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Comparative analysis between the alveolar recruitment maneuver and breath stacking technique in patients with acute lung injury

Análise comparativa entre a manobra de recrutamento alveolar e a técnica de breath stacking em pacientes com lesão pulmonar aguda

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ABSTRACT

Objective: To compare the effectiveness of the alveolar recruitment maneuver and the breath stacking technique with respect to lung mechanics and gas exchange in patients with acute lung injury.

Methods: Thirty patients were distributed into two groups: Group 1 - breath stacking; and Group 2 - alveolar recruitment maneuver. After undergoing conventional physical therapy, all patients received both treatments with an interval of 1 day between them. In the first group, the breath stacking technique was used initially, and subsequently, the alveolar recruitment maneuver was applied. Group 2 patients were initially subjected to alveolar recruitment, followed by the breath stacking technique. Measurements of lung compliance and airway resistance were evaluated before and after the use of both techniques. Gas analyses were collected before and after the techniques were used to evaluate oxygenation and gas exchange.

Results: Both groups had a significant increase in static compliance after breath stacking ($p=0.021$) and alveolar recruitment ($p=0.03$), but

with no significant differences between the groups ($p=0.95$). The dynamic compliance did not increase for the breath stacking ($p=0.22$) and alveolar recruitment ($p=0.074$) groups, with no significant difference between the groups ($p=0.11$). The airway resistance did not decrease for either groups, i.e., breath stacking ($p=0.91$) and alveolar recruitment ($p=0.82$), with no significant difference between the groups ($p=0.39$). The partial pressure of oxygen increased significantly after breath stacking ($p=0.013$) and alveolar recruitment ($p=0.04$), but there was no significant difference between the groups ($p=0.073$). The alveolar-arterial O_2 difference decreased for both groups after the breath stacking ($p=0.025$) and alveolar recruitment ($p=0.03$) interventions, and there was no significant difference between the groups ($p=0.81$).

Conclusion: Our data suggest that the breath stacking and alveolar recruitment techniques are effective in improving the lung mechanics and gas exchange in patients with acute lung injury.

Keywords: Positive-pressure respiration/methods; Respiratory mechanics; Breathing exercises; Pulmonary gas exchange; Physical therapy modalities

Conflicts of interest: None.

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INTRODUCTION

Patients who undergo general surgery have a high incidence of respiratory complications, such as progressive reduction of lung compliance, atelectasis, pneumonia, tracheobronchial infections and prolonged mechanical ventilation.⁽¹⁻³⁾ The incidence of these postsurgical complications ranges from 17% to 88% of the cases.⁽¹⁾ Complications occur due to decreased mucociliary clearance and reduction of lung capacity and volumes.⁽⁴⁾

These postsurgical complications are usually treated in the intensive care unit (ICU), where the presence of the physical therapist has become common. However, the effectiveness of physical therapy during the postoperative period is still controversial. Some authors have reported only a prophylactic efficacy of the treatment.⁽¹⁾ Conversely, other researchers have demonstrated the effectiveness of treatments such as bronchial hygiene and lung re-expansion for the clinical improvement of atelectasis, pneumonia, lung compliance and lung capacities.⁽⁵⁻⁷⁾ Other methods were already considered effective in promoting improvements to collapsed areas of the lung, such as treatment with positive-end expiratory pressure (PEEP), deep-breathing exercises, lung expansion and re-expansion, inspiratory obstruction, intermittent positive pressure, incentive spirometry and chest physical therapy.⁽¹⁾ However, there are few studies proving the efficacy of the individual techniques.⁽⁵⁾

The alveolar recruitment maneuver (ARM) has been used to reverse atelectatic areas.^(4,8-10) ARM can be performed using different techniques, which consist of increasing the lung volume or pressure and inverting the inspiration-expiration ratio (I:E).^(4,8-11) Bittencourt⁽⁸⁾ has reported greater effectiveness in increasing the lung volume or pressure when using extrinsic PEEP.

Another technique used in lung re-expansion that has been proven effective is the breath stacking (BS) technique, described by Marini in 1986, which yields good results in terms of improved oxygenation in patients with atelectasis.⁽¹⁾ However, the effects of this technique on respiratory mechanics in patients with severely impaired lung function must still be evaluated, which may contribute to important decisions in clinical practice.

