Pioneers in Mechanical Ventilation: Björn Jonson

Ehab G. Daoud [1]

DOI: https://doi.org/10.53097/JMV.10050

Cite: Daoud EG. Pioneers in Mechanical Ventilation: Björn Jonson. J Mech Vent 2022; 3(2):73-81.

Abstract

In this article, we highlight one of the pioneers of mechanical ventilation. Dr Björn Jonson is a physiologist, physician and currently a Professor Emeritus at Lund University in Sweden. He has spent the last sixty years of his life dedicated to research and inventions in the fields of respiratory failure and mechanical ventilation.

With several devices invented, more than fifteen patents, more than 200 published articles and concepts, Dr. Jonson's work has changed and revolutionized the way we understand the science of respiratory failure, and the way we practice and monitor mechanical ventilation today. More importantly, are the countless lives of patients saved all over the world because of his contribution.

Keywords: Flow regulators, Servo Ventilator, Capnography

Authors
1. Ehab Daoud. Professor of Medicine, JABSOM school of Medicine, University of Hawaii, Hawaii, USA

Corresponding author: Ehab Daoud
Email: edaoud@hawaii.edu

Conflict of interest/Disclosures: None
Funding: None

"With no history, there is no future."

New generations of mechanical ventilators have come a long way, with microprocessors now offering more intelligent modes, monitoring, and delivery capabilities than ever before. Have you ever stopped to think how did we get here? I bet you did.

The work done and still being done for the continuing evolution involved many dedicated clinicians, physicists, engineers and so many more, who do not get credit for their effort, work and ingenuity and are the unknown soldiers behind what we take for granted every day in our practice.

In this article we highlight the great work done by one of those pioneers that has changed mechanical ventilation forever over the late six decades.

I stumbled on a blog article titled, "This is Björn Jonson, who invented the modern ventilator for which he has never received a prize or even a Wikipedia page" [1] and thought to myself, I have never heard of the man, how is that possible, I'm an avid lover of medical history, especially of mechanical ventilation. The search for him began and it didn't take too long to find and track him. To my great pleasure, I found that he is still working and inventing in his home country of Sweden as a Professor Emeritus at Lund University. With not much hope of getting a reply, I e-mailed him introducing myself, our Journal of Mechanical Ventilation and wishing that I could interview him to learn about his work and publish a paper highlighting his career and inventions in a trivial attempt to repay the man who helped change the world of respiratory failure with respect to knowledge, management, and monitoring. I was shocked to receive an e-mail back from him accepting my invitation and supplying me with the whole story and other materials that I read all before meeting him.

Humility, simplicity, frankness, and sincerity were immediately noticed. He talked about his early career and gave much credit to his professors, colleagues and all the people who helped and encouraged him during his career.

Figure 1A: Professor Björn Jonson 1970 (middle)

Figure 1B: Professor Björn Jonson 2020

Question: Please tell us about yourself,

Answer: I was born in 1940. My parents died when I was 20 leaving me responsible for two younger sisters and I had to study and work for money. I became a physician and a physiologist interested in learning about lung physiology and stumbled on mechanical ventilation, which was in its infancy, and I did not know much about it at the time.

Question: How did it all start?

Answer: After graduation in 1959 in Malmö, I started medical school in Lund, Sweden. Within soon, I focused on physiology. My first paper was titled "Histamine metabolism in the brain of onscious cats". [2]
In 1962, I moved to the department of Clinical Physiology, a new discipline in Sweden. In 1964, in Atlanta, GA, USA I developed a "body plethysmograph" for studies of the mechanical properties of the lung. This led to two papers about alveolar pressure, airflow rate and lung inflation in the Journal of Applied Physiology. [3,4]

Question: How about mechanical ventilation?

Answer: Returning to Lund, I got involved in research about mechanical ventilation in patients with cardiac shock. We had a Bennet Ventilator, which was not able to adjust to the needs of the patient. At the time, ventilators were either pressure or volume controlled. The idea arose that ventilators should be flow controlled to allow full flexibility of ventilation. However, even professors in flow technology said that it is impossible to create a flow regulator suitable for a ventilator.

