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Abstract

The application of continuous positive airway pressure (CPAP) produces important hemodynamic alterations, which can influence breathing pattern (BP) and heart rate variability (HRV). The aim of this study was to evaluate the effects of different levels of CPAP on postoperative BP and HRV after coronary artery bypass grafting (CABG) surgery and the impact of CABG surgery on these variables. Eighteen patients undergoing CABG were evaluated postoperatively during spontaneous breathing (SB) and application of four levels of CPAP applied in random order: sham (3 cmH_2O), 5 cmH_2O, 8 cmH_2O, and 12 cmH_2O. HRV was analyzed in time and frequency domains and by nonlinear methods and BP was analyzed in different variables (breathing frequency, inspiratory tidal volume, inspiratory and expiratory time, total breath time, fractional inspiratory time, percent rib cage inspiratory contribution to tidal volume, phase relation during inspiration, phase relation during expiration). There was significant postoperative impairment in HRV and BP after CABG surgery compared to the preoperative period and improvement of DFAα1, DFAα2 and SD2 indexes, and ventilatory variables during postoperative CPAP application, with a greater effect when 8 and 12 cmH_2O were applied. A positive correlation ($P < 0.05$ and $r = 0.64$; Spearman) was found between DFAα1 and inspiratory time to the delta of 12 cmH_2O and SB of HRV and respiratory values. Acute application of CPAP was able to alter cardiac autonomic nervous system control and BP of patients undergoing CABG surgery and 8 and 12 cmH_2O of CPAP provided the best performance of pulmonary and cardiac autonomic functions.

Key words: Continuous positive airway pressure; Cardiovascular system; Autonomic nervous system; Ventilation; Coronary artery bypass

Introduction

Coronary artery bypass grafting (CABG) surgery is a well established and an effective treatment to reduce the symptoms and mortality of patients with coronary artery disease. The surgical procedure and the risk factors involved, such as the median sternotomy, cardiopulmonary bypass (CPB) and thoracic manipulation, are believed to be responsible for several changes in cardiorespiratory function after CABG surgery (1) with damage to cardiac autonomic function indicated by heart rate variability (HRV) (2,3) and changes in pulmonary function (4,5).

Several rehabilitation strategies have been applied to these patients in order to minimize the alterations of respiratory function (4,6). Although there is no consensus in the literature about the best physiotherapy respiratory intervention in patients undergoing CABG surgery (7), it seems that the application of noninvasive positive pressure ventilation improves lung function compared to conventional respiratory therapy (4,8).

Noninvasive positive pressure has been demonstrated to be an important adjunct to improve gas exchanges (8), reduce breathing work, the need of intubation (9), hospital stay (7), and mortality in several clinical conditions. Loeckinger

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et al. (10) observed an improvement of gas exchanges in patients who received continuous positive airway pressure (CPAP) application after cardiac surgery.

However, the application of positive airway pressure produces mechanical effects on the cardiovascular system with changes in hemodynamics and in the cardiac autonomic nervous system (11). We have not identified studies about the influence of short-term application of CPAP on the breathing pattern (BP) and HRV of patients undergoing CABG surgery.

Therefore, the aim of this study was to evaluate the effects of different levels of CPAP application on BP and HRV during the postoperative (PO) period of CABG surgery, as well as the impact of CABG surgery on these variables. We tested the hypothesis that higher levels of CPAP may positively influence BP and HRV.

Material and Methods

Design and study population

The study was a prospective, randomized, controlled, and double-blind trial. A total of 66 patients were screened, and 18 patients of both genders, with a clinical diagnosis of coronary artery disease who underwent elective CABG with CPB, median sternotomy incision and interposition of a saphenous vein, internal mammary artery or radial artery grafts were included in the study. Patients undergoing urgency surgery or CABG concomitant with valve or other cardiac surgery and using intra-aortic balloon and invasive ventilation for more than 24 h, with pacemakers or presenting previous cardiac surgery, recent acute myocardial infarction (less than 6 months), unstable angina, chronic heart rhythm disturbances, significant arrhythmia, valvular heart disease, chronic obstructive pulmonary disease, diabetic neuropathy, poor cognition, and other severe non-cardiac diseases were excluded from the study. The study protocol was approved by the Federal University of São Carlos Ethics Committee (200/2007) and written informed consent was obtained from all patients.

