

Experimental set-up for the mechanical characterization of lung under inflation

Ombeline Juteau^{a*}, Aline Bel-Brunon^b, Karine Bruyère-Garnier^b, Catherine Masson^a, Claire Bruna-Rosso^a

^a Univ Gustave Eiffel, Aix-Marseille Univ, LBA UMR_T24, F-13015 Marseille, France

^b Univ Lyon, Univ Gustave Eiffel, Univ Claude Bernard Lyon 1, LBMC UMR_T9406, F-69622 Lyon, France

* Corresponding author: ombeline.juteau@univ-eiffel.fr

Received date: 04/04/2025

Accepted date: 27/06/2025

Publication date: 27/10/2025

Keywords: Digital Image Correlation (DIC), experimental protocol, inflation, negative pressure, sheep lung

© 2025 The Authors

Licence CC-BY 4.0

Published by Société de Biomécanique

1. Introduction

Lung parenchyma is a complex tissue which mechanical behavior is greatly impacted when diseased. Acute Respiratory Distress Syndrome (ARDS) is a serious pathology, often underrecognized and its heterogeneity makes it even more difficult to treat. Even though it is known that ARDS modifies mechanical properties of the lung (Cressoni et al. 2014), there is a lack of quantifying data describing these changes to better understand the pathology. More generally, this gap also concerns quantitative mechanical data on the whole organ, which has only been studied a few times in recent years (Mariano et al. 2020; Dong et al. 2022).

Here we propose an experimental protocol to characterize healthy and ARDS sheep lungs mechanics under inflation, improving the one previously described in Pallière et al. (2019). The aim is to measure the pressure-volume behavior and the strain field of the lung when it is submitted to negative pressure, thus mimicking physiological lung distension in the thoracic cavity during natural breathing with the contraction of the diaphragm.

2. Methods

2.1 Lung segment preparation

Lungs were withdrawn from healthy sheep just after sacrifice and directly frozen at -80°C . They were thawed before testing and pulmonary segments were prepared, being either a whole lung or a lung segment. This is

a subtree from the respiratory tree that can breathe independently and with no leaks. To extract it, the lung segment was inflated by inserting a probe into its inlet bronchiole, accessible from the trachea. Then the segment was isolated by cutting all around it to best remove material from neighbouring segments. It was subsequently immersed in water, to estimate its initial volume by water displacement method. In view of measuring the strain field on the segment surface, the segment was speckled with a random pattern of black dots with the VIC Speckle Kit.

2. Experimental set-up

The experimental set-up is presented in Fig 1a. The lung segment is bathed in water in a hermetic enclosure made out of PMMA. A gastric or tracheal tube connects the bronchial end of the segment to an air circuit at atmospheric pressure. The enclosure is completely filled with water and purged to ensure that there is no remaining bubble. A syringe is connected to this enclosure through a pipe and its piston is activated through a hydraulic jack to add or remove a determined volume of water in the enclosure, thus creating depression.

A pressure sensor quantifies depression inside the enclosure. Two flow sensors at the end of the air circuit measure the flow rates entering and going out of the pulmonary segment. Finally, two cameras outside the enclosure record the segment, to analyse its surface deformations using DIC with Vic-3D software.

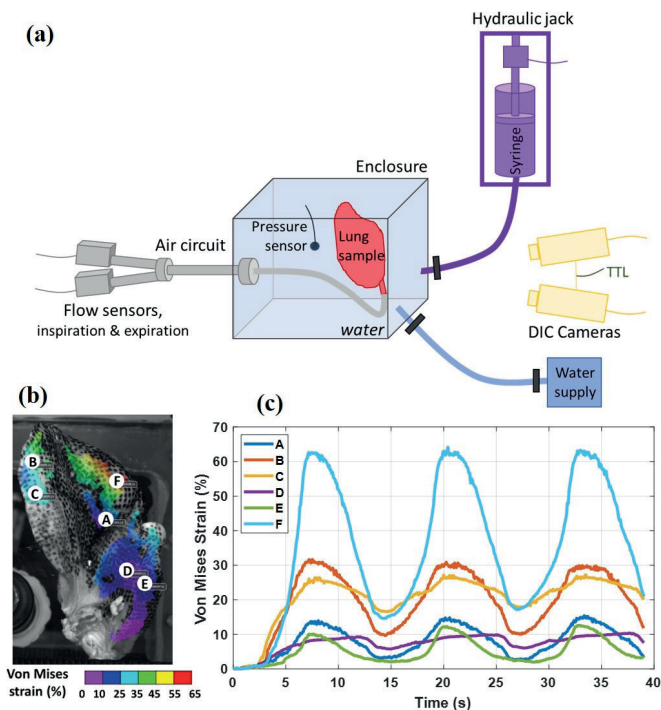


Figure 1. (a) Scheme of the experimental set-up; (b) Strain field on a sheep lung segment at the end of preconditioning obtained with DIC and (c) Strain evolution on 6 points (2 per visible lobe) of the same segment over time during 2 preconditioning cycles.