Flow regulator

After hard work, and many failures, I succeeded to design and construct the first acceptable flow regulator that was patented, (Figure 2). Together with Sven-Gunnar Olsson, an engineer at Siemens-Elema AB company in Sweden, we built a ventilator with these. In August 1967, on the day following patent application, we visited this company in Stockholm. Next week, we had signed a contract for further development of a flow-controlled ventilator.

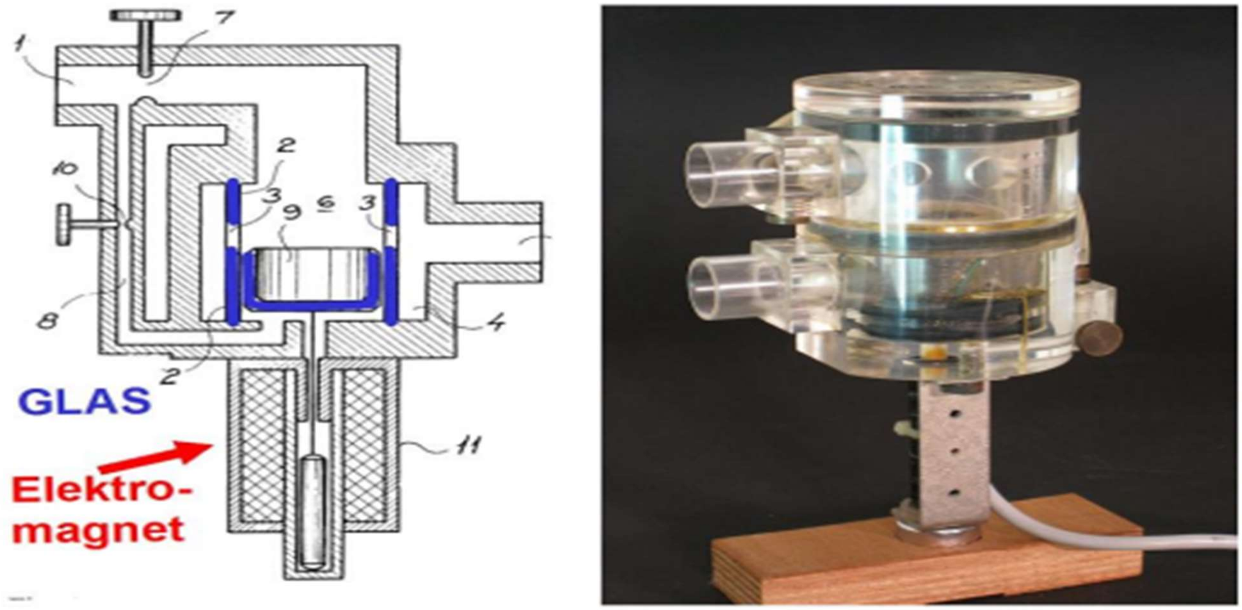

Figure 2: Left: Figure from my patent of the flow regulator. The cylinder and the piston were from a glass syringe, blue. Airflow into the opening 1 leads to an overpressure when the air passes through an adjustable resistor 7. When the flow reaches a certain value, this overpressure acting under the piston 9 will lift it until it gradually closes the openings 3 in the cylinder 2. Then flow cannot increase further. When the electromagnet lifts the piston, flow is completely shut off. Right: A flow regulator manufactured by the author.

The first ventilator with Alarms and Monitoring

Within 6 months of the contract, we had developed a ventilator with most of the features of the upcoming industrial product (Figure 3A). As a physiologist, I realized that a ventilator should not only blow gas into the lungs but that monitoring of ventilation and lung function was an equally important function. For that purpose, we developed electronic transducers for pressure and flow. For the first time, a ventilator could alarm for too low minute ventilation and for too high airway pressure to alert clinicians of potential hazards.

Patient trigger

The pressure signal allowed patient triggered breaths prompted by an inspiratory effort leading to a pressure below a preset minimum pressure. This was the first step towards assisted ventilation.

Question: I understand that you were not content with what you had achieved. What was the problem?

Answer: Even before the ventilator with my mechanical flow regulators was ready in 1968, we realized that the future was in full electronic control of flow. The highest expertise in electronics and regulation technology declared that it was impossible to construct a system fulfilling our specified requirements. We rejected their advice and in spring 1970, we had five units of the Servo Ventilator 900 for animal studies and for tests on humans with respiratory failure (Figure 3B). In 1971, it was on the Scandinavian market. It was small, lightweight (10 kg), noiseless with unequalled precision, flexibility and facilities for alarm and monitoring. All components in contact with the gas could very easily be sterilized. Compared to the noisy and heavy (160 kg) Engström Respirator, considered the gold standard at the time, the Servo Ventilator 900 appeared as a miracle.

