Revista Colombiana de Anestesiología
Colombian Journal of Anesthesiology
www.revcolanest.com.co

Essay

Blood flow and pulmonary ventilation: New paradigm?☆

Pedro José Herrera Gómez[a,*], *Gustavo Duarte*[b]

[a] *Assistant Professor, Anesthesiology and Resuscitation, Universidad Nacional de Colombia, Bogotá, Colombia*
[b] *Student, 3rd Graduate Program of Anesthesiology and Resuscitation, Universidad Nacional de Colombia, Bogotá, Colombia*

ARTICLE INFO

Article history:
Received 20 January 2013
Accepted 20 August 2013
Available online 12 October 2013

Keywords:
Ventilation
Perfusion
Fractalas
Gravitation
Lung

ABSTRACT

Gravity was established as the determinant factor regarding differences in the distribution of ventilation and perfusion in the lung by John West, concept that continue to be exposed, up to day, as a basic principle of the lung physiology.

The modern diagnostic images permit to demonstrate that gravity is not the determinant factor of these differences, a fact that generate big questions about concepts, among many others, support mechanical ventilations, ventilatory modes and one lung ventilation in lateral position during thoracic surgery.

This article reflects on the recent findings of perfusion and ventilation studies that question the paradigm of gravity as its main determinant, and their clinical implications.

Flujo sanguíneo y ventilación pulmonares: ¿nuevo paradigma?

Palabras clave:
Ventilación
Perfusión
Fractales
Gravitación
Pulmón

RESUMEN

La gravedad fue establecida como el factor determinante de las diferencias en la distribución de la ventilación y la perfusión pulmonares por John West, concepto que continúa exponiéndose hoy en día como principio básico de la fisiología pulmonar. Las imágenes diagnósticas modernas permiten demostrar que la gravedad no es el factor determinante de estas diferencias, hecho que genera grandes interrogantes sobre los conceptos que, entre muchos otros, sustentan la ventilación mecánica, los modos ventilatorios y la ventilación unipulmonar en decúbito lateral durante la cirugía de tórax. El presente artículo reflexiona sobre los recientes hallazgos de los estudios sobre perfusión y ventilación que cuestionan el paradigma de la gravedad como su determinante fundamental, y sobre sus implicaciones clínicas.

☆ Please cite this article as: Herrera Gómez PJ, Duarte G. Flujo Sanguíneo y Ventilación Pulmonares: Nuevo Paradigma?. Rev Colomb Anestesiol. 2013;41:280–282.

* *Corresponding author*. Calle 142 # 6 – 80. Bogotá, Colombia
E-mail address: pjherrerag@unal.edu.co (P.J. Herrera Gómez).

Introduction

The research by West et al.,[1–3] with radioactive gas isotopes such as Xenon, has shown that ventilation and perfusion increased in a cephalic-caudal direction. The differences were explained by the changes in pleural pressure resulting from the weight of the lung itself, for ventilation, and by the effect of gravity for perfusion. The pressure that keeps the alveoli opened – transpleural pressure – results from the differential between the alveolar and the pleural pressure. Pleural pressure becomes less sub-atmospheric at the basis, resulting in lower volume alveoli, with increased compliance and, consequently, increased relative ventilation. The force of gravity imposes a higher blood hydrostatic pressure that drops to the baseline and a pressure loss that rises to the apex, giving rise to West's zones as described in the classical respiratory physiology textbooks.[4,5] Later findings showed that changes in pulmonary volume cause changes in gravity.[6]

The imaging techniques used in West's pioneer studies gave mean blood flow measurements with means applicable to areas of the lung parenchyma located along the same horizontal plane. With the current high-resolution techniques that enable the identification of very small flow differences on the same horizontal plane, high blood flow variability in the same isogravitational plane, in 1 mm thick sections is demonstrated.[7] 50 mm sections show marked gravity-related changes in perfusion and ventilation on the vertical plane, with no differences in the horizontal plane.[8] This explains the findings by West's initial studies and others that came later. In contrast, high-resolution tests such as computed axial tomography or PET CT have shown changes in the distribution of ventilation and perfusion in iso-gravitational planes.[9]

