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Effects of different PEEP levels on respiratory mechanics and oxygenation after coronary artery bypass grafting

Efeitos de diferentes níveis de PEEP na mecânica respiratória e oxigenação após revascularização do miocárdio

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Abstract

Objective: **To compare the effects of different levels of positive end-expiratory pressure on respiratory mechanics and oxygenation indexes in the immediate postoperative period of coronary artery bypass grafting.**

Methods: **Randomized clinical trial in which 136 patients underwent coronary artery bypass grafting between January 2011 and March 2012 were divided into three groups and admitted to mechanical ventilation with different positive end-expiratory pressure levels: Group A, 5 cmH_2O (n=44), Group B, 8 cmH_2O (n=47) and Group C, 10 cmH_2O (n=45). Data about respiratory mechanics were obtained from mechanical ventilator monitor and oxygenation indexes from arterial blood gas samples, collected twenty minutes after intensive care unit admission. Patients with chronic obstructive pulmonary disease and patients submitted to off-pump, emergency or combined operations were not included. For statistical analysis, we used Kruskal-Wallis, G and Chi-square tests, considering results significant when *P*<0.05.**

Results: **Groups were homogeneous in terms of demographic, clinical and surgical variables. Patients ventilated with positive end-expiratory pressure of 10 cmH_2O (Group C) had best compliance (*P*=0.04) and airway resistance values, this, however, without statistical significance. They also had best oxygenation indexes, with statistical difference in all analyzed variables, and lower frequency of hypoxemia (*P*=0.03).**

Conclusion: **Higher levels of positive end-expiratory pressure in immediate postoperative period of coronary artery bypass grafting improved pulmonary compliance values and increased oxygenation indexes, resulting in lower frequency of hypoxemia.**

Descriptors: **Positive end-expiratory pressure. Respiratory mechanics. Oxygenation. Myocardial revascularization.**

Resumo

Objetivo: **Comparar os efeitos de diferentes níveis de pressão expiratória positiva final na mecânica respiratória e nos índices de oxigenação no pós-operatório imediato de revascularização do miocárdio.**

Métodos: **Ensaio clínico randomizado no qual 136 pacientes submetidos à revascularização do miocárdio, entre janeiro de 2011 e março de 2012, foram distribuídos em três grupos e admitidos na ventilação mecânica com diferentes níveis de pressão expiratória positiva final: Grupo A, 5 cmH_2O (n=44), Grupo B, 8 cmH_2O (n=47) e Grupo C, 10 cmH_2O (n=45), sendo os dados da mecânica respiratória obtidos do monitor do ventilador mecânico e os índices de oxigenação por meio de gasometria arterial coletada vinte minutos após a admissão na unidade de terapia intensiva. Não foram incluídos pacientes com doença pulmonar obstrutiva crônica, cirurgias associadas, de emergência ou sem circulação**

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Abbreviations, acronysm & symbols	
CABG	Coronary artery bypass grafting
COPD	Chronic obstructive pulmonary disease
CPB	Cardiopulmonary bypass
ICU	Intensive Care Unit
PEEP	Positive end-expiratory pressure

extracorpórea. Para análise estatística, empregaram-se os testes de Kruskal-Wallis, Teste G e Qui-quadrado, considerando os resultados significantes quando *P*<0,05.

***Resultados:* Os grupos apresentaram-se homogêneos em relação às variáveis demográficas, clínicas e cirúrgicas. Os pacientes ventilados com pressão expiratória positiva final de 10 cmH_2O (Grupo C) apresentaram os melhores valores de complacência (*P*=0,04) e de resistência das vias aéreas, esta, porém sem significância estatística. Apresentaram, ainda, os melhores índices de oxigenação, com diferença estatística em todas as variáveis estudadas, além de menor frequência de hipoxemia (*P*=0,03).**

***Conclusão:* Níveis mais elevados de pressão expiratória positiva final no pós-operatório imediato de revascularização do miocárdio incrementaram os valores de complacência pulmonar e melhoraram os índices de oxigenação, resultando acarretando em menor frequência de hipoxemia.**

***Descritores:* Respiração com pressão positiva. Mecânica respiratória. Oxigenação. Revascularização miocárdica.**

INTRODUCTION

Despite clinical treatment and percutaneous interventions advances, coronary artery bypass grafting (CABG) is widely used in treating patients with coronary heart disease [1]. Surgical treatment goals are symptoms relief, ischemic myocardium protection, ventricular function improvement, prevent heart attack, regain of physical, mental and social conditions and prolonging life and its quality [2].