3. Inflation parameter

At the time the test starts, the lung segment in the enclosure is deflated and its alveoli collapsed, which is not a physiologic state for a healthy subject. Therefore, the first step was a preconditioning to recruit the segment alveoli until it reached its end-expiration volume, which was estimated as twice the initial volume measured during sample preparation.

During natural respiration, lung volume oscillates between an end-expiration and an end-inspiration volumes so that alveoli do not collapse. Pseudo-breathing cycles were then applied on the sample, controlling the water volume variations in the enclosure with the displacement of the syringe. The volume of water removed by the syringe is assumed to be the same as the volume of air inspired by the lung.

4. Results and discussion

The described device offered the possibility to impose a controlled physiological lung distension. It was possible to follow the evolution of its strain field over time using DIC. Preliminary tests showed between 10 and 60%

maximum strain depending on the location. (Fig 1c), with negligible error of about 10^{-1} mm.

However, a delay was observed between the syringe command and the sample inflation response. This can be caused by different factors: deformation of the enclosure because of the depression, flow rate limited by the tube diameters in the air circuit, lung's own viscosity. Further analyses must be done to evaluate these contributions.

These are the first steps for a quantitative mechanical characterization of lung parenchyma under inflation. Unlike other ex-vivo lung inflation devices (Mariano et al. 2020; Dong et al. 2022), our enclosure places the sample in water rather than air. This is thought to better reproduce its physiological environment and gives a better control of the pressure in the enclosure because of the incompressibility of water. But this configuration lets the lung sample float, resulting in a difference in load compared to in-vivo condition.

5. Conclusions

This work established the bases for a mechanical characterisation of ex-vivo lung under inflation. The physiological conditions were precisely simulated with the sample immersed in water and with the pressure variation accurately mimicking pseudo-breathing.

Further tests will allow the study of healthy and ARDS sheep lungs from the same specie and the comparison of their mechanical behaviour. It will provide more insights into lung mechanics during inflation, with quantitative data specific to healthy and ARDS lung parenchyma behaviour. This data could be used to feed digital twin models, increasingly used to assist clinicians. For ARDS, this would help define the best ventilation settings to treat the patient.

Acknowledgements

Authors would like to sincerely thank the Cerimed (Centre Européen de Recherche en Imagerie Médicale) for providing sheep lungs.

Conflict of Interest Statement

None.

References

Cressoni, M., Cadringer, P., Chiurazzi, C., Amini, M., Gallazzi, E., Marino, A., Brioni, M., Carlesso, E., Chiumello, D., Quintel, M., et al. (2014).

- Lung inhomogeneity in patients with acute respiratory distress syndrome. *Am J Respir Crit Care Med*, 189(2):149–158. <https://doi.org/10.1164/rccm.201308-1567OC>
- Dong, S.-J., Wang, L., Chitano, P., Coxson, H. O., Vasilescu, D. M., Paré, P. D., & Seow, C. Y. (2022). Lung resistance and elastance are different in ex vivo sheep lungs ventilated by positive and negative pressures. *American Journal of Physiology-Lung Cellular and Molecular Physiology*, 322(5), L673–L682. <https://doi.org/10.1152/ajplung.00464.2021>
- Mariano, C. A., Sattari, S., Maghsoudi-Ganjeh, M., Tartibi, M., Lo, D.D., & Eskandari, M. (2020). Novel mechanical strain characterization of ventilated ex vivo porcine and murine lung using digital image correlation. *Front Physiol*, 11. <https://doi.org/10.3389/fphys.2020.600492>
- Pallièrre, T., Lanel, A., Bel-Brunon, A., Bruyère-Garnier, K., Biboulet, N., & Lubrecht, T. (2019). Experimental protocol to evaluate lung parenchyma properties under inflation. *Computer Methods in Biomechanics and Biomedical Engineering*, 22(sup1), S14–S16. <https://doi.org/10.1080/10255842.2020.1713461>