The Servo Ventilator 900 was a revolutionary machine.[5] It changed the way of ventilation and monitoring of the patients and became the new standard from which we could advance, and other companies could build on.

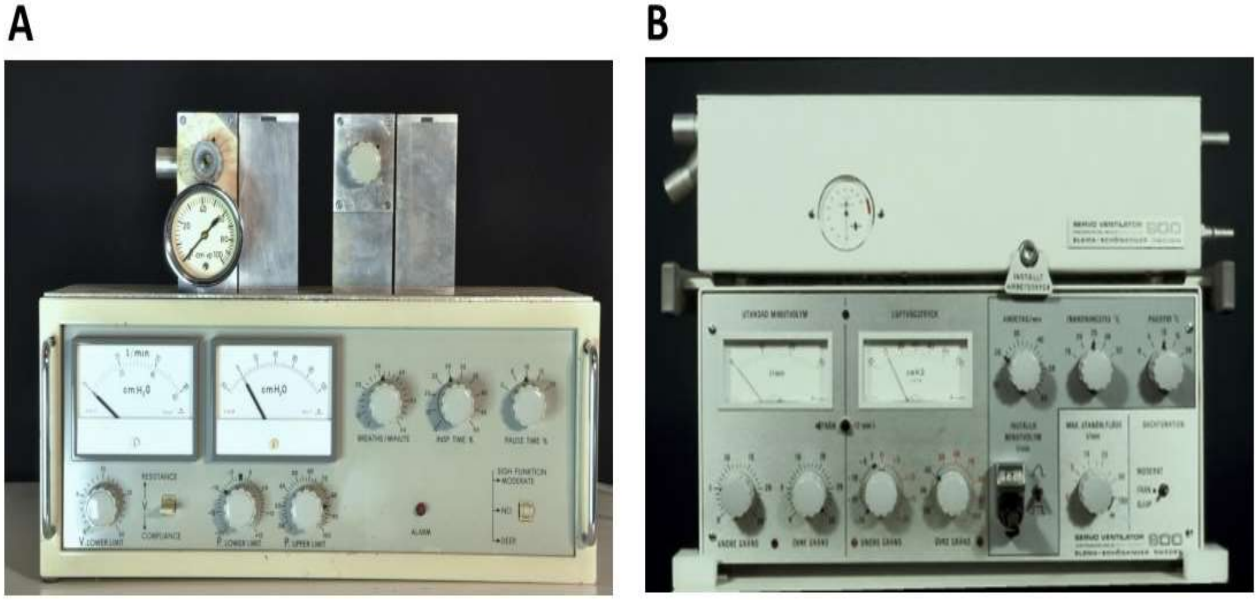

Figure 3. A: Prototype developed in 1968. B: Servo Ventilator 900 in 1971.

Question: After the Servo Ventilator 900, what were the advancements you refer to?

Answer: Our **PEEP Valve** was the first commercially device for Positive End Expiratory Pressure (PEEP) and available from the first year. I will always remember the dramatic effects of PEEP in ARDS. In these days many patients with the diagnosis ARDS had a treatable cause such as trauma and near drowning and offered less problems than most patients of today.

Lung Mechanics Calculator 940

The Servo Ventilator 900, connected to a recorder, allowed measurement of compliance and resistance of the respiratory system. The Lung Mechanics Calculator was described and marketed in 1975 (figure 4).[6] It monitors six parameters on the basis of the ventilator signals: Peak inspiratory pressure, post inspiratory pause pressure (plateau pressure), inspiratory and expiratory resistance, compliance, and End Expiratory Lung Pressure. End Expiratory Lung Pressure is total PEEP that includes auto-PEEP and the calculated value of compliance was based on this parameter, long before others "reinvented" this principle. This calculator offered monitoring of respiratory mechanics during mechanical ventilation in a way that even today is rare. [7,8]

Figure 4: Lung Mechanics Calculator 940

Volumetric Capnometry (CO_2 Analyzer 930)