Moreover, this surgery may cause organic alterations, such as respiratory and oxygenation failure in postoperative period, especially in elderly, obese and patients with left ventricular dysfunction (left ventricular ejection fraction <55%) and prolonged cardiopulmonary bypass (CPB) time (>120 minutes) [3]. Pulmonary complications associated to cardiac surgery include respiratory mechanics and gas exchange alterations, mainly due to alveolar collapse [4].

Positive end-expiratory pressure (PEEP) may improve oxygenation and prevent atelectasis [5], while keeping airway pressure positive throughout expiration, especially at the end, promoting alveolar and small airways recruitment and stabilization, reducing pulmonary shunt and increasing functional residual capacity, thus preventing alveolar collapse [6].

In this study, we compare the effects of different PEEP levels on respiratory mechanics and oxygenation indexes after CABG to identify the most effective mechanical ventilation parameter.

METHODS

Study design

Randomized clinical trial in a northeastern Brazilian federal university hospital.

Sample Composition

We studied 136 adult patients undergoing CABG between January 2011 and March 2012. We excluded patients with chronic obstructive pulmonary disease (COPD) and those requiring emergency, concomitant or off-pump surgeries. We also excluded patients who died in the perioperative period before weaning from mechanical ventilation.

Data Collection

Preoperatively, patients received information and an explanation about the research. Postoperatively, data were collected from a Physical Therapy Evaluation Form and medical records. This form was designed for the study and was divided into three parts: pre-, intra- and postoperative periods.

After ICU admission, mechanical ventilation was applied using mechanical ventilator Evita 2 dura (Dräger Medical, Lübeck, Germany). Patients were admitted to volume control mode, as service protocol, with following parameters: tidal volume between 6 and 8 ml/kg, respiratory rate equal to 14 bpm, inspiratory flow of 8 to 10 times the minute volume, inspiratory time equal 1 second and inspired oxygen fraction 40%.

Patients were assigned to one of three groups using a simple draw and ventilated with different PEEP values postoperatively, as follows: Group A, PEEP=5 cmH_2O (n=44); Group B, PEEP=8 cmH_2O (n=47); and Group C, PEEP=10 cmH_2O (n=45). After draw, information about which group the patient would be allocated, was given to ICU members. Intraoperatively, all patients were ventilated with PEEP 5 cmH_2O.

Twenty minutes after admission, respiratory mechanics data were recorded from mechanical ventilator monitor and arterial blood sample was collected and processed by ABL 800 FLEX blood gas analyzer (Radiometer, Bronshoj, Denmark), as routine, and then identified and calculated oxygenation indexes. After blood gas analysis, mechanical ventilation parameters were adjusted according to patient's therapeutic needs.

Once satisfactory clinical conditions were achieved, including hemodynamic stability; absence or minimal bleeding; Glasgow Coma Scale score ≥10; and minimum mechanical ventilation parameters on pressure support mode (PS=7 cmH_2O, PEEP=5 cmH_2O, FiO_2 <40%), patients were extubated and oxygen was administered by nasal catheter, as established by routine service.

Definitions

Arterial oxygen partial pressure and inspired oxygen fraction ratio (PaO_2/FiO_2) was classified as [7]:

- Normal: $PaO_2/FiO_2 > 300$ mmHg;
- Mild hypoxemia: 200 mmHg < $PaO_2/FiO_2 \leq 300$ mmHg;
- Moderate hypoxemia: 100 mmHg < $PaO_2/FiO_2 \leq 200$ mmHg;
- Severe hypoxemia: $PaO_2/FiO_2 \leq 100$ mmHg.

For arterial-alveolar oxygen partial pressure ratio (PaO_2/PAO_2), which estimates pulmonary shunt, the reference values was considered as 0.74 to 0.90 mmHg [8].

For Respiratory Index (RI), alveolar-arterial oxygen gradient and arterial oxygen partial pressure ratio [$P(A\text{-}a)O_2/PaO_2$], normal values are between 0.74 and 1.0 mmHg. Index greater than 2 mmHg reflects refractory hypoxemia and elevated pulmonary shunt [8].

Ethical Aspects

The study was approved by Research Ethics Committee of the Institution (No. 346/10), as required by Resolution 196/96 of the National Health Council and all patients signed written informed consent.

