Impacts in the Respiratory Mechanics of the Ventilator Hyperinsuflation in the Flow Bias Concept: a Narrative Review

Impactos na Mecânica Respiratória da Técnica de Hiperinsuflação com Ventilador Mecânico no Conceito Flow Bias Cefálico: uma Revisão Narrativa

Jéssica dos Santos Pereira da Rosa Gonçalves; Walkiria Shimoya-Bittencourt; Viviane Martins Santos; Michel Belmonte

*University of Cuiabá, Physiotherapy Course. MT, Brazil.
*University of Cuiabá, Stricto Sensu Graduate Program in Environment and Health. MT, Brazil.
*E-mail: wshimoya@yahoo.com.br
Recebido em: 22/05/19
Aprovado em: 30/08/19

Abstract

Patients who require invasive ventilatory support are subject to the deleterious effects of this, mainly ventilator-associated pneumonia (VAP). The physiotherapist, a member of the multiprofessional team, assists the patient with the purpose of promoting the recovery and preservation of the functionality, being able to minimize / avoid secondary complications. This study aims to identify the repercussions of mechanical ventilation hyperinsuflation (MVH) in the flow bias concept in respiratory mechanics. This study is a narrative review. MVH is an important resource commonly used in clinical practice that involves the manipulation of mechanical ventilator configurations to provide larger pulmonary volumes, and the generated airflow gradient may play a relevant role in mucus transport, with the concept of flow bias the main factor responsible for its direction. For the mobilization of the mucus towards the cephalic direction to occur, there must be a predominant expiratory flow, guaranteeing the peak ratio of expiratory flow / inspiratory flow peak (EFP / IFP) greater than 1.11. Maintenance of mechanical ventilation assures the patient to maintain the positive end-expiratory pressure (PEEP) and the oxygen inspired fraction, avoiding the deleterious effects of the mechanical ventilator disconnection. MVH is able to improve lung compliance without, however, increasing airway resistance. MVH in the cephalic flow bias concept is effective for the mucus mobilization in the central direction, being able to improve pulmonary compliance and peripheral oxygen saturation.

Keywords: Respiration, Artificial. Intensive Care Units. Physical Therapy Department, Hospital.

Resumo

Os pacientes internados que necessitam de suporte ventilatório invasivo estão sujeitos aos efeitos deletérios deste, principalmente a pneumonia associada à ventilação mecânica (PAV). O fisioterapeuta, integrante da equipe multiprofissional, assiste o paciente com a finalidade de promover a recuperação e preservação da funcionalidade, podendo minimizar/evitar complicações secundárias. Este estudo consiste em identificar as repercussões da hiperinsuflação com ventilador mecânico (HVM) no conceito flow bias na mecânica respiratória. O presente estudo trata-se de uma revisão narrativa. A HVM é um importante recurso comumente utilizado na prática clínica que envolve a manipulação das configurações do ventilador mecânico para fornecer maiores volumes pulmonares, e o gradiente de fluxo de ar gerado pode desempenhar um papel relevante no transporte do muco, sendo o conceito de flow bias cefálico o principal fator responsável pelo direcionamento deste. Para que a mobilização do muco em direção cefálica ocorra, deve existir um fluxo expiratório predominante, garantindo a razão pico de fluxo expiratório/pico de fluxo inspiratório (EF/PFI) maior do que 1.11. A manutenção do assistência ventilatória mecânica assegura ao paciente a manutenção da pressão positiva ao final da expansão (PEEP) e a fração inspirada de oxigênio (FiO₂), evitando os efeitos deletérios da desconexão do ventilador mecânico. A HVM é capaz de melhorar a complacência pulmonar sem, no entanto, aumentar a resistência das vias aéreas. A HVM no conceito flow bias cefálico é eficaz para a mobilização do muco em direção central, sendo capaz de melhorar a complacência pulmonar e saturação periférica de oxigênio (SpO₂).