Volumetric capnography was introduced by me in a study performed in 1975 in infants undergoing deep hypothermia for cardiac surgery, using a prototype of the CO_2 Analyzer 930. [9,10] The fast response of the infrared sensor (6 ms) allowed perfect synchrony with the equally fast flow signal, a prerequisite for accurate measurement of expired CO_2 volumes per breath or per minute, dead space apart from end tidal CO_2. Our analysis of physiology behind volumetric capnography is of seminal nature.[11] This analyzer has been and still is a key instrument for large number of studies. [11-16]

Question: Were there any contributions to the field of respiratory failure and mechanical ventilation other than the ones above?

Answer: In parallel with the development of the Servo Ventilator 900, I constructed the Face Chamber for neonatal CPAP treatment that was marketed by Siemens -Elema. [17] Based on the combination of the face chamber and the ventilator, we became, under Nils Svenningsen, a global leader in neonatal ventilation. [17-22]

My group has studied basic physiology related to pulmonary surfactant. When a wetting agent is administered to the alveoli, the permeability of the alveolocapillary membrane increases more than 100 times. [23-28] A healthy mammalian lung exhibits zero pressure volume hysteresis during small and large breath. [29] While a lung with normal surfactant tolerates thousands of cycles of collapse and re-expansion, a lung with perturbed surfactant becomes injured by such a procedure. [30-31] Our observations cannot be explained by the traditional wet model of the alveolar surface. Rather, they are in line with a model of a normally dry alveolus in which surfactant is directly adsorbed at the alveolar surface as proposed by Hills. [32] Remarkably, this theory that may be fundamental for the understanding of the nature and treatment of ARDS has not been devoted much interest.

In 1981, we developed a high frequency ventilator. Protective ventilation was achieved in animal experiments. [33-35] However, we saw conceptual problems with extremely high respiratory frequencies combined with corresponding difficulties in monitoring and tuning ventilation to the need of the patient, which would not fit in clinical routine. Rather, based on analysis of data from more traditional methods, in the same year I concluded: "*A respiratory pattern at RDS should be so chosen as to gently open up closed units and then maintain aeration and stability throughout the respiratory cycle"*. [36] My analysis and conclusion is an original contribution to the field.

Additionally, in 1981, we introduced the ServoVentilator 900C that allowed new modes of ventilation like synchronized intermittent mandatory ventilation and pressure supported ventilation. The latter mode became a standard for weaning the patient from mechanical ventilation. I proposed that the inspiration should be interrupted when flow rate had decreased to 25% or 30% of peak inspiratory flow and that solved this problem. I also proposed that the ventilator should have facilities for momentary external computer control of its function. This facility has been used for many of my studies of pulmonary mechanics and gas exchange at health and in ARDS.

Our studies in 1989-2006 of pulmonary mechanics have contributed to understanding of how "*to gently open up closed units and then maintain aeration and stability throughout the respiratory cycle"*. The physical and physiological background of expiratory lung collapse and inspiratory re-expansion was in detail explored. That the lower inflexion point of the inspiratory elastic P/V-curve was proposed to be used to set PEEP was shown to be flawed. It was shown that achievement and maintenance of an open lung was accomplished by the combination of an adequate PEEP and a proper tidal volume. [37-45]

As lung protective ventilation requires low tidal volumes it is crucial to minimize dead space. With computer control of the Servo Ventilator 900C, we showed that CO_2 exchange can easily be enhanced by a proper inspiratory flow pattern as we foresaw when we in the sixties constructed the first ventilators. [46-49] The most efficient way to reduce the dead space is to bring fresh gas to the tip of the tracheal tube before start of inspiration. This is done by aspiration of dead space (ASPIDS) or partially by circuit flushing. [50-53]

Pressure, flow, and CO_2 signals from the ventilator allow detailed analysis of gas exchange and mechanics. Computer simulation can then be used to identify ventilator settings, which lead to the goal of ventilation, which in ARDS is to achieve lung protective ventilation with adequate CO_2 elimination.