Therefore, the present study aimed to compare, in relation to conventional physical therapy, the effectiveness of the BS and ARM techniques in lung mechanics and gas exchange in patients with acute lung injury.

METHODS

The present investigation was a crossover study conducted in the ICU of a public hospital in São Paulo (*Hospital Regional Sul*), from June 2009 to June 2011. The project was analyzed and the study was approved by the Research Ethics Committee of the hospital (no. 407/13). All family members or guardians of the patients involved in the present study signed an informed consent form after being duly informed of the procedures and interventions performed.

Patients meeting the following criteria were included in the present study: from both genders; over 18 years of age; in the postoperative period of surgery requiring general anesthesia, with involvement of at least two quadrants in the chest radiograph, oxygenation index <200, orotracheal intubation, sedation, indication for respiratory physical therapy and hemodynamically stable without the use of vasoactive drugs; and whose guardian signed the informed consent form.

The exclusion criteria consisted of patients with severe traumatic brain injury with intracranial hypertension, cardiogenic and/or hypovolemic shock, preexisting cardiac disease, renal failure (creatinine >1.3) and cardiac arrhythmia.

The study followed a protocol for recording (on a specific evaluation form) data from all participating subjects, including name, age, gender, weight, height, body mass index (BMI) and diagnosis. All individuals underwent conventional chest physical therapy, using maneuvers to remove bronchial secretions, followed by aspiration of the orotracheal tube using an open and sterile system.

After this procedure and having met all the inclusion criteria, the patients were randomly assigned to two groups. Patients from the first group (BS group) underwent conventional chest physical therapy combined with the BS technique. On the next day, they received conventional chest physical therapy combined with ARM. Patients from the second group (ARM group) were subjected to conventional respiratory physical therapy combined with ARM, and on the next day, they received conventional respiratory physical therapy combined with BS.

During the application of the techniques, the patients received volume-controlled mechanical ventilation, and the following parameters were maintained: tidal volume of 8mL/kg, PEEP of 8cmH₂O, fraction of inspired oxygen (FiO₂) of 100% and respiratory rate of 12 breaths per minute.

After conventional respiratory physical therapy, lung mechanics data (static compliance of the respiratory system - C_{st}, dynamic compliance of the respiratory system - C_{dyn} and airway resistance - R_{sr}) were collected using the Dixtal DX3010 device. Concurrently, an arterial blood sample was collected from the radial artery for analysis of arterial blood gases (partial pressure of oxygen - PaO₂ and partial pressure of carbon dioxide - PaCO₂) and of arterial oxygen saturation (SaO₂). Subsequently, the patients were randomly subjected to ARM or BS.

To assess the effect of the intervention, the subjects were reassessed after the technique was applied, and lung mechanics data were again collected using the same device. Subsequently, another blood sample was collected for arterial blood gas analysis. The time interval between the blood collections for arterial blood gas analysis and the intervention was 10 minutes. The procedures were performed in reverse order on the next day.

BS was performed at the bedside with the patient in a 45° supine position.⁽¹²⁾ The technique consists of occluding the expiratory limb of the mechanic ventilator circuit with the subject performing repetitive inspiratory efforts for 20 seconds; subsequently, the expiratory limb is released, and the subject expires freely. The technique was performed six consecutive times, totaling 120 seconds with an interval of 2 minutes between applications.

ARM was performed at the bedside with the patient in a 45° supine position. The technique consisted of raising PEEP to the optimal level previously determined by calculating the progressive PEEP.⁽¹²⁾ Based on the optimal PEEP, PEEP was raised 2cmH₂O at a time until achieving the best lung compliance. The lowest PEEP that produced the best lung compliance was used to perform the ARM,⁽¹³⁾ which was applied for 30 seconds in four series, also totaling 120 seconds of recruitment.

To assess the lung mechanics, the individual was precluded from performing spontaneous breaths. If the individual had a respiratory drive, then sedation was increased under medical prescription.

Statistical analysis

The data obtained are expressed as the mean and standard deviation. Data symmetry was analyzed using the Kolmogorov-Smirnov test. Lung mechanics variables before and after application of the BS or ARM techniques were analyzed for all patients (n=30) using the paired *t* test. To compare the delta lung mechanics (pre minus post BS or ARM) between the two groups (n=15), the unpaired *t* test was used. Differences were considered significant when $p < 0.05$.