Palavras-chave: Respiração Artificial. Unidades de Terapia Intensiva. Serviço Hospitalar de Fisioterapia.

1 Introduction

Patients hospitalized in intensive care units (ICU) require, in their majority, invasive ventilatory support and, thus, are subject not only to the benefits of the institution of this support, such as the gas exchange maintenance and reduction of respiratory work, but also to the deleterious effects associated with it, such as the transport mechanism involvement, the mucociliary deprecation and cough inefectivity.

The application of positive pressure in the lungs, by means of a prosthesis, can generate systemic repercussions and, as a result of these prolong the hospitalization time, as well as increase the morbidity-mortality. Just as the mechanical ventilation, the immobility imposed on the patient for sedation and generalized muscle weakness contributes to the retention of secretions in the airways, resulting in partial or total obstruction, with consequent alveolar hypoventilation, development of atelectasis, hypoxemia and increased respiratory work. The anesthetics/sedatives often used in these conditions also lead to hypoventilation and hypoxemia, changing the pulmonary compliance, thereby inhibiting the physiological mechanism of cough, favoring the...
development of micro-organisms in these non-ventilated areas and resulting in pneumonia associated with mechanical ventilation (VAP)\textsuperscript{13,14}. VAP is one of the main factors that contribute to the increase of mortality, duration of ICU stay, duration of hospitalization and costs related to health\textsuperscript{10,15}. The estimate of mortality attributed to this infection varies in different studies, but approximately 33\% of patients with VAP die as a direct result of this, being translated into the prolongation of hospitalization for around 12 days and in increased costs around $40,000 per episode\textsuperscript{16}.

Among the complications, respiratory dysfunction is an important disease in ICU. Physiotherapy operates with the objective of promoting the pervious airways management, retain or recruit lung volumes, optimize oxygenation and prevent secondary respiratory complications\textsuperscript{17,18}. The hyperinflation technique is employed to treat the retention of secretions, reversal of atelectasis, optimize the pulmonary oxygenation, and has been routinely used by physiotherapists from the beginning of years 1970\textsuperscript{19,20}. The manual hyperinflation uses the resuscitation balloon and was described for the first time in the decade of 1960, while the hyperinflation with mechanical ventilator (HVM) is by comparison a relatively new technique and was first described in 2002, and again in 2006\textsuperscript{21-23}.

Therefore, the objective of this study is to identify the MVH repercussions in the cephalic flow bias concept on respiratory mechanics.

\section*{2 Development}
\subsection*{2.1 Methodology}

The present study is a narrative review on hyperinflation with mechanical ventilator in the cephalic flow bias concept and its impacts/effectiveness. The search for articles was performed in electronic databases Medline, Bireme, Lilacs, SciELO, PubMed and PEDro, covering both Portuguese and English languages and using the following descriptors: “Intensive Care Unit”, “Flow Bias”, “Static Complacency”, “Airway Resistance”, “Mechanical Hyperinflation” and “Secondary Pulmonary Complications”. Through the search procedure 84 publications were identified, initially, (in Portuguese language and English 64) potentially eligible for inclusion in this review.

The references that met the inclusion criteria were evaluated, regardless of the journal, namely: (a) sample should include patient belonging to the intensive therapy unit mechanically ventilated; (b) use of the HVM and pulmonary complications; (c) national/international data collection; (d) article/book of original research with humans - including review articles; (e) approval of the corresponding relevant ethics committee - for those who need them. Theses, Dissertations and Monographs are excluded, since the implementation of a systematic search of the same is impossible logistically.

\subsection*{2.2 Discussion}

According to Dennis et al.\textsuperscript{24} the physiotherapeutic intervention in the ICU is based on clinical reasoning after a complete and systematic evaluation is an integral component of the support for the management of these patients, boasting wide diversity of practices/techniques. However, currently in agreement with Dias et al.\textsuperscript{9}, Cerqueira et al.\textsuperscript{25} and Sricharoenchai et al.\textsuperscript{26} it has been debated extensively about the safety of the procedures application.