Experimental procedures

During the preoperative period, patients underwent clinical cardiac assessment before their inclusion in the study. The physiotherapist's evaluation consisted of anamnesis and physical examination, including data about previous diseases and the present illness, lifestyle and eating habits. In addition, patients were instructed about the surgical procedures, tracheal intubation and the importance of physiotherapy for their postoperative recovery.

After the initial evaluation, all patients that fulfilled the inclusion criteria underwent the interventions and measurements of the study, on the day before the surgery and on the second PO day, after the mediastinum tube had been removed and the patient had been in spontaneous breathing (SB). The protocol was carried out only during the afternoon to exclude the influence of circadian rhythm alterations on HRV. CPAP application during the preoperative period aimed to familiarize the patients for the PO intervention. Spirometric tests were performed during the preoperative period in order to exclude patients with chronic obstructive pulmonary disease. Surgical and hospital data were recorded postoperatively.

Study protocol and measurements

Data were collected with the patient in the seated position during SB and with ventilatory assistance using CPAP ventilation (Breas PV100, Sweden) without supplemental oxygen, with a 21% oxygen fraction (environmental air), according to the following conditions: a) SB, b) 3 cmH_2O (sham) (12), c) CPAP = 5 cmH_2O, d) CPAP = 8 cmH_2O, and e) CPAP = 12 cmH_2O.

Data were first collected during the SB condition. Next, the patient was submitted to the four different levels of CPAP applied in a random order, each for approximately 20 min, after a sufficient time to adapt the patient to each selected level. A rest interval of 30 min was allowed between applications. The experiment was performed by two investigators. One of them was aware of the CPAP intervention, while the other, responsible for data analysis, just collected the physiological data and did not know about the levels applied. Patients were unaware of the pressure levels to which they were submitted.

HRV and BP were recorded during each condition. The heart rate (HR) and R-R intervals (R-Ri) were recorded continuously using a Polar S810i telemetry system (Polar®, Finland). BP was assessed by respiratory inductive plethysmography (LifeShirt System, Vivometrics Inc., USA) and was monitored using the thoracic and abdominal inductance plethysmography bands integrated in the LifeShirt garment located at the levels of the nipples and umbilicus, respectively. Data were recorded with a portable device, stored on a flash memory card inserted in the LifeShirt recorder and then downloaded to a computer into the VivoLogic analysis software (Vivometrics) accompanying the LifeShirt in order to analyze the respiratory data. An 800-mL specific bag was used for the volumetric adjustment procedure (13).

At the end of each CPAP application, a modified Borg scale (0-10) was applied in order to monitor subjective responses regarding dyspnea and pain, and systolic and diastolic blood pressures were registered indirectly with a manual aneroid sphygmomanometer (Becton Dickinson, Brazil) and a stethoscope (3M Litmann, USA) for patient monitoring.

Analysis of breathing pattern and heart rate variability

All artifacts were reviewed by visual inspection on a computer monitor. Only segments with more than 90% pure signal beats were included in the final analysis. The most stable sections containing at least 256 points of sample frequency were chosen for HRV analysis, as recommended (14). The data were entered into the Kubios HRV Analysis software (MATLAB, version 2 beta, Kuopio, Finland).

HRV was analyzed by mathematical and linear statistical models in the time and frequency domains, and by nonlinear models. In the time domain, the mean R-Ri, standard deviation of all R-Ri (SDNN) in ms, which reflects all the cyclic components responsible for variability during the recording period and is an estimate of overall HRV, and root mean square of the squares of the differences between successive R-Ri (rMSSD), in ms, representative of parasympathetic activity (14) were analyzed.