The sample was calculated considering $\alpha = 0.05$, with a statistical power of 80% ($\beta = 0.20$), and considering a difference of 4cmH₂O between the lung compliance before and after application of the technique as improved lung mechanics, with a standard deviation of 5.4 units. To answer the main research question, the sample size calculation revealed that 19 patients per group would have to be evaluated.

RESULTS

The sample consisted of 30 patients, distributed into two groups of 15 patients each. The mean age was 49.8 years, and 80% of the patients were male. The groups were homogeneous regarding age, gender, BMI and diagnosis (Table 1). In all cases, there was no need to increase the sedation because the patients did not have a respiratory drive at the moment of data collection.

Table 1 - Clinical and demographic characteristics of the breath stacking and alveolar recruitment groups on the first day of application of the techniques

Variables	BS (N=15)	ARM (N=15)	p value
Age (years)	49.8±12	47±11	0.99
Males (%)	80	80	
BMI (kg/m ²)	26.4±3.2	25.1±3.5	0.99
Cst (cm H ₂ O)	35±5.8	31.9±6.7	0.3
Cdyn (cm H ₂ O)	24.4±2.6	23.2±4.3	0.7
Raw (ml/cm H ₂ O)	18±8	15±5.2	0.32
PaCO ₂ (mmHg)	41.6±16.2	40.9±11.8	0.6
A-a (mmHg)	527.7±25.3	527.6±32	0.8

BS - breath stacking; ARM - alveolar recruitment maneuver; BMI - body mass index; Cst - Static compliance; Cdyn - dynamic compliance; Raw - airway resistance; PaCO₂ - partial pressure of carbon dioxide in arterial blood; A-a - alveolar-arterial. Data are expressed as the mean±standard deviation.

Immediately after the BS technique was applied, the patients exhibited an improvement in Cst from 35±5.8mL/cmH₂O to 40.7±7mL/cmH₂O ($p = 0.021$). For ARM, there was an improvement in Cst from 31.9±6.8mL/cmH₂O to 38.6±9.2 mL/cmH₂O ($p = 0.03$) immediately after the technique was used. The delta improvement (pre minus post) of Cst was similar for both groups ($p = 0.95$) (Figure 1).

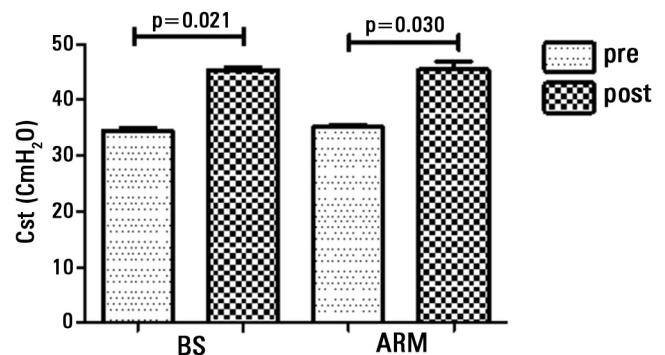


Figure 1 - Evaluation of static compliance of the respiratory system for the pre- and post-intervention groups. Cst - static compliance.

The mean C_{dyn} was 24.5±3.4mL/cmH₂O and 26.2±4.2mL/cm H₂O before and after BS was used, respectively (p=0.222). Moreover, there was no improvement before and after ARM was applied, with mean of 23.2±4.3mL/cmH₂O and 26.6±5.8mL/cmH₂O, respectively (p=0.074). No significant difference was found between the deltas (pre minus post) of the groups (p=0.11).

The mean R_{sr} before and after the techniques were applied was 18.2±8mL/cmH₂O and 18.5±8.1mL/cmH₂O, respectively (p=0.914). For ARM, the mean R_{sr} decreased from 15±5.3mL/cmH₂O before the technique was used to 14.6±5.1mL/cmH₂O after it was applied (p=0.821). No significant difference was found between the deltas (pre minus post) of the groups (p=0.39).

