need for curarisation, prone position or extracorporeal lung support (Rocco et al. 2010).

## Conclusion

In conclusion, in the future the CT scan could play a relevant role to better define the optimal tidal volume and PEEP, as well as response to recruitment manoeuvres, in order to avoid excessive stress and strain. Studies investigating the clinical relevance of information from CT included in specific ventilation management algorithms are warranted.

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