In the frequency domain analysis, the components of the power spectrum were analyzed using the Fast Fourier Transform in the following components: low frequency (LF; 0.04-0.15 Hz), representative of sympathetic activity; high frequency (HF; 0.15-0.4 Hz), representative of parasympathetic activity; both in normalized units, and LF/HF ratio, representative of sympathoadrenal vagal balance (14,15).

In nonlinear analysis, we used Poincaré plot measure indexes SD1 and SD2 (the standard deviation of the Poincaré plot perpendicular and along the line of identity, respectively), representative of parasympathetic autonomic activity and total HRV (16), respectively. Detrended fluctuations analysis (DFA) was also carried out using DFAα1 (short-term correlation properties of R-Ri) and DFAα2 (long-term correlation properties of R-Ri) indexes. This technique of analysis, previously developed and described by Peng et al. (17), quantifies the presence or absence of fractal-like correlation properties in biological time series and has been used to evaluate the risk of mortality in various groups, being a good predictor of benign and malignant arrhythmias, sudden cardiac death and total mortality in patients with reduced left ventricle ejection fraction, with acute myocardial infarction and with other cardiovascular diseases (18-21).

For BP analysis, we used the following variables: breathing frequency (BF), inspiratory tidal volume (ViVol), inspiratory time (Ti), expiratory time (Te), total breath time (Tt), fractional inspiratory time (Ti/Tt), percent rib cage inspiratory contribution to tidal volume (%RCi), phase relation during inspiration (PhRIB) and expiration (PhREB). The PhRIB and PhREB indexes determine the degree of thoracoabdominal synchrony and refer to the phase relation during inspiration and expiration, respectively. These indexes represent the percentage of time during a respiratory cycle in which the movements of the rib cage and abdomen are in opposite directions, indicating the delay of the movement of the rib cage over the abdomen at the beginning of inspiration (PhRIB) and expiration (PhREB) (22). To obtain the respiratory inductive plethysmographic sum signal for absolute volume in mL, a quantitative calibration was carried out (fixed volume least squares calibration) before the analysis of the respiratory variables, which provided a breath-by-breath calculation of the breathing pattern variables. A total of 30 points of this breath-by-breath calculation for each patient were chosen for analysis.

Statistical analysis

Statistical analysis was performed using the GraphPad InStat for Windows software, Version 3.0. Normal distribution of the data was evaluated using the Shapiro-Wilk test and, according to the characteristics and normality of the values, parametric or non-parametric tests were applied. Repeated measures ANOVA with the Tukey *post hoc* test or the Friedman test with the Dunn *post hoc* test were used for analysis of all conditions studied (PO). Spearman correlation was used to evaluate the relationship between delta of 12 cmH_2O and SB of HRV indexes and respiratory variables in the 2nd PO period. The paired *t*-test or Wilcoxon test was used for the comparison between preoperative and 2nd PO (spontaneous breathing). The level of significance was set at $P < 0.05$ in all analyses.

Results

Population characteristics

Of all patients with CABG surgery prescription, only 18 were included in the final sample (2nd PO day). Table 1 shows baseline characteristics and surgical and hospital data.

Table 1. Baseline, surgical and hospital data of the 18 patients studied.