Statistical Analysis

Collected data were assessed using Stata/SE statistical software version 11.1 (StataCorp, College Station, TX, USA). We used Shapiro-Wilk test for normality in groups. Quantitative variables were described as mean and standard deviation and differences were confirmed using Kruskal–Wallis test. Qualitative variables were expressed as proportions and association between these variables and outcome was tested using G and Chi-square tests. Results were considered statistically significant when P<0.05.

RESULTS

One hundred sixty-seven patients underwent CABG during the study period, with 29 not participating because of CABG and another surgical procedure association (22 patients); COPD (6 patients); and off-pump surgery (1 patient). Two other patients were excluded because of death before weaning from mechanical ventilation. The mortality in this population was 1.2%.

Final sample was composed by 136 patients, predominantly male (70.6%) with mean age 60±9.3 years and body mass index 26.6±3.8 kg/cm^2. Groups did not differ significantly in demographic, clinical and surgical parameters (Tables 1 and 2).

Table 1. Demographic and clinical data for patients undergoing CABG

Variables	Group A PEEP = 5 cmH_2O (n = 44)	Group B PEEP = 8 cmH_2O (n = 47)	Group C PEEP = 10 cmH_2O (n = 45)	Total (%)	P
Gender					0.42[a]
Male	29	32	35	96 (70.6)	
Female	15	15	10	40 (29.4)	
Age group					0.90[a]
< 60 years	20	22	19	61 (44.9)	
> 60 years	24	25	26	75 (55.1)	
Origin					0.19[a]
Capital	23	17	16	56 (41.2)	
Countryside	21	30	29	80 (58.8)	
BMI (kg/cm^2)					0.74[a]
Normal	18	16	14	48 (35.3)	
Overweight	17	24	22	63 (46.3)	
Obese	9	7	9	25 (18.4)	
Comorbidities					0.58[a]
Hypertension	33	39	34	106 (77.9)	0.52[a]
Diabetes mellitus	22	19	23	64 (47.1)	0.40[a]
Smoking	17	12	15	44 (32.4)	0.21[a]
Dyslipidemia	6	13	12	31 (22.8)	0.81[a]
Myocardial infarction	9	9	11	29 (21.3)	0.10[b]
Chronic renal failure	4	2	8	14 (10.3)	0.80[b]
Coronary angioplasty	1	1	2	4 (2.9)	0.79[b]
Stroke	2	1	1	4 (2.9)	

[a]Chi-square test; [b]G test; BMI, body mass index

Table 2. Surgical data for patients undergoing CABG.

Variables	Group A PEEP = 5 cmH_2O (n = 44)	Group B PEEP = 8 cmH_2O (n = 47)	Group C PEEP = 10 cmH_2O (n = 45)	Mean ± SD	*P*
Number of bypasses	2.5 ± 0.6	2.5 ± 0.8	2.5 ± 0.7	2.5 ± 0.7	0.99
Number of drainage tubes	1.8 ± 0.5	1.7 ± 0.6	1.9 ± 0.3	1.8 ± 0.5	0.15
Pump time (min)	89.9 ± 34.2	83.7 ± 29.2	85. 9 ± 2.8	86.4 ± 30.3	0.87
Aortic clamp time (min)	63.3 ± 24.7	60.6 ± 23.6	61.6 ± 21.8	61.8 ± 23.2	0.97
Surgery time (min)	241.4 ± 58.1	227.5 ± 47.5	234.5 ± 43.2	234.3 ± 49.9	0.42

Data displayed as mean ± standard deviation. Kruskal-Wallis test

Table 3. PEEP level, respiratory mechanics and oxygenation indices association.

Variável	Group A PEEP = 5 (n = 44)	Group B PEEP = 8 (n = 47)	Group C PEEP = 10 (n = 45)	*P*
Compliance (ml/cmH_2O)	47.4 ± 12.5	47.9 ± 19.3	55.8 ± 19.1	0.04
Airway resistance (cmH_2O/l.s-1)	8.1 ± 2.7	7.6 ± 4.2	7.0 ± 2.6	0.14
SpO_2 (%)	97.1 ± 2.6	97.5 ± 1.7	98.5 ± 1.2	0.002
PaO_2 (mmHg)	108.0 ± 36	111.6 ± 28.3	131.3 ± 33.9	0.002
PaO_2/FiO_2 (mmHg)	269.9 ± 89.8	278.9 ± 70.6	328.2 ± 84.8	0.002
PaO_2/PAO_2 (mmHg)	0.43 ± 0.14	0.45 ± 0.11	0.53 ± 0.13	0.002
$P(A-a)O_2$ (mmHg)	139.3 ± 34.3	136.3 ± 28.0	116.8 ± 33	0.004
$P(A-a)O_2/PaO_2$ (mmHg)	1.53 ± 0.78	1.38 ± 0.65	1.02 ± 0.55	0.003