Regarding oxygenation, the use of BS significantly improved PaO₂, from 91.1±19.1mmHg to 113.3±26.2mmHg (p=0.013). Similarly, oxygenation improved significantly after ARM was used, from 84.2±29 mmHg to 102.8±18.7mmHg (p=0.046) (Figure 2). The delta PaO₂ (pre minus post) was similar between the BS (p=0.073) and ARM (p=0.32) groups. Regarding PaCO₂, BS caused a non-significant reduction from 41.6±16.2mmHg to 39.7±23.4mmHg (p=0.796). By contrast, after ARM was used, there was a non-significant increase from 40.9±11.8mmHg to 47.2±22.3mmHg (p=0.396). The delta PaCO₂ (pre minus post) was similar between the groups (p=0.117).

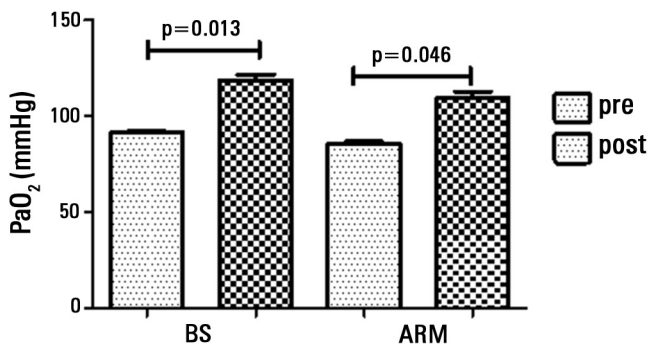


Figure 2 - Evaluation of the arterial oxygen pressure in the pre- and post-intervention groups. PaO₂ - partial pressure of oxygen.

The alveolar-arterial oxygen pressure difference (P(A-a)O₂) decreased significantly after BS was applied, from 527.7±33.8 to 500.1±30.2 (p=0.025). After ARM was used, the (P(A-a)O₂) difference decreased from 527.6±34.3 to 501.2±25.7 (p=0.034). The P(A-a)O₂ difference was similar between the groups immediately after the techniques were applied (p=0.813) (Figure 3).

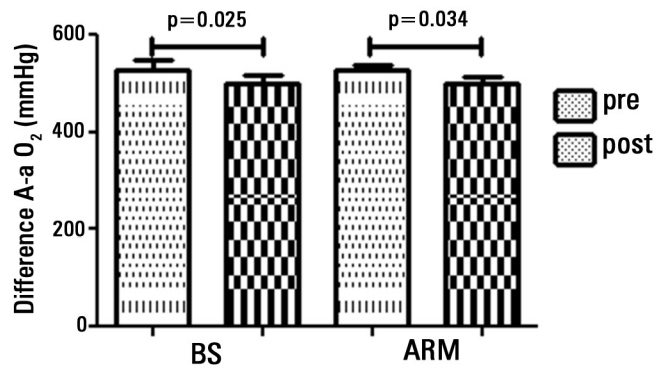


Figure 3 - Distribution of the alveolar-arterial O₂ difference at two time points: before and after application of the techniques in groups I and II.

DISCUSSION

The present study showed that both the BS and ARM techniques led to improved lung mechanics in patients with acute lung injury. However, C_{dyn} did not improve with the use of these techniques.

The differential of the present study was the adaptation of the BS technique in the orotracheal tube. This technique consists of occluding the patient’s mask at expiration. Thus, the expiratory limb of the ventilator was occluded in the intubated patient. In cases where the threshold pressure was reached, the ventilator cycled continuously for 20 seconds, when the valve was then released. Studies of BS have not evaluated the lung compliance and oxygenation of patients subjected to this technique; the present investigation is the first study to assess these features.

Previous research has revealed that respiratory disorders that occur after surgery with general anesthesia include reduced lung volumes and capacities, progressively reduced lung compliance, atelectasis, pneumonia, tracheobronchial infection, acute respiratory failure, hypoventilation, pleural effusion, bronchospasm, hypoxemia, respiratory failure, bronchitis, decreased effectiveness of cough and prolonged mechanical ventilation.⁽¹⁻⁴⁾ The Third Brazilian Consensus on Mechanical Ventilation complements these findings by stating that atelectasis occurs in dependent areas immediately after the establishment of general anesthesia.⁽¹¹⁾ These complications are mainly related to decreased mucociliary clearance,⁽¹⁴⁾ decreased lung volume and alveolar collapse. The present study used the BS and ARM techniques, aiming to improve the respiratory mechanics by reverting alveolar collapse and increasing the inspired lung volume, thereby improving lung compliance and R_{sr}, in addition to reverting hypoxemia in patients with

acute lung injury. The results demonstrated that using both techniques promoted an improvement in Cst, increased oxygenation and reduced the alveolar-arterial O₂ difference.