Since the decade of 1980, however, evidences emerged that the transport of secretions in the airways is influenced not only by the expiratory flow, but also by the relationship established between the inspiratory and expiratory flows, i.e., by the flow bias\textsuperscript{27}, and may change the layer of secretion covering the airways. In normal conditions, the diameter of the flexible airways increases during inspiration and decreases during expiration. This dynamic airways during the respiratory cycle causes acceleration of the expiratory air flow in relation to generating inspiratory flow, therefore, a cephalic flow bias, i.e., from distal to proximal direction\textsuperscript{28}.

HVM involves the manipulation of the mechanical ventilator settings to provide higher lung volumes. However, during mechanical ventilation, the air flows can play an important role in the transport of mucus and the concept of flow cephalic bias consisting of the expiratory flow acceleration in relation to the inspiratory flow, in virtue of the airway compression during expiration, which assists in the mucus displacement in the direction of the trachea\textsuperscript{28-30}.

The series of studies conducted in the decade of 1980 identified as critical threshold for the flow bias, the ratio between the expiratory flow (PEF) and the inspiratory flow peak (PFI) (ratio PEF/PFI) equal to 1.11. Being the ration PEF/PFI greater than 1.11 determines the secretion displacement toward the mouth (distal to proximal) and, less than 1.11 determines the secretion displacement toward inside the lungs (proximal to distal). This threshold can still be interpreted in another way, i.e., the mucus displacement occurs when one of the workflows achieves at least a value 10\% higher than the other, and the direction of travel shall be determined by the flow of greater value or a difference of PEF - PFI ≥ 17 L/min\textsuperscript{32}. And according to Thomas\textsuperscript{31}, in addition to the latter, there is also the reason PFI/PEF ≤ 0.9 and PEF ≥ 40 L/min.

HVM in the cephalic bias concept consists of increasing the current volume (VT) in the proportions of 10 to 20ml/kg based on the calculation of the weight predicted until the VT target or the limit of 40 cmH\textsubscript{2}O of prolonged $P_{\text{peak}}$, inspiratory time (Tinsp), constant flow, respiratory frequency (RF) of 6 - 8, FiO2 and unchanged PEEP\textsuperscript{12,20,27,30,32}. The goal is to generate the as high as possible PEF (by means of the adjustment of high current volume)\textsuperscript{32} and smaller PFI (through the increase of inspiratory time and the use of the square flow wave)\textsuperscript{12,30}.

Knowing only the respiratory system mechanics does not guarantee the safety of the technique, making it necessary...
the knowledge of the hemodynamic impacts of the technique used. Thus, some authors who studied HVM concluded that it produces no significant hemodynamic changes\textsuperscript{22,33}. Savian, et al.\textsuperscript{23} and Dennis et al.\textsuperscript{24} also corroborate the previous findings and affirm that HVM is safe and effective. Regarding the evaluation of SpO\textsubscript{2} showed an increase after the HVM, which may explain this finding due to the increased area available for gas exchanges\textsuperscript{25}.

Regarding the respiratory mechanics, studies have demonstrated a significant increase in lung compliance after the HVM\textsuperscript{23,34}. Other similar findings were found, attributing this increase in lung compliance due to the fact that the hyperinflation distributes better air flow, resulting in the collapsed lung re-expansion units\textsuperscript{23}. On the other hand, RaW showed no statistically significant variations\textsuperscript{32}.

The dynamics of the inspiratory and expiratory air flow generated by the inspiratory and expiratory adjustments in the mechanical ventilator can contribute substantially in the mucus movement, however this has little relevance in the clinical environment and deserves more recognition. So that the mucus mobilization in the cephalic direction occurs, there must be a predominant expiratory flow. In contrast, the persistent caudal migration can result in clinical consequences, because the relationship PEF/PFI lower than 1.11 favors the secretion displacement to the lungs interior\textsuperscript{29}.