SpO_2 – oxygen saturation; PaO_2 – arterial oxygen partial pressure; FiO_2 – inspired oxygen fraction; PAO_2 – alveolar oxygen partial pressure; $P(A-a)O_2$ – alveolar-arterial oxygen gradient; $P(A-a)O_2/PaO_2$ – respiratory index. Kruskal-Wallis test

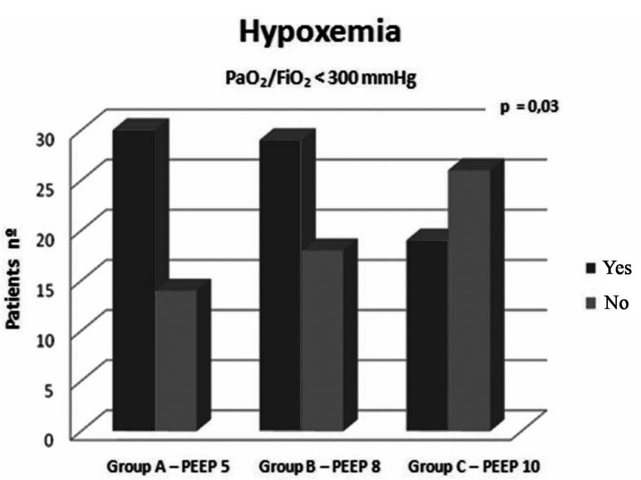

Fig. 1 - Hypoxemia frequency, by group, in patients undergoing CABG and ventilated with different PEEP levels in immediate postoperative period. PaO_2 - arterial oxygen partial pressure, FiO_2 - inspired oxygen fraction, PEEP - Positive end-expiratory pressure. Chi-square test.

Compliance mean was 50.3±17.5 ml/cmH_2O while airway resistance mean was 7.6±3.3 cmH_2O/L/s. When associated different levels of PEEP to respiratory mechanics, patients ventilated with PEEP 10 cmH_2O (Group C) had higher compliance values (*P*=0.04) and lower airway resistance values with no statistical significance.

Oxygen saturation (SpO_2) mean was 97.7±2%. Arterial oxygen partial pressure (PaO_2) mean, determined immediately after ICU admission, was 116.9±34.1 mmHg, ranging from 53.7 to 203 mmHg. PaO_2/FiO_2 ratio mean was 292.3±85.2, ranging from 134.3 to 507.5.

Regarding hypoxemia severity, we found that 42.6% of patients had normal PaO_2/FiO_2 ratio. Mild hypoxemia was also observed in 42.6% of patients and 14.7% of patients had moderate hypoxemia. No patient had severe hypoxemia.

Arterial-alveolar oxygen partial pressure ratio (PaO_2/PAO_2) mean was 0.47±0.14 mmHg. Only 4.4% of the patients presented normal value.

Alveolar-arterial oxygen gradient [$P(A-a)O_2$] mean was 130.8±34.3 mmHg. Respiratory Index mean was of 1.31±0.69 mmHg and was normal in only 15.4% of patients.

Highest SpO_2, PaO_2, PaO_2/FiO_2 and PaO_2/PAO_2 and lowest $P(A-a)O_2$ and RI means were found in patients ventilated with PEEP 10 cmH_2O (Group C), and all of these variables had statistically significant differences between groups. Group C patients had also less hypoxemia occurrence (68.2% vs. 61.7% vs. 42.4%, *P*=0.03) (Figure 1).

Respiratory mechanics and oxygenation association between groups are shown in Table 3.

In the present study hemodynamics measurements such as arterial blood pressure and heart rate were not assessed. However, no significant hemodynamic changes were observed in any patient.

DISCUSSION

In this study that assessed the relation between different PEEP levels and respiratory mechanics and oxygenation indexes on postoperative CABG, showed that higher levels of PEEP (10 cmH_2O) may promote a respiratory mechanics values increase and provide better oxygenation indexes in immediate postoperative period.

Previous studies showed that use of PEEP in high level after elective CABG improves oxygenation and lung compliance [9,10].

Decreased lung compliance after CABG is well established, probably due interstitial edema, hemorrhage and vascular congestion that increases lung stiffness [11]. In cardiac surgery immediate postoperative period, static compliance is lower than normal, probably reflecting atelectasis [9]. These changes may be related to intraoperative procedures as mechanical ventilation with low volumes and low PEEP levels and sternotomy, which alters chest wall compliance [12].