The BS technique was corroborated by two studies. One showed that the technique increases the amplitude and duration of thoracic expansion,^(1,15) whereas the second study revealed that BS increases lung volumes.⁽¹⁾ Other investigations compared the effect of high inspiratory volumes sustained in pauses of up to 5 seconds and volumes without inspiratory pauses and found a reversible effect for atelectasis in patients who were in the inspiratory pause group.^(14,15)

A study⁽¹⁵⁾ of 26 patients who underwent surgery showed that BS increases the inspiratory volume, and other investigations demonstrated an increase of 15% to 20% in lung volumes.⁽¹⁶⁻¹⁹⁾ Reolon et al.⁽²⁰⁾ found a mean increase of 58% in the inspiratory volume and reversal of atelectatic areas. Another research group⁽²¹⁾ observed improved respiratory muscle strength in individuals subjected to the BS technique. This improvement causes increased chest expansion, thus increasing static and dynamic lung compliance and oxygenation, as well as reversing atelectasis.⁽¹⁸⁻²³⁾

Certain methods have been discussed regarding ARM. Authors report the use of 30 and 40cmH₂O PEEP. Others, however, report a 15cmH₂O delta, not allowing the peak pressure to exceed 40cmH₂O. This fact indicates that the literature on postoperative ARM is still controversial, especially regarding the method of progressive PEEP increases. The Third Brazilian Consensus on Mechanical Ventilation states that ARM has a grade B recommendation because it reverses postoperative atelectasis.⁽¹¹⁾ Our results showed that ARM also improves static compliance and oxygenation and reduces the alveolar-arterial O₂ difference. This most likely occurred because the lung areas were recruited and began to display a better ventilation-perfusion ratio.

ARM not only reverses the atelectasis processes but also decreases the patient's time on mechanical ventilation, thereby decreasing lung injuries caused by prolonged mechanical ventilation.⁽²⁾ However, alveolar collapse followed by distension repeatedly causes deleterious effects on the lung parenchyma because it creates shear forces in the alveolar wall, thus increasing the release of inflammatory mediators and aggravating the injury.⁽⁹⁾ Therefore, the use of ARM does not have the expected effect unless used with alveolar stabilization techniques.⁽¹¹⁾ It has also been shown that employing other techniques, such as continuous positive airway pressure (CPAP), also reduces the hospitalization time.⁽²⁴⁾ A study confirmed this fact by showing that the oxygenation index and shunt values return to baseline values 30 minutes after the application of ARM.⁽²⁰⁾ Another investigation demonstrated that employing these techniques may reduce the duration of mechanical ventilation and the length of the ICU stay.⁽²¹⁾

The present study has several limitations. The sample was not sufficient to provide statistical power to our results because 19 patients per group were necessary and our groups comprised only 15 patients. Moreover, the study was not blind and was conducted at a single center. The results consist of short-term outcomes and cannot be extrapolated to medium-term periods, especially for the gas exchange and lung mechanics variables. Moreover, no clinical outcome was evaluated. We suggest that additional investigations with larger samples and more comprehensive measures of lung mechanics be performed.

CONCLUSION

The assessment of lung mechanics in a group of acute-lung-injury patients older than 35 years suggested that the breath stacking and alveolar recruitment maneuver techniques are effective in improving lung mechanics and gas exchange.

RESUMO

Objetivo: Comparar a eficácia da manobra de recrutamento alveolar e a técnica de *breath stacking*, na mecânica pulmonar e na troca gasosa, em pacientes com lesão pulmonar aguda.