Although it is not always possible to adjust an expiratory flow bias, it seems, at least interesting to seek to avoid or minimize the occurrence of an inspiratory flow bias, with the potential to promote the secretions movement toward inside the lungs. Therefore, some researchers suggest that the flow curves of the mechanical ventilator should also be analyzed/monitored in relation to the flow current in force and its possible action on the pulmonary secretions displacement\textsuperscript{35-37}.

Studies in animals and pulmonary models have demonstrated consistently that the bias of inspiratory or expiratory flow may result in liquid migration of mucus in the direction of the flow bias\textsuperscript{38-40}. Thus, Volpe et al.\textsuperscript{12} reaffirms that the bias of flow obtained with the fan settings can clear or incorporate the mucus during the mechanical ventilation.

For physiological explanation of the technique HVM, Chaves et al.\textsuperscript{32}, is based on the principle of presence of the Hering-Breuer reflex that allows the use of momentary current volumes higher than those recommended in the literature, generating a more effective expiratory flow peak for the removal of secretions in the airways of intubated and mechanically ventilated patients. The results of this study showed that the HVM increased the expiratory flow without modifying hemodynamic parameters of patients hospitalized in the ICU. Conversely, smaller PFI is resulting from increased inspiratory time and the use of square wave flow\textsuperscript{27}. However, the square wave flow is restricted to volumetric modes.

It is important to remember that the mechanical properties of the respiratory system can exert some influence in the PFI only during the ventilatory modes at pressure\textsuperscript{27} and depend mainly on the impedance which, in turn, is directly proportional to the airways resistance\textsuperscript{31}. During the pressure modes, the reduction of PFI can be obtained by means of decrease in inspiratory pressure (pressure delta) and by slowing the speed of the inspiratory flow (reduction of rail, slope or rise time - depending on the fan). However, the first adjustment reduces the current volume, which also reduces the PEF, and may annul the effect of inspiratory pressure reduction on the resulting flow bias and can also generate discomfort to the patient. Another unfavorable factor is that in spontaneous ventilation, the patient exercises control over the inspiratory and expiratory flows; therefore, undertakes the maintenance of a cephalic flow bias\textsuperscript{27}.

There is a variety of ventilation modes used for the HVM Dennis et al.\textsuperscript{24} and Hayes et al.\textsuperscript{19}. However, Thomas\textsuperscript{31} conducted a limited survey to guide the selection of the HVM settings to optimize their application for the secretions mobilization, analyzing the PFI and PEF generated during the HVM performed in different ventilation modes, in order to provide recommendations to guide the application of the technique. The results suggest that the SIMV-V mode is more successful than the PSV and SIMV-P, by achieving the ratio bias PFI/PEF ≤ 0.9, this being this the main factor in comparison with other modes, generating gradients of desired flows, in addition to gathering a greater proportion of tests with characteristics of ideal flows (PFI/PEF ≤ 0.9 = 80%; PEF -PFI ≥ 5.30 L/min= 47%, PEF ≥ 40L/min = 69% and all the three previous properties= 47% of the samples).

Regarding the PEEP, since the inspired volume is maintained, its setting does not influence the PEF therefrom, with the exception of patients with unstable airways, in which PEEP may result in an increase of the PEF by preventing the collapse of dynamic airways\textsuperscript{30}. When the use of high PEEP and FiO2 are necessary, the HVM should preferably be used in detriment of the technique of manual hyperinflation Ortiz et al.\textsuperscript{41} In severe patients, the physiotherapist must monitor the pressures, volumes and flows used during the technique, thus allowing a better adjustment of the same Berney and Deneby\textsuperscript{42}. Beyond the control of ventilatory parameters, especially the mean pressure, current volume and peak pressure, the HVM when used properly is a safe alternative to allow the patients’ maintenance in mechanical ventilation throughout the maneuver, assuring the FIO2 and PEEP Guimarães and Lemes\textsuperscript{43} and avoiding the adverse effects of disconnecting the fan, such as the loss of functional residual capacity (FRC), decreased oxygenation and increased shear stress of distal lung units\textsuperscript{19,44-46}. Another factor to be considered is that when performing the HVM the professional assistant prevents the contamination associated with the disconnection of the ventilatory circuit\textsuperscript{47}, as well as reducing the chances of transmissions of infection both for the patient and for the care team\textsuperscript{20,24}.
3 Conclusion