Staton et al. [13] compares pulmonary outcomes in patients undergoing on- or off-pump CABG, concluding that compliance is lower in patients undergoing on-pump surgery, instead of worse gas exchange and later extubation. In our study, all patients underwent on-pump surgery, being expected worst compliance values. High PEEP was able to improve compliance in this sample.

Babik et al. [14] assesses respiratory mechanics changes during cardiac surgery, showing that airway resistance increases more than 70% in patients undergoing on-pump surgery, does not changing in off-pump. Auler Jr et al. [11] in a prospective trial that assessed effects of PEEP on respiratory mechanics and hemodynamics of CABG patients concluded that higher levels of PEEP promote reduction in airway resistance. Similar findings were found in our study, but with no statistical significance.

According to Singh et al. [15], gas exchange changes are the most significant postoperative CABG complications. Thence, we chose study oxygenation indexes because they appropriately reflect changes in pulmonary function after on-pump surgery [16].

Despite this and other studies show advantages of high PEEP on oxygenation and compliance, controversies about their real advantages still remain.

In randomized controlled trial performed by Marvel et al. [17] with patients undergoing CABG and ventilated with PEEP levels of 0, 5 or 10 cmH_2O, it was demonstrated that higher levels of PEEP not provides sustained beneficial effect on arterial oxygenation. This effect was also found by Celebi et al. [18] in another randomized controlled trial in which patients were ventilated with PEEP titrated to achieve the best PaO_2.

Michalopoulos et al. [19] examined the effects of different levels of PEEP (0.5 and 10 cmH_2O) in arterial oxygenation in patients after cardiac surgery and showed no advantage in gas exchange applying low levels of PEEP when compared to no PEEP.

Moreover, Dongelmans et al. [10] comparing application of high level of PEEP (10 cmH_2O) with physiological level (5 cmH_2O) after CABG, showed that higher values of PEEP improves oxygenation and lung compliance, despite association with increased mechanical ventilation duration.

Oxygenation index or PaO_2/FiO_2 ratio routinely quantifies alveolar collapse in mechanically ventilated patients in postoperative period [20], being the preferred method for pulmonary function assessment [21].

Weiss et al. [22] reported PaO_2/FiO_2 decrease during the first 12 hours after on-pump CABG, calculated after anesthesia induction and compared with values obtained one, six and 12 hours after pump in 460 patients. These authors concluded that, despite improvements in cardiopulmonary bypass techniques, hypoxemia is still common in cardiac surgery postoperative period. In our study, we observed similar data, since more than half patients had some hypoxemia degree in ICU admission, being reduced when we used higher PEEP (10 cmH_2O).

Alveolar-arterial gradient [$P(A-a)O_2$] is increased in patients with impaired gas exchange in any FiO_2 range, with higher values than normal individuals. As reported by Terzi and Dragosavac [23], $P(A-a)O_2$ values in on-pump postoperative patients ranged from 119 mmHg (FiO_2 40%) to 338 mmHg (FiO_2 100%). Similar results were found in our study, which showed high values in all groups, being lower when applied higher PEEP.

CONCLUSION

Higher levels of PEEP provided beneficial effects for patients undergoing CABG by increasing oxygenation indexes, reducing hypoxemia and significantly improving lung compliance in immediate postoperative period.

Authors' roles & responsabilities	
DLB	Study design, data collection and manuscript writing
VJSN	Study design and manuscript writing
MAGC	Data collection
TEPB	Data collection
NPS	Data collection
IML	Data collection
EDF	Statistical analysis
JLSL	Text revision

REFERENCES

1. Piegas LS, Bittar OJ, Haddad N. Cirurgia de revascularização miocárdica: resultados do Sistema Único de Saúde. Arq Bras Cardiol. 2009;93(5):555-60.

2. Lima RC, Kubrusly LF, Nery ACS, Pinheiro BB, Brick AV, Souza DSR, et al. Diretrizes da cirurgia de revascularização miocárdica,

valvopatias e doenças da aorta. Arq Bras Cardiol. 2004;82(supl. 5):1-20.

3. Szeles TF, Yoshinaga EM, Alencar W, Brudniewski M, Ferreira FS, Auler Jr. JOC, et al. Hipoxemia após revascularização miocárdica: análise dos fatores de risco. Rev Bras Anestesiol. 2008;58(2):124-36.