Age (years)	58.6 ± 8.9
Male gender (%)	13 (72.2)
Weight (kg)	69.5 ± 10.7
Height (m)	1.61 ± 0.1
BMI (kg/m^2)	26.7 ± 3.8
Medical history (%)	
Smoking	14 (77.8)
Arterial hypertension (medicated)	14 (77.8)
Diabetes mellitus	11 (61.1)
Dyslipidemia	13 (72.2)
Pharmacological treatment (preoperative, %)	
Beta-blockers	15 (83.3)
ACE inhibitor	4 (22.2)
Diuretics	7 (38.9)
Peri- and postoperative data	
CPBT (min)	81.8 ± 25.6
ACCT (min)	45.2 ± 13.5
Duration of surgery (min)	181.1 ± 66.2
Mechanical ventilation (h)	9.5 ± 6.8
Coronary artery grafts (number)	2.4 ± 1.0
LIMA/SV/RA grafts (number)	16/13/1
ICU stay (days)	2.4 ± 1.1
Total hospital stay (days)	11.5 ± 4.6
Hospital stay before surgery (days)	6.4 ± 4.3

Data are reported as means ± SD, absolute values and percentage. BMI = body mass index; ACE = angiotensin-converting enzyme; CPBT = cardiopulmonary bypass time; ACCT = aortic cross-clamping time; LIMA = left internal mammary artery; SV = saphenous vein; RA = radial artery; ICU = intensive care unit.

Heart rate variability and breathing pattern responses after CABG surgery

Table 2 shows the HRV of patients before and after CABG surgery. There was a reduction of mean R-Ri and SDNN, rMSSD, SD1, SD2, and DFAα1 indexes, with an increase of mean HR in CABG PO compared to the preoperative period. Table 3 presents the patients' BP responses before and after CABG surgery. There was an increase of BF and PhRIB, PhREB indexes, as well as a reduction of Ti, Te and Tt in CABG PO, compared to the preoperative period. These analyses were carried out with 17 patients in the final sample for data pairing since one patient's data during SB in the preoperative period presented poor quality of the stretch signal, being unsuitable for processing and analysis.

Table 2. Heart rate variability variables in the preoperative and postoperative periods during spontaneous breathing.

	Preoperative (N = 17)	Postoperative (N = 17)
R-Ri mean (ms)	900.8 ± 163.4	658.3 ± 120.2*
SDNN (ms)	18 ± 5.8	9.6 ± 5.2*
HR mean (bpm)	69 ± 14.2	93.9 ± 16*
rMSSD (ms)	19.5 ± 5.9	7.1 ± 2.6*
LF (nu)	49.6 ± 22.2	37.8 ± 27.7
HF (nu)	50.3 ± 22.3	62.1 ± 27.6
LF/HF	1.1 ± 0.6	0.8 ± 0.7
SD1 (ms)	13.9 ± 4.3	5.4 ± 1.7*
SD2 (ms)	34.7 ± 8.4	15 ± 6.9*
DFAα1	1.1 ± 0.3	0.8 ± 0.4*
DFAα2	0.9 ± 0.1	1 ± 0.2

Data are reported as means ± SD. R-Ri = R-R intervals; SDNN = standard deviation of all R-Ri; HR = heart rate; rMSSD = root mean square of the squares of the differences between successive R-Ri; LF = low frequency, in normalized units (nu); HF = high frequency; LF/HF = low/high frequency ratio; SD1 = the standard deviation of the Poincaré plot perpendicular to the line of identity; SD2 = the standard deviation of the Poincaré plot along the line of identity; DFAα1= short-term correlation properties of R-Ri; DFAα2 = long-term correlation properties of R-Ri. *P < 0.05 compared to preoperative group (Student paired *t*-test).

Table 3. Respiratory inductive plethysmographic variables in the preoperative and postoperative periods during spontaneous breathing.

	Preoperative (N = 17)	Postoperative (N = 17)
BF (breaths/min)	18.8 (15-22)	24.2 (19-30)*
ViVol (mL)	500 (350-900)	620 (500-800)
Ti (s)	1.2 (1.0-1.4)	0.9 (0.7-1.1)*
Te (s)	1.9 (1.6-2.6)	1.4 (1.2-1.9)*
Tt (s)	3.2 (2.7-4.0)	2.4 (2.0-3.0)*
Ti/Tt	0.4 (0.34-0.44)	0.4 (0.34-0.41)
%RCi	82 (72.3-89.9)	87.3 (69.7-97.0)
PhRIB (%)	5.0 (1.6-10.5)	11.1 (2.7-20.9)*
PhREB (%)	2.6 (0.9-9.5)	10.7 (2.7-28.2)*