HVM in the cephalic flow bias is safe and effective when performed in a thorough and concise way, allowing a cephalic expiratory flow gradient and contributing with the secretion carriage. After the completion of the HVM there was an increase in lung compliance, inferring about the recruitment of previously collapsed areas by atelectasis and/or secretion.

References

1. Ciesla ND. Chest physical therapy for patients in the intensive care unit. Phys Ther 1996;76(6):609-25. doi: 10.1093/ptj/76.6.609
2. McCarren B, Alison JA, Herbert RD. Manual vibration increases expiratory flow rate via increased intrapleural pressure in healthy adults: an experimental study. Aust J Physiother2006;52(4):267-71.
3. Jerre G, Silva TJ, Beraldo MA, Gastaldi A, Kondo C, Leme F et al. Fisioterapia no paciente sob ventilação mecânica. J Bras Pneumol 2007;33:142-50. doi: 10.1590/S1806-37132007000800010.
4. Gosselink R, Bott J, Johnson M, Dean E, Nava S, Norrenberg M, et al. Physiotherapy for adult patients with critical illness: recommendations of the European Respiratory Society and European Society of Intensive Care Medicine Task Force on Physiotherapy for Critically Ill Patients. Int Care Med 2008;34(7):1188-99. doi: 10.1007/s00134-008-1026-7.
5. Esteban A, Anzueto A, Frutos F, Alia I, Brochard L, Stewart TE, et al. Mechanical Ventilation International Study Group. Characteristics and outcomes in adult patients receiving mechanical ventilation: a 28-day international study. JAMA 2002;287(3):345-55.
6. Carvalho CRR. Pneumonia associada à ventilação mecânica. J Bras Pneumol 2006;32(4):20-2.
7. Esteban A, Frutos-Vivar F, Muriel A, Ferguson ND, Peñuelas O, Abraira V, et al. Evolution of mortality over time in patients receiving mechanical ventilation. Am J Respir Crit Care Med 2013;188(2):220-30. doi: 10.1164/rcm.201212-2169OC
8. Dias CM, Siqueira TM, Faccio TR, Gontijo LC, Salge JASB, Volpe MS. Efetividade e segurança da técnica de higiene brônquica: hiperinsuflação manual com compressoratorácico. Rev Bras Ter Intensiva 2011;23(2):190-8. doi: 10.1590/S0103-507X2011000200012.
9. Fraça EET, Ferrari F, Fernandes P, Cavalcanti R, Duarte A, Martinez BP, et al. Fisioterapia em pacientes críticos adultos: recomendações do Departamento de Fisioterapia da Associação de Medicina Intensiva Brasileira. Rev Bras Ter Intensiva 2012;24(1):6-22. doi: 10.1590/S0103-507X2012000100003.
10. Oliveira J, Zagalo C, Cavocho-Silva P. Prevention of ventilator-associated pneumonia. Rev Port Pneumol 2014;20:152-61. doi: 10.1016/j.rppneu.2014.01.002
11. Guglielmintoni J, Alzlieu M, Maury E, Guidet B, Offenstadt S, et al. Intubated intensive care patients. Heart Lung 2006;35(5):334-41. doi: 10.1016/j.hrtlng.2006.02.003
12. Dennis D, Jacob W, Budgeon C. Ventilator versus manual hyperinflation in clearing sputum in ventilated intensive care unit patients. Anaesth Intensive Care 2012;40(1):142-9. doi: 10.1177/0310057X1204000117