Barotrauma is avoided by limiting plateau pressure to a safe level and volutrauma (atelectrauma) by searching a setting that minimizes pressure swings (delta-pressure). A system for that purpose was patented in 2003 and 2014 (US 6,578,575 and SE 536 624). In a study of a porcine ARDS model, we applied all methods for dead space reduction including ASPIDS and the patented concept to find the best lung protective setting. It really worked and lung protection was achieved as shown by our sophisticated analysis of lung mechanics and gas exchange. [54] However, the scientific and industrial societies appear un-impressed.

Question: What are you working on now?

Answer: I am searching for partners who can contribute to the development of a capnographic prognostic index in ARDS, which I described in 2018. [55] The index defines the efficiency of CO_2 elimination (EFFi)

For the last two years I have been busy with in writing an essay, *Physics and Physiology for Lung Protective Ventilation*. It summarizes my contributions related to mechanical ventilation. While I have reached some success, much has not been applied, neither in the scientific and clinical communities nor in the or industrial world. At my age, 82, the obstacles are high, but I will not give up. A dream is still to take part in the development of a ventilator that offers truly efficient lung protective ventilation. It should be better than any present ventilator although it might be less sophisticated than the current ICU ventilators. It should be easy to learn and to use by the staffs during following pandemics.

By the way, summer is approaching, and I will together with my wife, sail for a long period.

Question: What do you think are the challenges in mechanical ventilation today?

Answer: The research in mechanical ventilation is not focused on essentials. For example, all the studies that look for a single parameter like best PEEP or optimal tidal volume to prevent ventilator induced lung injury (VILI). There is no such optimal parameter. All parameters related to mechanics and gas exchange must be weighed together to form a truly non-injurious ventilatory strategy as we have shown. [54]

Question: What advice do you give to current clinicians and researchers working with mechanical ventilation?

Answer: Strive to understand physics and physiology of the condition you meet. I was lucky in my career to meet so many good people who encouraged and helped me to succeed. There are still good people around, find them! Make your ideas clear and believe and work on them despite all difficulties! Nothing should stop you, just do it!

References

1. Neoshero. This is Björn Jonsson, who invented the modern ventilator for which he has never received a price or even a Wikipedia page [Online forum post]. Reddit. https://www.reddit.com/r/europe/comments/gtcwhv/this_is_bj%C3%B6rn_jonsson_who_invented_the_modern/

2. Jonson B, White T. Histamine metabolism in the brain of conscious cats. Proc Soc Exp Biol Med 1964; 115:874-876.

3. Bouhuys A, Jonson B. Alveolar pressure, airflow rate, and lung inflation in man. J Appl Physiol 1967; 22(6):1086-1100.

4. Jonson B, Bouhuys A. Measurement of alveolar pressure. J Appl Physiol 1967; 22(6):1081-1085.

5. Ingelstedt S, Jonson B, Nordström L, et al. A servo-controlled ventilator measuring expired minute volume, airway flow and pressure. Acta Anaesthesiol Scand 1972; 16:7-27.

6. Jonson B, Nordström L, Olsson S, et al. Monitoring of ventilation and lung mechanics during automatic ventilation. A new device. Bull Physiopathol Respir 1975; 11(5):729-743.

7. Prakash O, Jonson B, Meij S. Techniques of respiratory monitoring. Int J Clin Monit Comput 1984; 1(2):49-58.

8. Prakash O, Meij S, Bos E, et al. Lung mechanics in patients undergoing mitral valve replacement. The value of monitoring of compliance and resistance. Crit Care Med 1978; 6(6):370-372.

9. Prakash O, Jonson B, Bos E, et al. Cardiorespiratory and metabolic effects of profound hypothermia. Crit Care Med 1978; 6(5):340-346.

10. Olsson S, Fletcher R, Jonson B, et al. Clinical studies of gas exchange during ventilatory support–a method using the Siemens-Elema CO_2 analyzer. Br J Anaesth 1980; 52(5):491-499.

11. Fletcher R, Jonson B, Cumming G, et al. The concept of deadspace with special reference to the single breath test for carbon dioxide. Br J Anaesth 1981;53 (1):77-88.

12. Fletcher R, Jonson B. Prediction of the physiological dead space/tidal volume ratio during anaesthesia/IPPV from simple pre-operative tests. Acta Anaesthesiol Scand 1981;2 5(1):58-62.