4. Wynne R, Botti M. Postoperative pulmonary dysfunction in adults after cardiac surgery with cardiopulmonary bypass: clinical significance and implications for practice. Am J Crit Care. 2004;13(5):384-93.

5. Auler Jr JOC, Galas FRBG, Hajjar LA, Franca S. Ventilação mecânica no intra-operatório. J Bras Pneumol. 2007;33(suppl. 2):137-41.

6. Alexandre BL, Araújo SG, Machado MGR. Pressões respiratórias máximas. In: Machado MGR, ed. Bases da fisioterapia respiratória: terapia intensiva e reabilitação. Rio de Janeiro: Guanabara-Koogan; 2008.

7. ARDS Definition Task Force, Ranieri VM, Rubenfeld GD, Thompson BT, Ferguson ND, Caldwell E, Fan E, et al. Acute respiratory distress syndrome: the Berlin Definition. JAMA. 2012;307(23):2526-33.

8. José A, Dias EC, Santos VLA, Chiavone PA. Valor preditivo dos gases arteriais e índices de oxigenação no desmame da ventilação mecânica. Rev Bras Ter Intensiva. 2001;13(2):50-7.

9. Valta P, Takala J, Eissa NT, Milic-Emili J. Effects of PEEP on respiratory mechanics after open heart surgery. Chest. 1992;102(1):227-33.

10. Dongelmans DA, Hemmes SN, Kudoga AC, Veelo DP, Binnekade JM, Schultz MJ. Positive end-expiratory pressure following coronary artery bypass grafting. Minerva Anestesiol. 2012;78(7):790-800.

11. Auler JO Jr, Carmona MJ, Barbas CV, Saldiva PH, Malbouisson LM. The effects of positive end-expiratory pressure on respiratory system mechanics and hemodynamics in postoperative cardiac surgery patients. Braz J Med Biol Res. 2000;33(1):31-42.

12. Ambrozin ARP, Cataneo AJM. Aspectos da função pulmonar após revascularização do miocárdio relacionados com risco pré-operatório. Rev Bras Cir Cardiovasc. 2005;20(4):408-15.

13. Staton GW, Williams WH, Mahoney EM, Hu J, Chu H, Duke PG, et al. Pulmonary outcomes of off-pump vs on-pump coronary artery bypass surgery in a randomized trial. Chest. 2005;127(3):892-901.

14. Babik B, Asztalos T, Peták F, Deák ZI, Hantos Z. Changes in respiratory mechanics during cardiac surgery. Anesth Analg. 2003;96(5):1280-7.

15. Singh NP, Vargas FS, Cukier A, Terra-Filho M, Teixeira LR, Light RW. Arterial blood gases after coronary artery bypass surgery. Chest. 1992;102(5):1337-41.

16. Cui H, Zhang M, Xiao F, Li Y, Wang J, Chen H. Comparison and correlative analysis of pulmonary function markers after extracorporeal circulation. Beijing Da Xue Xue Bao. 2003;35(2):195-9.

17. Marvel SL, Elliott CG, Tocino I, Greenway LW, Metcalf SM, Chapman RH. Positive end-expiratory pressure following coronary artery bypass grafting. Chest. 1986;90(4):537-41.

18. Celebi S, Köner O, Menda F, Korkut K, Suzer K, Cakar N. The pulmonary and hemodynamic effects of two different recruitment maneuvers after cardiac surgery. Anesth Analg. 2007;104(2):384-90.

19. Michalopoulos A, Anthi A, Rellos K, Geroulanos S. Effects of positive end-expiratory pressure (PEEP) in cardiac surgery patients. Respir Med. 1998;92(6):858-62.

20. Reis-Miranda D, Struijs A, Koetsier P, van Thiel R, Schepp R, Hop W, et al. Open lung ventilation improves functional residual capacity after extubation in cardiac surgery. Crit Care Med. 2005;33(10):2253-8.

21. MacNaughton PD. Assessment of lung function in the ventilated patient. Intensive Care Med. 1997;23(8):810-8.

22. Weiss YG, Merin G, Koganov E, Ribo A, Oppenheim-Eden A, Medalion B, et al. Postcardiopulmonary bypass hypoxemia: a prospective study on incidence, risk factors, and clinical significance. J Cardiothorac Vasc Anesth. 2000;14(5):506-13.

23. Terzi RGG, Dragosavac D. Monitorização do intercâmbio gasoso pulmonar no paciente submetido à ventilação mecânica. In: Carvalho CRR, ed. Ventilação mecânica. Vol. 1. São Paulo:Atheneu;2000. p.199-204.