13. Clement AJ, Hübisch SK. Chest physiotherapy by the ‘bag squeezing’ method: a guide to technique. Physiotherapy 1968;54(10):355-9.
14. Berney S, Denehy L. A comparison of the effects of manual and ventilator hyperinflation on static lung compliance and sputum production in intubated and ventilated intensive care patients. Physiother Res Int 2002;7(2):100-8.
15. Savian C, Paratz J, Davies A. Comparison of the effectiveness of manual and ventilator hyperinflation at different levels of positive end-expiratory pressure in artificially ventilated and intubated intensive care patients. Heart Lung 2006;35(5):334-41. doi: 10.1179/108331906X98921
16. Volpe MS. Efetividade e segurança da técnica de higiene brônquica: hiperinsuflação manual com compressoratorácico. Rev Bras Ter Intensiva 2012;24(1):6-22. doi: 10.1590/S0103-507X2012000100003.
17. Oliveira J, Zagalo C, Cavocho-Silva P. Prevention of ventilator-associated pneumonia. Rev Port Pneumol 2014;20:152-61. doi: 10.1016/j.rppneu.2014.01.002
18. Guglielmintoni J, Alzlieu M, Maury E, Guidet B, Offenstadt S, et al. Intubated intensive care patients. Heart Lung 2006;35(5):334-41. doi: 10.1016/j.hrtlng.2006.02.003
19. Dennis D, Jacob W, Budgeon C. Ventilator versus manual hyperinflation in clearing sputum in ventilated intensive care unit patients. Anaesth Intensive Care 2012;40(1):142-9. doi: 10.1177/0310057X1204000117
20. Clement AJ, Hübisch SK. Chest physiotherapy by the ‘bag squeezing’ method: a guide to technique. Physiotherapy 1968;54(10):355-9.
21. Berney S, Denehy L. A comparison of the effects of manual and ventilator hyperinflation on static lung compliance and sputum production in intubated and ventilated intensive care patients. Physiother Res Int 2002;7(2):100-8.
22. Savian C, Paratz J, Davies A. Comparison of the effectiveness of manual and ventilator hyperinflation at different levels of positive end-expiratory pressure in artificially ventilated and intubated intensive care patients. Heart Lung 2006;35(5):334-41. doi: 10.1179/108331906X98921
23. Volpe MS. Ajuste do flow bias – relação entre os fluxos inspiratório e expiratório para remoção de secreção em pacientes críticos adultos. In: Associação Brasileira de Fisioterapia Cardiorespiratória e Fisioterapia em Terapia Intensiva. PROFISIO Programa de Atualização em Fisioterapia em Terapia Intensiva Adulto: Ciclo 6. Porto Alegre: Artmed Panameri- cana; 2015. p. 95-109.
24. Fink JB. Forced expiratory technique, directed cough, and autogenic drainage. Respir Care 2007;52(9):1210-21.
25. Ntoumenopoulos G, Shannon H, Main E. Do commonly used
ventilator settings for mechanically ventilated adults have the potential to embed secretions or promote clearance? Respir Care 2011;56(12):1887-92. doi: 10.4187/respcare.01229.