Data are reported as median (first quartile-third quartile). BF = breathing frequency; ViVol = inspiratory tidal volume; Ti = inspiratory time; Te = expiratory time; Tt = total breath time; Ti/Tt = fractional inspiratory time; %RCi = percent rib cage inspiratory contribution to tidal volume; PhRIB = phase relation during inspiration; PhREB = phase relation during expiration. *P < 0.05 compared to preoperative group (Wilcoxon test).

Heart rate variability responses during CPAP application

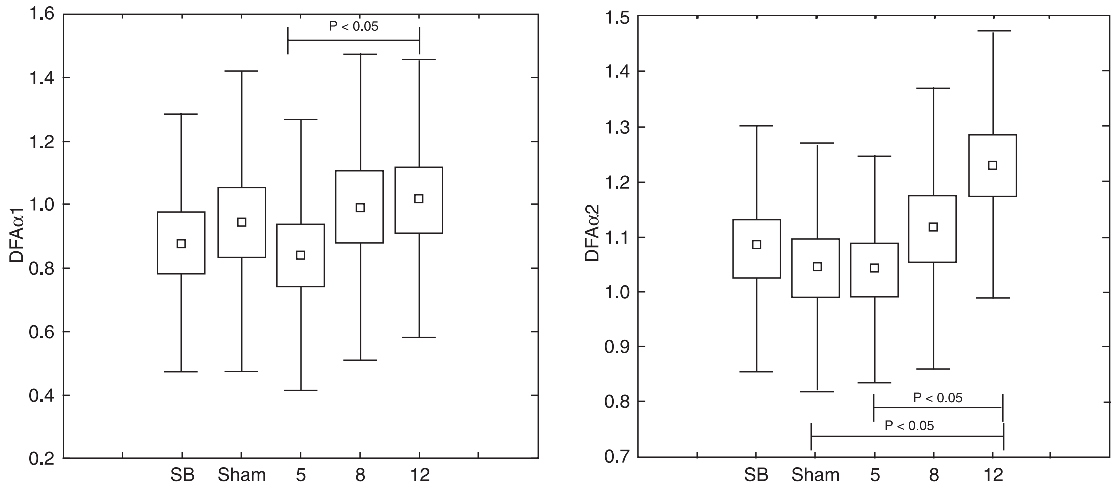
CPAP application on the 2nd PO day provoked significant alterations of DFAα1, DFAα2 and SD2 (Figure 1). There was an increase of DFAα1 during application of 12 cmH_2O compared to 5 cmH_2O and an increase of DFAα2 index during 12 cmH_2O compared to the sham condition and 5 cmH_2O. Regarding the SD2 index, we observed an increase when the higher CPAP levels were applied (12 and 8 cmH_2O), compared to SB and the lower CPAP level (5 cmH_2O). There was a decrease of SD2 during 5 cmH_2O compared to the sham condition.

Breathing pattern responses during CPAP application

Table 4 presents the ventilatory variables during SB and different levels of positive airway pressure application. There was BF reduction and an increase of Ti, Te and Tt during the sham condition and at all levels applied compared to SB. ViVol values were increased during 5, 8, and 12 cmH_2O compared to sham ventilation and SB. There was a decrease of %RCi during all levels of CPAP application and during the sham condition compared to SB, and a decrease of its values during 8 cmH_2O compared to the sham condition. However, 12 cmH_2O provoked an increase of %RCi compared to 8 cmH_2O. The PhRIB index was increased during 12 cmH_2O compared to SB and 8 cmH_2O. Peripheral oxygen saturation presented higher values during all levels applied (5, 8 and 12 cmH_2O) compared to the SB condition. Figure 2 shows correlations between ventilatory variables and HRV values of delta between 12 cmH_2O and SB condition. There was a positive correlation between DFAα1 index and Ti.