Ventilation differences

Initially, the distribution of pulmonary ventilation was determined using gas radioactive isotopes such as ^{133}Xe, the element of choice because of its low absorption. Tracking of radiolabelled gas is done with detectors that provided a bi-dimensional image of a highly complex three-dimensional structure such as the lung. The use of high-resolution tomography shows areas of higher ventilation in the same horizontal plane and toward the pulmonary hilum.[10]

Perfusion differences

Gravity was therefore considered the determining factor for the distribution of ventilation and pulmonary blood flow; as we move away in a cephalic direction, the pulmonary artery hydrostatic pressure decreases resulting in a reduced blood flow to the apexes and increased blood flow toward the basis, where the blood flow will be higher.[11] Moreover, the lung's weight imposes changes in the pleural pressure and, consequently, in the size of the alveoli, their ability to distend and finally in ventilation.

Some trials performed under zero gravity, microgravity and hypergravity question these arguments.[12,13] Montmerle et al. found differences in surrogate measures such as cardiogenic oscillations used as indicators of the differential in oxygen and carbon dioxide concentrations in pulmonary units that also reflected differences in pulmonary perfusion.

The evaluation of ventilation distribution and perfusion in pigs by Altemeier et al., using a variance analysis, quantified the contribution of the structure to ventilation and perfusion differences attributing 74.0% ± 4.7% for ventilation and 63.3% ± 4.2% for perfusion.[14] The contribution of gravitational forces and of postural changes will then be fundamentally less important than what was traditionally thought.

Subsequent studies[10,14] correlated the differences found in blood flow with lung tissue volume. The analysis with functional magnetic resonance and measurement of regional proton density using FLASH (Fast Low Angle SHot), Hopkins et al. found that when the differences identified in perfusion are normalized against the tissue density, the blood flow distribution is uniform throughout the lung. This is what the Slinky effect suggests: a gravity-dependent spring deforms under its own weight.[15] A quantitative photon emission computed tomography suggests that the differences in blood flow distribution and ventilation may also be due to the alterations in the pulmonary parenchyma resulting from postural changes that could account for such differences. Variations resulting from postural changes from supine to prone lead to variations in the distribution of pulmonary tissue. This theory is supported by the differences between the left and right lateral decubitus. In left lateral decubitus the dependent lung is the smallest volume lung and under these conditions, any changes in ventilation and perfusion do not favor the dependent lung.

The experiments in the last decade have given rise to the structural model of pulmonary physiology that replaces the concept of random embryo formation of the pulmonary vessels and bronchi by a fractal model mainly characterized by the repetition of a baseline structure wherein the vascular and bronchial anatomy follow a constant mathematical ratio.[16–18] An asymmetric division of the airway is initially observed from the source bronchi; left bronchus/right bronchus = 0.8 and remains unchanged until the last divisions; this pattern repeats itself in the blood vessels. Such asymmetric division would mainly account for the differences in pulmonary ventilation and perfusion.

Conclusions

West's model has been the foundation for understanding the distribution of pulmonary perfusion and ventilation. It is applicable to various medical situations and in particular to the ventilation modes used in several clinical and surgical scenarios. One that comes to mind is the ventilation under constant changes in the position of the patient with varying pathologies, particularly the ARDS and anesthesia for chest surgery in lateral decubitus and one-lung ventilation conceptually based on the assumptions of the gravitational model.

Several secondary reviews conclude that prone decubitus ventilation has a positive effect on severe ARDS patients. The information requires careful consideration prior to its adoption into clinical practice, since the risk of complications from patient's mobilization such as extubation, loss of central or arterial lines and pressure ulcers may offset the benefits. Moreover, prone ventilation represents a simplistic approach to the referred models. As already mentioned, the gas exchange issue is more probably related to structural pulmonary disorders inherent to ARDS, the key ventilation – perfusion determinant.