30. Li Bassi G, Saucedo L, Marti JD, Rigol M, Esperatti M, Luque N, et al. Effects of duty cycle and positive end-expiratory pressure on mucus clearance during mechanical ventilation*. Crit Care Med 2012;40(3):895-902. doi: 10.1097/ CCM.0b013e318236efb5.

31. Thomas PJ. The effect of mechanical ventilator settings during ventilator hyperinflation techniques: a bench-top analysis. Anaesth Intensive Care 2015;43(1):81-7. doi: 10.1177/0310057X1504300112

32. Chaves MJ, Pedreira MJR, Felix JE, Alcino Filho C, Baptista AF. A hiperinsuflação pulmonar induzida pelo ventilador mecânico em paciente intubados como terapia de higiene brônquica. Rev Pesq Fisioter 2016;6(3):291-7. doi: 10.17267/2238-2704rfp.v6i3.1011

33. Naue WS, Forgiarini Junior LA, Dias AS, Vieira SR. Chest compression with a higher level of pressure support ventilation: effects on secretion removal, hemodynamics, and respiratory mechanics in patients on mechanical ventilation. J Bras Pneumol 2014;40(1):55-60. doi: 10.1590/S1806-37132014000100008.

34. Lemes DA, Zin WA, Guimaraes FS. Hiperinfiltração pressure support ventilation improves secretion clearance and respiratory mechanics in ventilated patients with pulmonary infection: a randomised crossover trial. Aust J Physiother 2009;55(4):249-54.

35. Ntoumenopoulos G. Mucous move: embed it or expel it-the patient, the clinician, and now the ventilator. Respir Care 2008;53(10):1276-9.

36. Zanella A, Bellani G, Pesenti A. Airway pressure and flow monitoring. Current Opinion in Critical Care 2010;16(3):255-60.

37. Volpe MS, Amato MB. Is it time to monitor flow bias during mechanical ventilation? Respir Care 2011;56(12):1970-1. doi: 10.4187/respcare.01643.

38. Kim CS, Iglesias AJ, Sackner MA. Mucus clearance by two-phase gas-liquid flow mechanism: asymmetric periodic flow model. J Appl Physiol (1985) 1987;62(3):959-71. doi: 10.1152/jappl.1987.62.3.959

39. Benjamin RG, Chapman GA, Kim CS, Sackner MA. Removal of bronchial secretions by two-phase gas-liquid transport. Chest 1989;95(3):658-63. doi: 10.1378/chest.95.3.658

40. Freitag L, Long Wm, Kim Cs, Wanner A. Removal of excessive bronchial secretions by asymmetric high-frequency oscillations. J Appl Physiol 1989;67(2):614-9.

41. Ortiz TA, Forti G, Volpe MS, Carvalho CRR, Amato MBP, Tucci MR. Experimental study on the efficiency and safety of the manual hyperinflation maneuver as a secretion clearance technique. J Bras Pneumol 2013;39(2):205-13. doi:10.1590/S1806-37132013000200012.

42. Berney S, Denehy L, Pretto J. Head-down tilt and manual hyperinflation enhance sputum clearance in patients who are intubated and ventilated. Aust J Physiother 2004;50(1):9-14.

43. Guimarães F, Lemes DH. Hiperinsuflação terapêutica em terapia intensiva. In: Associação Brasileira de Fisioterapia Cardiorrespiratória e Fisioterapia em Terapia Intensiva; PRO-FISIO Programa de Atualização em Fisioterapia em Terapia Intensiva Adulto: Ciclo 6. Porto Alegre: Artmed Panamericana; 2015.p.139-151.

44. Lindberg P, Gunnarsson L, Tokics L, Andersson T, Stranberg A, Brismar B, Hedenstierna G. Atelectasis and lung function in the postoperative period. Acta Anaesthesiol Scand 1992;36(6):546-53.

45. Hedenstierna G, Tokics L, Lundquist H, Brismar B. Phrenic nerve stimulation during halothane anesthesia. Anesthesiology 1994;80(4):751-60.

46. McCann UG, Schiller HJ, Carney DE, Gatto LA, Steinberg JM, Nieman GF. Visual validation of the mechanical stabilizing effects of positive end-expiratory pressure at the alveolar level. J Surg Res 2001;99(2):335-42. doi: 10.1006/jscr.2001.6179.

47. Assmann CB, Vieira PJC, Kutchak F, Rieder MM, Forgiarini SGI, Forgiarini Junior LA. Hiperinsuflação pulmonar com ventilador mecânico versus aspiração traqueal isolada na higiene brônquica de pacientes submetidos à ventilação mecânica. Rev Bras Ter Intensiva 2016;28(1):27-32. doi:10.5935/0103-507X.20160010.