Discussion

The main finding of our study was that patients undergoing CABG surgery presented important damage in HRV and BP. To our knowledge, this is the first study to compare the effects of different levels of CPAP on respiratory pattern (evaluated by respiratory inductive plethysmography) and autonomic nervous control of heart rate in patients submitted



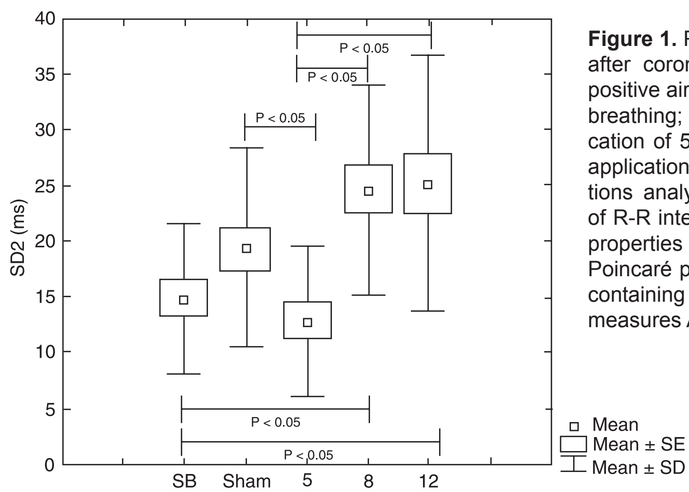


Figure 1. Postoperative heart rate variability responses after coronary artery bypass grafting surgery during positive airway pressure application. SB = spontaneous breathing; Sham = application of 3 cmH_2O; 5 = application of 5 cmH_2O; 8 = application of 8 cmH_2O; 12 = application of 12 cmH_2O; DFAα1 = detrended fluctuations analysis index (short-term correlation properties of R-R intervals (R-Ri)); DFAα2 = long-term correlation properties of R-Ri; SD2 = the standard deviation of the Poincaré plot along the line of identity. Data for groups containing 18 patients each were compared by repeated measures ANOVA with the Tukey *post hoc* test.

Table 4. Respiratory inductive plethysmographic variables during the postoperative period.

	SB	Sham	5 cmH_2O	8 cmH_2O	12 cmH_2O
BF (breaths/min)	24.3 (19-24)	22.9 (19-26)*	22.9 (20-25)**	22.9 (19-27)$^{+}$	23.4 (19-26)$^{++}$
ViVol (mL)	518.5 (435-641)	558 (470-659)	569.5 (489-668)**‡	573 (516-658)$^{+€}$	592 (529-680)$^{++£}$
Ti (s)	0.94 (0.76-1.12)	1.00 (0.86-1.22)*	1.00 (0.88-1.16)**	0.98 (0.86-1.19)$^{+}$	1.00 (0.84-1.18)$^{++}$
Te (s)	1.4 (1.2-1.8)	1.5 (1.2-1.9)*	1.5 (1.3-1.8)**	1.5 (1.3-1.8)$^{+}$	1.5 (1.3-1.8)$^{++}$
Tt (s)	2.4 (2-3)	2.6 (2-3)*	2.6 (2-3)**	2.5 (2-3)$^{+}$	2.5 (2-3)$^{++}$
Ti/Tt	0.38 (0.34-0.41)	0.39 (0.35-0.43)	0.39 (0.35-0.43)	0.39 (0.35-0.42)	0.39 (0.34-0.42)
%RCi	91.5 (70-96)	89.8 (68-95)*	89.6 (68-96)**	87.6 (69-96)$^{+€}$	88.2 (63-96)$^{++\infty}$
PhRIB (%)	10.3 (2-19)	12.1 (3-23)	13.9 (3-22)	11.6 (2-21)	12.5 (2-27)$^{++\infty}$
PhREB (%)	9.8 (3-27)	11.8 (2-22)	11.4 (4-23)	10.5 (3-19)	11.2 (3-26)
SpO_2 (%)	88 (85-93)	88 (87-94)	90 (85-93)**	89 (83-94)$^{+}$	90 (86-93)$^{++}$