Métodos: Trinta pacientes foram distribuídos em dois grupos: Grupo 1 - *breath stacking* e Grupo 2 - manobra de recrutamento alveolar. Após receberem atendimento de fisioterapia convencional, todos os pacientes receberam ambos os tratamentos, com intervalo de 1 dia entre eles. No primeiro

grupo foi aplicada primeiramente a técnica de *breath stacking* e, posteriormente, a manobra de recrutamento alveolar. Já os pacientes do segundo Grupo 2 foram submetidos inicialmente ao recrutamento alveolar e, após, a técnica de *breath stacking*. Foram avaliadas as medidas de complacência pulmonar e de resistência de vias aéreas antes e após a aplicação de ambas as técnicas. Foram coletadas gasometrias arteriais pré e pós-técnicas para avaliar a oxigenação e a troca gasosa.

Resultados: Ambos os grupos apresentaram aumento significativo da complacência estática após *breath stacking*

($p=0,021$) e recrutamento alveolar ($p=0,03$), mas não houve diferença entre eles ($p=0,95$). A complacência dinâmica não aumentou para os grupos *breath stacking* ($p=0,22$) e recrutamento alveolar ($p=0,074$), sem diferença entre os grupos ($p=0,11$). A resistência de vias aéreas não diminuiu para ambos os grupos: *breath stacking* ($p=0,91$) e recrutamento alveolar ($0,82$), sem diferença entre os grupos $p=0,39$. A pressão parcial de oxigênio aumentou significativamente após *breath stacking* ($p=0,013$) e recrutamento alveolar ($p=0,04$); mas entre os grupos não houve diferença ($p=0,073$). A diferença alvéolo

arterial de O_2 diminuiu para ambos os grupos após intervenções *breath stacking* ($p=0,025$) e recrutamento alveolar ($p=0,03$), não sendo diferente entre os grupos ($p=0,81$).

Conclusão: Nossos dados sugerem que as técnicas *breath stacking* e de recrutamento alveolar são eficazes em melhorar a mecânica pulmonar e a troca gasosa em pacientes com lesão pulmonar aguda.

Descritores: Respiração com pressão positiva/métodos; Mecânica respiratória; Exercícios respiratórios; Troca gasosa pulmonar; Modalidades de fisioterapia

