Human and Rat Lung DIC Strain Comparisons: A Preliminary Study

M. Shankel[1], C.A. Mariano[1], and M. Eskandari[1a]

[1]Department of Mechanical Engineering, University of California, Riverside CA, USA

[a]mona.eskandari@ucr.edu

Abstract. In this representative study, regional surface strains and distributions in one rat lung and one human lung under positive- and negative-pressure ventilation are compared ex vivo. Lungs were inflated to 20 cmH_2O using a custom ventilator interfaced with digital image correlation to capture surface strains. The rat lung exhibited lower strain magnitudes and heterogeneity compared to the human lung for both ventilation modes. Negative pressure ventilation saw reduced strain magnitude and heterogeneity relative to positive pressure ventilation in both species, which is important for ventilator-induced injury association.

Introduction

Artificial mechanical ventilation uses positive pressure ventilation (PPV) and is a life-saving intervention used to support gas exchange during respiratory failure. Paradoxically, it can damage lung tissue, leading to ventilator-induced lung injury (VILI) [1]. Animal models, particularly rodents, are widely used to investigate ventilation-induced injury due to the practical limitations of human experimentation [1–2]. Despite this, direct comparisons of respiratory behavior between species remain limited, leaving uncertainty in the translational relevance of rodent lung mechanics, particularly as found recently [3]. Additionally, studies suggest that negative pressure ventilation (NPV; physiological breathing) may reduce injury compared to PPV, although observed effects vary across species [4–5]. To address these gaps, we compare regional lung strain distributions in rat and human lungs using digital image correlation (DIC) providing preliminary insights into regional strain interspecies differences and the influence of ventilation mode on lung mechanics.

Methodology

A male Sprague–Dawley rat (258 g) was euthanized and lungs were extracted in accordance with IACUC protocol (Kuali #132). The lungs were inflated and speckled with a fine mist of waterproof paint to enable contrast for digital image correlation (DIC) strain tracking [1]. Specimens were mounted to a custom dual-piston electromechanical ventilator. PPV was applied via the trachea, analyzed for 20 cmH_2O; NPV achieved by reducing chamber pressure and analyzed at a matched transpulmonary pressure of 20 cmH_2O [1]. DIC data were acquired at 10 Hz with a resolution of 4096 × 3000 pixels. Anonymized human cadaveric lungs from a female donor (70.3 kg; Donor Network West; University of California, Riverside, IRB #HS-20-180) were tested within 72 hours post-mortem. A DIC speckle pattern was applied using white spray paint and an exfoliator pad [4]. Specimens were similarly subjected to PPV and NPV, and analyzed at 20 cmH_2O transpulmonary pressure. Surface strain analysis was performed by defining facet subsets (20 pixels for rat, 30 pixels for human) with a point spacing of 15 pixels, selected to minimize data loss during large deformations (Trilion Quality Systems, GOM ARAMIS, 2018) [6]. Lobar regions were segmented to quantify regional surface deformation. Strain contour maps were generated at corresponding pressures for both species and ventilation modes (Fig. 1A,B) [1]. Strain distributions were further quantified using surface-area-weighted histograms, from which mean and interquartile ranges were calculated to assess strain magnitude and heterogeneity (Fig. 1C,D) [1].

Results

Surface strain contour maps demonstrate visible differences in strain magnitude and heterogeneity across species and ventilation modes (Fig. 1A,B). Rat lungs exhibit overall lower strain levels, with only localized regions approaching ~40% under PPV, dissimilar to NPV. Under PPV, higher strains are concentrated near rat cranial regions, whereas NPV produces a more uniform strain distribution. In contrast, human lungs exhibit substantially higher and more widespread strains under PPV, with large surface areas exceeding ~40%. These elevated strains are reduced under NPV. Histogram analysis (Fig. 1C,D) representing strain distributions as a fraction of the surface, supports these observations. Rat lungs show lower mean strains and narrower interquartile ranges compared to human lungs. Additionally, both mean strain and interquartile range decrease under NPV relative to PPV for both species, indicating reduced strain magnitude and heterogeneity with physiological ventilation.