Data are reported as median (first quartile-third quartile) for 18 patients. All patients were submitted to SB, sham and 5, 8 and 12 cmH_2O CPAP. SB = spontaneous breathing; sham = 3 cmH_2O; BF = breathing frequency; ViVol = inspiratory tidal volume; Ti = inspiratory time; Te = expiratory time; Tt = total breath time; Ti/Tt = fractional inspiratory time; %RCi = percent rib cage inspiratory contribution to tidal volume; PhRIB = phase relation during inspiration; PhREB = phase relation during expiration; SpO_2 = peripheral oxygen saturation. $P < 0.05$: *sham *vs* SB; **5 cmH_2O *vs* SB; $^{+}$8 cmH_2O *vs* SB; $^{++}$12 cmH_2O *vs* SB; ‡5 cmH_2O *vs* sham; $^{€}$8 cmH_2O *vs* sham; $^{£}$12 cmH_2O *vs* sham; $^{\infty}$12 cmH_2O *vs* 8 cmH_2O (Friedman test with Dunn *post hoc* test).

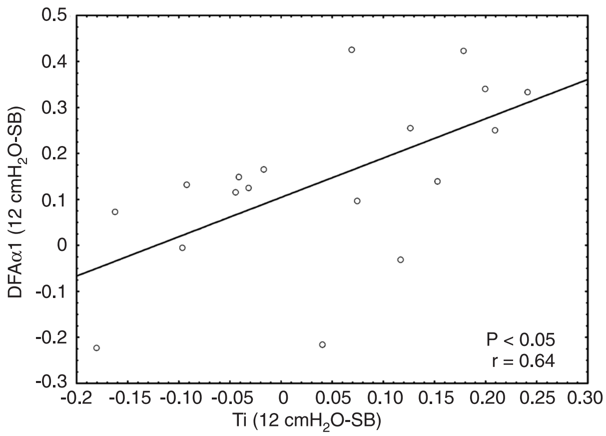


Figure 2. Correlation between detrended fluctuations analysis (DFAα1) index (short-term correlation properties of R-R intervals (R-Ri)) and Ti (inspiratory time). Delta between 12 cmH_2O and spontaneous breathing (SB) of the ventilatory variables and heart rate variability values. Spearman correlation.

to bypass grafting surgery. These results are important since short-term interventions are commonly used in respiratory therapy in these patients during hospitalization. We found that higher levels of positive pressure (8 and 12 cmH_2O) applied by CPAP were able to positively modify the cardiac autonomic function and BP of these patients.

Important deleterious alterations of pulmonary function have been described after CABG (4). In agreement with our study, Kristjánsdóttir et al. (23) observed that CABG resulted in rib cage movements and BP worsening, as previously observed with an instrument measuring respiratory movements. Atelectasis has been reported to occur after the onset of general anesthesia and the cardiopulmonary bypass may markedly contribute to an inflammatory reaction in the lungs and postoperative atelectasis (24-27). This atelectasis, if persistent, may lead to postoperative pulmonary complications, including hypoxemia, increased shunt fraction and work of breathing (28).

In this context, CPAP is important by producing airway dilation, improving arterial oxygenation, gas exchanges and indirectly the BP with a reduction of respiratory rate and an increase in tidal volume (8-10,29) in the first days after cardiac surgery. In the present study, we observed that CPAP decreased respiratory breathing and increased expiratory, inspiratory and total times, as well as peripheral oxygen saturation. Importantly as a novel result, our study showed that CPAP was able to reduce %RCi during all levels of positive pressure applied, contributing to a better respiratory synchronism, especially at the higher levels applied. Celebi et al. (30) observed a lower atelectasis score in recruitment maneuvers with application of high levels of CPAP (40 cmH_2O) and positive end-expiratory pressure (PEEP) (20 cmH_2O) during a short period of time with subsequent decremental levels, when compared to those achieved in patients receiving about 5 cmH_2O PEEP. This could be explained, according to the authors, by the levels applied since a PEEP level of 5 cmH_2O is unable to open the lung after surgery.