REFERENCES

- Dias CM, Plácido TR, Ferreira MF, Guimarães FS, Menezes SL. Inspirometria de incentivo e breath stacking: repercussões sobre a capacidade inspiratória em indivíduos submetidos à cirurgia abdominal. *Rev Bras Fisioter.* 2008;12(2):94-9.
- Malbouissou LM, Humberto F, Rodrigues RR, Carmona MJ, Auler Júnior JO. Atelectasias durante anestesia: fisiopatologia e tratamento. *Rev Bras Anestesiol.* 2008;58(1):73-83.
- Filardo FA, Faresin SM, Fernandes AL. Validade de um índice prognóstico para ocorrência de complicações pulmonares no pós-operatório de cirurgia abdominal alta. *Rev Assoc Med Bras.* 2002;48(3):209-16.
- Auler Júnior JO, Nozawa E, Toma E, Kobayashi E, Degaki KL, Feltrim MI, et al. Manobra de recrutamento alveolar na reversão da hipoxemia no pós-operatório imediato em cirurgia cardíaca. *Rev Bras Anestesiol.* 2007;57(5):476-88.
- 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 Supl 2:S142-50.
- Leguisamo CP, Kalil RA, Furlani AP. A efetividade de uma proposta fisioterapêutica pré-operatória para cirurgia de revascularização do miocárdio. *Rev Bras Cir Cardiovasc.* 2005;20(2):134-41.
- Rosa FK, Roese CA, Savi A, Dias AS, Monteiro MB. Comportamento da mecânica pulmonar após a aplicação de protocolo de fisioterapia respiratória e aspiração traqueal em pacientes com ventilação mecânica invasiva. *Rev Bras Ter Intensiva.* 2007;19(2):170-5.
- Bitencourt WS. Recrutamento alveolar: indicações e técnicas. In: Ismar Cavalcanti I, Cantinho F, Assad A. *Medicina perioperatória: anestesia, dor, pós-operatório e reanimação.* Rio de Janeiro: SAERJ; 2005. p. 921-6.
- Costa DC, Rocha E, Ribeiro TF. Associação das manobras de recrutamento alveolar e posição prona na síndrome do desconforto respiratório agudo. *Rev Bras Ter Intensiva.* 2009;21(2):197-203.
- Gonçalves LO, Cicarelli DD. Manobra de recrutamento alveolar em anestesia: como, quando e porque utilizá-la. *Rev Bras Anestesiol.* 2005;55(6):631-8.
- Amato MB, Carvalho CR, Ísola A, Vieira S, Rotman V, Moock M, et al. Ventilação mecânica na lesão pulmonar aguda (LPA)/Síndrome do desconforto respiratório agudo (SDRA). *J Bras Pneumol.* 2007;33 Supl 2:S119-27.
- Porto EF, Castro AA, Leite JR, Miranda SV, Lancouth A, Kumpel C. Análise comparativa da complacência do sistema respiratório em três diferentes posições no leito (lateral, sentada e dorsal) em pacientes submetidos à ventilação mecânica invasiva prolongada. *Rev Bras Ter Intensiva.* 2008;20(3):213-9.
- Suter PM, Fairley B, Isenberg MD. Optimum end-expiratory airway pressure in patients with acute pulmonary failure. *N Engl J Med.* 1975;292(6):284-9.
- Foti G, Cereda M, Sparacino M, De Marchi L, Villa F, Pesenti A. Effects of periodic lung recruitment maneuvers on gas exchange and respiratory mechanics in mechanically ventilated acute respiratory distress syndrome (ARDS) patients. *Intensive Care Med.* 2000;26(5):501-7.
- Auler Júnior JO, Galas FR, Hajjar LA, França S. Ventilação mecânica no intra-operatório. *J Bras Pneumol.* 2007;33 Supl 2:S137-41.
- Thoren L. Post-operative pulmonary complications: observations on their prevention by means of physiotherapy. *Acta Chir Scand.* 1954;107 (2-3):193-205.
- Baker WL, Lamb VJ, Marini JJ. Breath-stacking increases the depth and duration of chest expansion by incentive spirometry. *Am Rev Respir Dis.* 1990;141(2):343-6.
- Overend TJ, Anderson CM, Lucy SD, Bhatia C, Jonsson BI, Timmermans C. The effect of incentive spirometry on postoperative pulmonary complications: a systematic review. *Chest.* 2001;120(3):971-8.
- Coelho DL, Belisário TG, Souza LF, Zacheu FS, Oliveira JF, Guimarães FS, et al. Efeitos respiratórios da espirometria de incentivo e do breath stacking no pós-operatório de cirurgia cardíaca. *Rev Bras Fisioter.* 2010;14(Supl 1):422.
- Reolon VO, Casagrande J, Lorenzon I, Kessler A. Treinamento muscular ventilatório por breath stacking em indivíduos jovens e hígidos [Internet]. In: X Salão de Iniciação Científica PUCRS. 2009. [citado 2014 Jan 25]. Disponível em: http://www.pucrs.br/edipucrs/XSalaoc/Ciencias_da_Saude/Fisioterapia_e_Terapia_Ocupacional/71493-VITORIO_ORTIZ_REOLON.pdf
- Reolon VO, Casagrande JB, Lorenzon IM, Spigolon AP, Gonçalves RR, Bueno AD, et al. Breath stacking aumenta a força muscular ventilatória em indivíduos jovens e hígidos. *Rev Bras Fisioter.* 2010;14(Supl 1):296.
- Oczenski W, Hörmann C, Keller C, Lorenz N, Kepka A, Schwarz S, et al. Recruitment maneuvers after a positive end-expiratory pressure trial do not induce sustained effects in early adult respiratory distress syndrome. *Anesthesiology.* 2004;101(3):620-5.
- Castro AA, Calil SR, Freitas SA, Oliveira AB, Porto EF. Chest physiotherapy effectiveness to reduce hospitalization and mechanical ventilation length of stay, pulmonary infection rate and mortality in ICU patients. *Respir Med.* 2013;107(1):68-74.
- Squadrone V, Coha M, Cerutti E, Schellino MM, Biolino P, Ocella P, Belloni G, Vilianis G, Fiore G, Cavallo F, Ranieri VM; Piedmont Intensive Care Units Network (PICUN). Continuous positive airway pressure for treatment of postoperative hypoxemia: a randomized controlled trial. *JAMA.* 2005;293(5):589-95.