These new findings question the validity of West's model and raise some questions regarding the foundation of the ventilation strategies used in ICUs and surgery based on such assumptions. The new model has begun to generate studies and scientific debates that should provide a novel explanation to old concepts. Regardless of whether the new paradigm is established or ruled out, it is mandatory to continue explaining numerous medical interventions under West's gravitational model.

Funding

Resources own authors.

Conflict of interest

The authors have no conflicts of interest to declare.

REFERENCES

1. West JB, Dollery CT, Naimark A. Distribution of blood flow in isolated lung; relation to vascular and alveolar pressures. J Appl Physiol. 1964;19:713–24.
2. West JB, Dollery CT. Distribution of blood flow and ventilation – perfusion ratio in the lung, measured with radioactive carbon dioxide. J Appl Physiol. 1960;15:405–10.
3. Milic-Emili J, Henderson JAM, Dolovich MB, Trop D, Kaneko K. Regional distribution of inspired gas in the lung. J Appl Physiol. 1966;21:749–59.
4. Moreno R, Ramases F. Manual de Anestesia y Medicina Perioperatoria en Cirugía torácica. Madrid: Ergon; 2009.
5. Benumoff J. Anesthesia for thoracic surgery. 2nd ed. Philadelphia: WB. Saunders; 1995.
6. Hughes JM, Glazier JB, Maloney JE, West JB. Effect of lung volume on the distribution of pulmonary blood flow in man. Respir Physiol. 1968;4:58–72.
7. Galvin I, Drummond GB, Nirmalan M. Distribution of blood flow and ventilation in the lung: gravity is not the only factor. Br J Anaesth. 2007;98:420–8.
8. Borrowes K, Tawhai M. Computational predictions of pulmonary blood flow gradients: gravity versus structure. Resp Physiol Neurobiol. 2006;154:515–23.
9. Petersson J, Rohdin M, Sánchez A, Nyrén S, Jacobsson H, Larsson S, Lindahl S, Linnarsson D, Neradilek B, Polissar N, Glenny R, Mure M. Regional lung blood flow and ventilation in upright humans studied with quantitative SPECT. Resp Physiol Neurobiol. 2009;166:54–60.
10. Petersson J, Rohdin M, Sánchez A, Hans SN, Larsson S, Lindhal S, Linnarsson D, Neradilek B, Polissar NL, Glenny R, Mure M. Posture primarily affects lung tissue distribution with minor effect on blood flow and ventilation. Resp Physiol Neurobiol. 2007;156:293–303.
11. West JB. Ventilation – perfusion inequality and overall gas exchange in computer models of the lung. Respir Physiol Neurobiol. 1969;7:88–110.
12. Montmerle S, Sundblad P, Linnarsson D. Residual heterogeneity of intra and interregional pulmonary perfusion in short term microgravity. J Appl Physiol. 2005;98: 2268–77.
13. Hlastala MP, Chormuck MA, Self DA. Pulmonary blood flow redistribution by increased gravitational force. J Appl Physiol. 1998;84:1278–88.
14. Altemeier WA, McKinney S, Krueger M, Glenny R. Effect of posture on regional gas exchange in pigs. J Appl Physiol. 2004;97:2104–11.
15. Hopkins S, Cortney-Henderson A, Levin D, Yamada K, Arai T, Buxton R, Prisk K. Vertical gradients in regional lung density and perfusion in the supine human lung: the Slinky effect. J Appl Physiol. 2007;103:240–8.
16. Altemeier W, McKinney S, Glenny R. Fractal nature of regional ventilation distribution. J Appl Physiol. 2000;88:1551–7.
17. Wagner W, Todoran T, Tanabe N, Wagner T, Tanner J, Glenny R, Presson R. Pulmonary capillary perfusion: intra – alveolar fractal patterns and interalveolar dependence. J Appl Physiol. 1999;86:825–31.
18. Capra F. The web of life – a new scientific understanding of living systems. New York: Anchor Books; 1996.