13. Fletcher R, Jonson B. Deadspace and the single breath test for carbon dioxide during anaesthesia and artificial ventilation: effects of tidal volume and frequency of respiration. Br J Anaesth 1984; 56(2):109-119.

14. Fletcher R, Jonson B. A new method for calculation of ventilatory deadspace. British Journal of Anaesthesia 1989; 63(5):639-640.

15. Fletcher R, Malmkvist G, Niklason L, et al. On-line measurement of gas-exchange during cardiac surgery. Acta Anaesthesiol Scand 1986; 30(4):295-299.

16. Fletcher R, Nordström L, Werner O, et al. A possible source of error in gas exchange measurements. Anesthesiology 1983; 59(1):77.

17. Ahlström H, Jonson B, Svenningsen NW. Continuous positive airway pressure with a face chamber in early treatment of idiopathic respiratory distress syndrome. Acta Paediatr 1973; 62(4):433-436.

18. Svenningsen NW, Jonson B, Lindroth M, et al. Consecutive study of early CPAP-application in hyaline membrane disease. Eur J Pediatr 1979; 131(1):9-19.

19. Ahlström H, Jonson B. Pulmonary mechanics in infants. Methodological aspects. Scand J Respir Dis 1974; 55(2):129-140.

20. Ahlström H, Jonson B. Pulmonary mechanics during the first year of life. Scand J Respir Dis 1974; 55(2):141-154.

21. Ahlström H, Jonson B, Svenningsen NW. Continuous postive airways pressure treatment by a face chamber in idiopathic respiratory distress syndrome. Arch Dis Child 1976; 51(1):13-21.

22. Andreasson B, Lindroth M, Svenningsen NW, et al. Measurement of ventilation and respiratory mechanics during continuous positive airway pressure (CPAP) treatment in infants. Acta Paediatr Scand 1989; 78(2):194-204.

23. Wollmer P, Evander E, Jonson B, Lachmann B. Pulmonary clearance of inhaled 99mTc-DTPA: effect of surfactant depletion in rabbits. Clin Physiol 1986; 6(1):85-89.

24. Liu JM, Evander E, Zhao J, et al. Alveolar albumin leakage during large tidal volume ventilation and surfactant dysfunction. Clin Physiol 2001; 21(4):421-427.

25. John J, Taskar V, Evander E, et al. Additive nature of distension and surfactant perturbation on alveolocapillary permeability. Eur Respir J 1997; 10(1):192-199.

26. Evander E, Wollmer P, Valind S, et al. Biexponential pulmonary clearance of 99mTc-DTPA induced by detergent aerosol. J Appl Physiol 1994; 77(1):190-196.

27. Evander E, Wollmer P, Jonson B, et al. Pulmonary clearance of inhaled 99mTc-DTPA: effects of surfactant depletion by lung lavage. J Appl Physiol 1987; 62(4):1611-1614.

28. Evander E, Wollmer P, Jonson B. Pulmonary clearance of inhaled 99mTc-DTPA: effect of the detergent dioctyl sodium sulfosuccinate in aerosol. Clin Physiol 1988; 8(2):105-111.

29. Svantesson C, John J, Taskar V, et al. Respiratory mechanics in rabbits ventilated with different tidal volumes. Respir Physiol 1996; 106(3):307-316.

30. Taskar V, John J, Evander E, et al. Healthy lungs tolerate repetitive collapse and reopening during short periods of mechanical ventilation. Acta Anaesthesiol Scand 1995; 39(3):370-376.

31. Taskar V, John J, Evander E, et al. Surfactant dysfunction makes lungs vulnerable to repetitive collapse and reexpansion. Am J Respir Crit Care Med 1997;155(1):313-320.

32. Hills BA. What is the true role of surfactant in the lung? Thorax 1981; 36(1):1-4.

33. Jonson B, Lachmann B. Setting and monitoring of high-frequency jet ventilation in severe respiratory distress syndrome. Crit Care Med 1989; 17(10):1020-1024.

34. Jonson B, Lachmann B, Fletcher R. Monitoring of physiological parameters during high frequency ventilation (HFV). Acta Anaesthesiol Scand Suppl 1989; 90:165-169.

35. Lachmann B, Schairer W, Hafner Met al. Volume-controlled ventilation with superimposed high frequency ventilation during expiration in healthy and surfactant-depleted pig lungs. Acta Anaesthesiol Scand Suppl 1989; 90:117-119.