Regarding cardiac autonomic activity, it has been reported that CABG surgery produces significant alterations in cardiac autonomic function with reduction of HRV (31). It is known that the aging process is related to HRV (32) reduction, and altered autonomic regulation after cardiac surgery can precipitate the appearance of cardiac arrhythmias and increase the risk of sudden death. Some investigators have observed HRV reduction after myocardial revascularization surgery, which can return to preoperative values within 2 months (3,33).

In our study, we also observed deleterious changes in HRV after CABG with a decrease of linear (in the time domain) and nonlinear indexes, Poincaré plot, and DFA. These modifications after CABG can be related to the acute effects of surgery, with injuries to the autonomic nerve fibers or to the sinus node, and to the effects of anesthesia, surgical stress, pain, myocardial ischemia, and medications, as well as the effects of extracorporeal circulation, which is not a benign intervention and is associated with large numbers of adverse consequences (1,34).

Despite the important changes provoked by surgery, we observed that CPAP was able to positively modify HRV at the higher levels studied (8 and 12 cmH_2O), as observed by nonlinear indexes that may directly characterize the complexity, irregularity and predictability of the properties of biological systems and complement conventional measures of variability (35).

The effects of different levels of CPAP on the activity of the autonomic cardiovascular system have been poorly explored in the literature; nevertheless, it is known that higher levels can produce acute deleterious effects on hemodynamic properties (36). Important hemodynamic alterations have been reported to occur when high levels of CPAP (>15 cmH_2O) are applied to healthy subjects (12). In contrast, we used lower values when compared to the cited studies.

We observed in our study that moderate values of CPAP (8 and 12 cmH_2O) acutely increased HRV, as evaluated by nonlinear indexes in patients during the 2nd PO of CABG. An increase in SD2 index suggests a total HRV improvement (16). The decrease of DFA indexes may be associated with greater likelihood of cardiac events and mortality. Ksela et al. (37) observed a greater decline of nonlinear indexes (DFA) in patients who developed cardiac arrhythmias in the postoperative period compared with those who maintained stable sinus rhythm.

Our study focused on the acute effects of CPAP and possibly there was only an acute cardiovascular stress, which could have decreased HRV due to a sympathetic response to a reduction of cardiac output. However, our results may be due to the levels of positive airway pressure applied since it has been shown that moderate CPAP levels (10 cmH_2O) inhibit cardiac sympathetic nervous activity in heart failure patients (38). Moreover, it has been demonstrated that immediately after cardiac surgery patients present an imbalance of vagal and sympathetic regulation, with vagal activity suppression (3,31). In this condition, CPAP application may have improved the activity of the parasympathetic nervous system, reflecting an increase of HRV.

Regarding the correlations between the delta of the ventilatory variables and HRV, we observed that the greater variation in inspiratory time, the greater the influence on cardiac autonomic control, suggesting that BP can positively modulate HRV with higher levels of CPAP application.

In this way, although it is impossible for us to extend the present results to long-term CPAP application and to speculate about the effects on cardiac events, we did observe a real acute improvement of HRV and a reduction of indexes associated with cardiac events in patients undergoing CABG with short-term CPAP application. In this context, associated with the pulmonary results, we could observe a greater and better influence of the higher levels of positive pressure applied. Thus, our findings may provide a mechanism for the beneficial actions of CPAP in PO cardiac surgery as an adjunct therapy for an early cardiopulmonary rehabilitation of these patients during hospital convalescence.

Acknowledgments

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