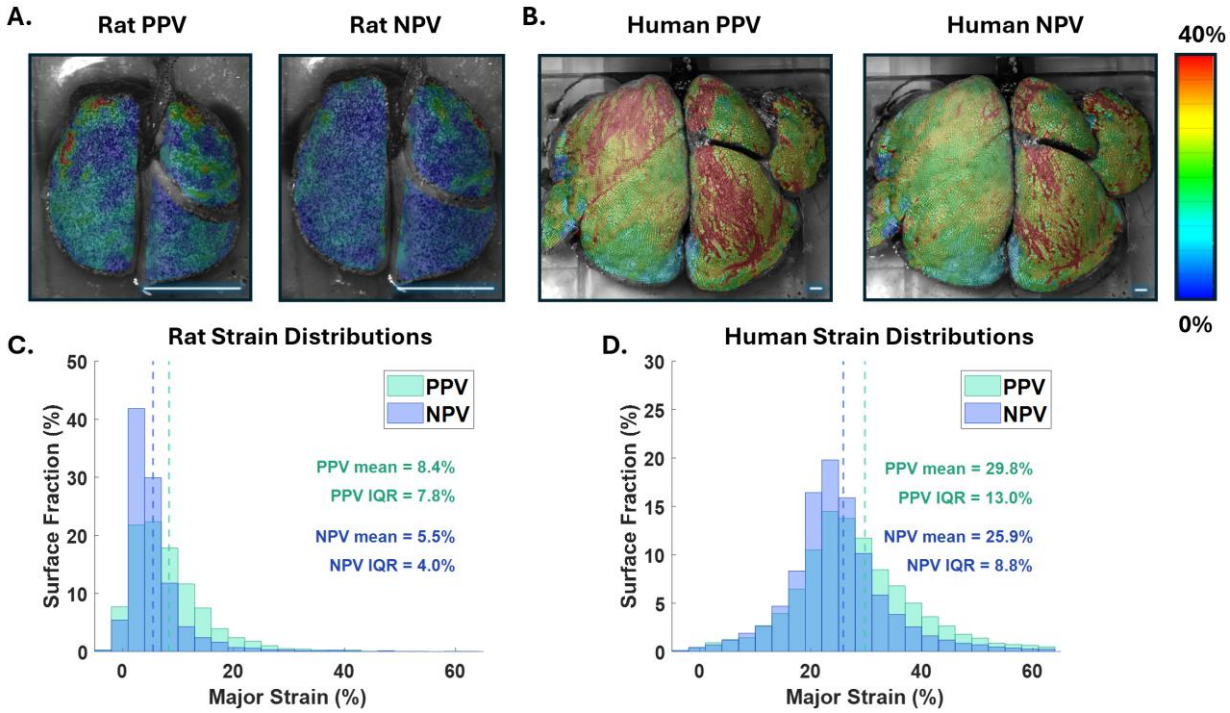

Figure 1. Rat and human lung surface strains at 20 cmH_2O. (A–B) Strain contour maps under PPV and NPV for rat (A) and human (B) lungs with 2 cm scale bars (bottom right). (C–D) Strain distributions showing major strain as a fraction of the lung surface for rat (C) and human (D) lungs.

Discussion and Conclusions

This study provides first insights and expectations for interspecies comparison of regional lung surface strains between rat and human lungs under PPV and NPV. While only a representative study, preliminary notable differences in both strain magnitude and heterogeneity were observed, with rat lungs exhibiting an IQR of 7.8% compared to 13.0% in human lungs under PPV. These differences are important to quantify, as increased regional strain heterogeneity has been associated with elevated risk of ventilator-induced lung injury (VILI) [1]; accordingly, the greater heterogeneity observed in this human lung suggests that pressure levels that may be considered safe in rodent models may correspond to higher injury risk in humans. This is notable given that 20 cmH_2O is commonly used as a safety threshold in both species. However, the present results indicate that this pressure produces substantially lower strain magnitudes and heterogeneity in rat lungs, raising concerns about the translational equivalence of such thresholds across species [2].

This study is limited in its ex vivo design; however, previous work using digital volume correlation has demonstrated similar strain patterns in vivo, supporting the relevance of these findings [7]. Both species exhibited reductions in mean strain and interquartile range when comparing NPV to PPV, consistent with prior studies in rats and pigs [1,4]. Notably, the magnitude of this reduction was greater in human lungs, which may reflect size-dependent mechanical differences between the species and warrants further investigation. In contrast, prior work in mouse lungs reported increased regional surface strains under NPV relative to PPV [8], highlighting potential species-specific responses to ventilation mode. The substantially higher strain magnitudes and heterogeneity observed in human lungs suggest important differences in mechanical response that may influence VILI susceptibility and should be considered when translating findings from animal models.

References

[1] M. Shankel, A. Badrou, T.M. Nelson and M. Eskandari: Surfactant-depleted rat lungs: A characterization of organ- and tissue-level mechanics under negative and positive pressure ventilation, *J. Biomech. Eng.* Vol. 147 (2025).

[2] M. Pecchiari, A. Monaco, A. Koutsoukou, P. Della Valle, G. Gentile and E. D'Angelo: Effects of various modes of mechanical ventilation in normal rats, *Anesthesiology* Vol. 120 (2014) p. 943–950.

[3] G.O. Ramirez, C.A. Mariano, D. Carter and M. Eskandari: Visceral pleura mechanics: Characterization of human, pig, and rat lung material properties, *Acta Biomater.* (2024).

[4] S. Sattari, C.A. Mariano, W.G. Kuschner, H. Taheri, J.H.T. Bates and M. Eskandari: Positive- and negative-pressure ventilation characterized by local and global pulmonary mechanics, *Am. J. Respir. Crit. Care Med.* (2023).

[5] K.A.M. Quiros, C.A. Mariano, M. Shankel, T.M. Nelson and M. Eskandari: Human ex vivo lung mechanics differ under positive- and negative-pressure ventilation, *Respir. Res.* (2026).

[6] C.A. Mariano, S. Sattari, M. Maghsoudi-Ganjeh, M. Tartibi, D.D. Lo and M. Eskandari: Novel mechanical strain characterization of ventilated ex vivo porcine and murine lung using digital image correlation, *Front. Physiol.* Vol. 11 (2020)

[7] H. Arora, R.L. Mitchell, R. Johnston, M. Manolesos, D. Howells, J.M. Sherwood, A.J. Bodey and K. Wanelik: Correlating local volumetric tissue strains with global lung mechanics measurements, *Materials* Vol. 14 (2021)

[8] T.M. Nelson, K.A.M. Quiros and M. Eskandari: Interactive effects of pulmonary pathologies and ventilation modes driving heterogeneous and anisotropic regional strain mechanics, *Sci. Rep.* Vol. 15 (2025)