36. Johnson B. Postive airway pressure: some physcial and biological effects. In: Prakash O, editor. Applied physiology in clinical respiratory care. The Hague, Netherlands: Martinus Nojhoff Publishers, 1982:125-139.

37. Svantesson C, Sigurdsson S, Larsson A, Jonson B. Effects of recruitment of collapsed lung units on the elastic pressure-volume relationship in anaesthetised healthy adults. Acta Anaesthesiol Scand 1998; 42(10):1149-1156.

38. Jonson B. Elastic pressure-volume curves in acute lung injury and acute respiratory distress syndrome. Intensive Care Med 2005; 31(2):205-212.

39. Jonson B, Svantesson C. Elastic pressure-volume curves: what information do they convey? Thorax 1999;5 4(1):82-87.

40. Richard JC, Maggiore SM, Jonson B, et al. Influence of tidal volume on alveolar recruitment. Respective role of PEEP and a recruitment maneuver. Am J Respir Crit Care Med 2001; 163(7):1609-1613.

41. Richard JC, Brochard L, Vandelet P, et al. Respective effects of end-expiratory and end-inspiratory pressures on alveolar recruitment in acute lung injury. Crit Care Med 2003; 31(1):89-92.

42. Maggiore SM, Jonson B, Richard JC, et al. Alveolar derecruitment at decremental positive end-expiratory pressure levels in acute lung injury: comparison with the lower inflection point, oxygenation, and compliance. Am J Respir Crit Care Med 2001; 164(5):795-801.

43. Jonson B, Richard JC, Straus C, et al. Pressure-volume curves and compliance in acute lung injury: evidence of recruitment above the lower inflection point. Am J Respir Crit Care Med 1999; 159(1):1172-1178.
44. Similowski T, Levy P, Corbeil C, et al. Viscoelastic behavior of lung and chest wall in dogs determined by flow interruption. J Appl Physiol 1989; 67(6):2219-2229.

45. Levy P, Similowski T, Corbeil C, et al. A method for studying the static volume-pressure curves of the respiratory system during mechanical ventilation. J Crit Care 1989; 4(2):83-89.

46. Aboab J, Niklason L, Uttman L, et al. Dead space and CO_2 elimination related to pattern of inspiratory gas delivery in ARDS patients. Crit Care 2012; 16(2):R39.

47. Aboab J, Niklason L, Uttman L, et al CO_2 elimination at varying inspiratory pause in acute lung injury. Clin Physiol Funct Imaging 2007; 27(1):2-6.

48. Sturesson LW, Malmkvist G, Allvin S, et al. An appropriate inspiratory flow pattern can enhance CO_2 exchange, facilitating protective ventilation of healthy lungs. Br J Anaesth 2016; 117(2):243-249.

49. Uttman L, Jonson B. A prolonged postinspiratory pause enhances CO_2 elimination by reducing airway dead space. Clin Physiol Funct Imaging 2003; 23(5):252-256.

50. De Robertis E, Servillo G, Jonson B, et al. Aspiration of dead space allows normocapnic ventilation at low tidal volumes in man. Intensive Care Med 1999; 25(7):674-679.

51. De Robertis E, Servillo G, Tufano R, et al. Aspiration of dead space allows isocapnic low tidal volume ventilation in acute lung injury. Relationships to gas exchange and mechanics. Intensive Care Med 2001; 27(9):1496-1503.

52. De Robertis E, Sigurdsson SE, Drefeldt B, et al. Aspiration of airway dead space. A new method to enhance CO_2 elimination. Am J Respir Crit Care Med 1999; 159(3):728-732.

53. De Robertis E, Uttman L, Jonson B. Re-inspiration of CO_2 from ventilator circuit: effects of circuit flushing and aspiration of dead space up to high respiratory rate. Crit Care 2010; 14(2):R73.

54. Uttman L, Bitzen U, De Robertis Eet al. Protective ventilation in experimental acute respiratory distress syndrome after ventilator-induced

lung injury: a randomized controlled trial. Br J Anaesth 2012; 109(4):584-594.

55. Jonson B. Volumetric capnography for noninvasive monitoring of acute respiratory distress syndrome. Am J Respir Crit Care Med 2018; 198(3):396-398.